Willie Pearson, Jr. · Lisa M. Frehill
Connie L. McNeely *Editors*

Advancing Women in Science

An International Perspective

Springer

Advancing Women in Science

Willie Pearson, Jr. • Lisa M. Frehill
Connie L. McNeely
Editors

Advancing Women in Science

An International Perspective

Springer

Editors
Willie Pearson, Jr.
School of History, Technology, and Society
Georgia Institute of Technology
Atlanta, GA, USA

Lisa M. Frehill
Energetics Technology Center (ETC)
St. Charles, MD, USA

Connie L. McNeely
School of Policy, Government, and
International Affairs
George Mason University
Fairfax, VA, USA

ISBN 978-3-319-08628-6   ISBN 978-3-319-08629-3 (eBook)
DOI 10.1007/978-3-319-08629-3
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014956705

© Vignette 8.1 is authored by a U.S. Government employee
© Springer International Publishing Switzerland 2015
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

Since the late 1970s, in both the United States and Europe, there has been innovative and important academic work on the interrelations between gender and science, technology (mostly information and communications technology, ICT), and innovation.[1] This work was then extended to other regions where science and technology were less developed (such as Latin America).

Lerman et al. (2003) and Wajcman (2004) place the beginnings of feminist research on science and technology in the 1970s. These authors are among those who made significant contributions to the start and development of this field. In the 1980s, these studies illuminated the important progress, which was enriched and enhanced substantially from the 1990s to today (e.g., Haraway 1985; Plant 1988; Turkle 1995). Gender equality became a central concern for research and science policies in the European Union (EU) beginning in the 1990s. For example, in the EU's Sixth Framework Programme (FP6), gender equality was addressed both in quantitative terms (emphasis on increasing the number of women scientists) and in qualitative terms (the recognition of gender as an analytic category to be included by researchers in this field); since then, it has been sustained by continuous programs supported by the EU.

A turning point in Latin America was the UNESCO (United Nations Educational, Scientific, and Cultural Organization) Regional Forum on Women and Science (Bariloche, Argentina, 1998), which laid the foundation for the World Conference on Science for the XII Century: A New Commitment – UNESCO (Budapest, Hungary, 1999), which, in turn, led to the creation of the UNESCO Regional Chair for Women, Science, and Technology in Latin America, based in FLACSO Argentina.[2] Other important "drivers" in the advancement of this field have been the Ibero-American Conferences on Science, Technology, and Gender, which take place every 2 years; the first was celebrated in Madrid in 1996.

---

[1] The literature on Gender and Science is too vast to account for it in this foreword. I will refer primarily to three of the most cited sources: Harding (1986, 1991), and Fox Keller (1995).

[2] Facultad Latinoamericana de Ciencias Sociales—Sede Académica Argentina.

In general, in a slow but persistent manner, a corpus of knowledge has been developed by the intertwining of science and technology (S&T) with diverse social science and humanities disciplines in terms of both theory and application (e.g., history, sociology, anthropology, cultural studies, education, philosophy, epistemology, and gender studies or feminist theory). In spite or because of important theoretical and methodological differences, the research in these fields has contributed (both implicitly and explicitly) to problematize what was considered universal, objective, and neutral knowledge and scientific and technological practices and products, revealing their connections with beliefs, values, and gender stereotypes predominant in the socio-historic context in which S&T is produced, disseminated, legitimized, and used.

Research also has shown male dominance in these fields, not only in terms of numbers, or in their presence in decision-making in S&T institutions, but also in the construction of what is conceived and valued as scientific and technological knowledge, demonstrating its androcentric or patriarchal biases concealed by the accepted criteria of rationality, validity, relevance, and excellence. Sara Delamont (1997), for example, points to the bias in science studies "towards exciting, high status men working in elite centres of "big science" excellence," rather than the "routine science" in which most women are involved.

Many studies across disciplines have also consistently provided evidence on a set of issues that affect each other reciprocally: the "invisibilization" or devaluation of women's contributions to the development of S&T throughout history, which has led to some impressive and somewhat "archeological" recovery work through biographies of women researchers and inventors who have been ignored since ancient times to the present, or who simply did not receive the same recognition and acknowledgement as men. Research also has examined both latent and manifest sexism in S&T education, expressed in the curricula and educational materials, student/teacher interactions and peer relations, and the "chilly" climate which undervalues women's capabilities in scientific careers, especially those in which they are a minority, such as engineering and informatics—all factors that tend to discourage girls and young women from choosing S&T as fields of study and professional careers. Virtually all the work in this area reaches the same conclusion, which was expressed in the 1995 United Nations Fourth World Conference on Women Beijing, China:

Science curricula in particular are gender-biased. Science textbooks do not relate to women's and girls' daily experience and fail to give recognition to women scientists. Girls are often deprived of basic education in mathematics and science and technical training, which provide knowledge that they could apply to improve their daily lives and enhance their employment opportunities.

Another line of research deals with the complexity of obstacles that limit the full participation of women in S&T professional work in universities and in the private sector, including those that were evident in the past and therefore more easily challenged, as well as those that were embedded in institutional cultures that have a powerful influence in maintaining gender inequalities and discriminatory practices. Another line of research focused on recovering and analyzing the knowledge created by women's groups in different cultures on issues related to health, agriculture, astronomy, and chemistry, among others, that have been ignored for decades and not validated as scientific.

These lines of research continue to provide new findings, and to stimulate and inform lively debates. The development of different theoretical trends within gender or feminist theory (liberal, marxist, radical, postmodern, cyberfeminist, post-colonial, queer, etc.) is also inspiring new debates, questions, and research problems.

Following Londa Schiebinger (2010), among the research institutions, non-governmental agencies, and governments that have developed gender equality S&T policies over the past several decades, we can identify three categories of strategic approaches:

1. *Fix the numbers of women* focuses on increasing women's participation in S&T. This strategy tends to make women "the problem" (their lack of education, motivation, self-devaluation) and, as a "solution" proposes more education and empowerment. Gender bias in S&T foundations, developments, results, and institutions that produce it is often ignored. One of its consequences is that, "to achieve success, women or girls are often required to assume male values, behaviors, and life rhythms." Note, however, that the inclusion strategy that prevailed for decades has moved from a formal approach to equal opportunities, to the analysis of the roots of marginalization and the systematic invisibility or devaluation of women's contributions to S&T, investigating the diverse effects of a "gender blind" science and the meaning that this segregation has on the production and uses of knowledge.
2. *Fix the institutions* promotes gender equality in careers through structural change in research organizations. In this regard, knowledge and the systematic use of gender-based analysis for planning, mentoring, and assessing policies, practices, and programs are essential, to which should be added the creation of new and more sensitive indicators on gender differences and inequalities. Accordingly, structural change cannot be limited to gender equality in quantitative terms. It requires institutional changes including, for example, norms, structures, criteria for recruitment, assessment and promotion, priorities in research agendas, and assigned funds, as well as less obvious matters such as everyday interpersonal relationships, language, organizational climate, and organization of the work process, among others.
3. *Fix the knowledge* or *gendered innovations* posits that science, technology, and gender representations and values are co-constructed through interaction processes in socio-cultural contexts. This approach is quite recent and promising, and it has been used especially in gender and ICT studies. The goal of this strategy is to "create gender-responsible science and technology, thereby enhancing the lives of both women and men worldwide." Lastly, and with the horizon in sight, it states the need to develop methods and studies to enhance excellence through gender analysis for basic and applied research in science, medicine, and engineering "as a resource to stimulate creativity (…) and by doing so to enhance the lives of both men and women."

The related literature—especially reports from conferences, workshops, and other events where these topics have been discussed—makes clear that many researchers intend for their findings to motivate processes of change and inform policy making. Although the relationships between research on gender in S&T and on policy making in these fields are more complex and slower than we would prefer, there have been important advances towards achieving this fundamental goal.

The chapters and vignettes included in this volume are a part of this journey.

April 2014 Gloria Bonder

References

Delamont, S. Three Blind Spots? A Comment on the Sociology of Science by a Puzzled Outsider. *Social Studies of Science* 17(1) (February 1987).

Fox Keller, E. 1995. *Reflections on Gender and Science*. New Haven, CT: Yale University Press.

Haraway, D. 1985. A Manifesto for Cyborgs: Science Technology, and Social Feminism in the 1980. *Socialist Review* 80

Harding, S. 1986. *The Science Question in Feminism*. Ithaca, NY: Cornell University Press.

______. 1991. *Whose Science? Whose Knowledge? Milton Keynes Bucks* Milton Keynes: Open University Press.

Lerman, N., R. Oldenziel, and A.P. Mohun. 2003. *Gender and Technology*: *A Reader*. Baltimore, MD: John Hopkins University Press.

Plant, S. 1988. *Zeros and Ones: Digital Women + The New Technoculture*. London: Fourth Estate.

Schiebinger, L. ed. *Gendered Innovations: Mainstreaming Sex and Gender Analysis into Basic and Applied Research Topic*. Report 2010, www.genderandscience.org

Turkle, S. 1995. *Life on the Screen: Identity in the Age of the Internet*. New York: Simon & Shuster.

Judy, Wajcman. 2008. *Gender and the Cultures of Corporations and Work Continuity and Change*. TELOS (January–March).

Acknowledgments

This project has a long history that dates back to a 14–15 November 2005 Organization for Economic Cooperation and Development (OECD) Conference on Declining Student Enrolment in Science and Technology held in Amsterdam, The Netherlands. During this meeting, a small group of women and men decided to mobilize and focus global attention on the cross-cutting theme of gender. At the time, however, the group quickly discovered that related cross-cultural research was somewhat limited. Consequently, the group agreed to seek funding to bring together an international cadre of scholars in a workshop format with the goal of producing an edited volume to address the critical issues surrounding the topic. Daryl Chubin, Cheryl B. Leggon, Shirley M. Malcom, Willie Pearson, Jr., and Terry Russell (as principal investigator) developed and submitted a proposal to the United States (US) National Science Foundation (NSF) that was funded (NSF/EHR Grant No. 1048010), with the award going to the Association for Institutional Research (AIR, Russell's affiliation). This project would have been difficult to implement without the strong support of our Program Officers: Myles Boylan and Carol Stoel. The primary role of Program Officer for the project was assumed by Carol Stoel; to her, we owe a great deal of gratitude for her continued encouragement when confronted with many logistical challenges. We also appreciate the support of two other NSF officials. Barbara Olds (former Program Officer, NSF) served on the OECD Conference Organizing Committee and played a major role in inviting the US conference attendees. Wanda E. Ward (former Acting Assistant Director, Division of Education and Human Resources, NSF) participated in the OECD Conference and the resulting two major workshops that were convened for the project. In addition, special thanks are due to former US Ambassador to the OECD, Constance A. Morella, who attended the 2005 conference and supported the project during her tenure.

Shortly after the grant award, Russell retired and the project was transferred to the Commission on Professionals in Science and Technology, which held the first workshop, with Lisa Frehill joining as the new principal investigator. Subsequently, the project was transferred to the US National Academies, which held the final workshop in 2011 and produced the 2012 workshop report, *Blueprint for the Future: Framing the Issues of Women in Science in a Global Context*.

This edited volume is the culmination of the original goal. Throughout the long, arduous journey, Chubin, Leggon, Malcom, Pearson, and Russell remained committed and, along the way, several others joined in to complete the journey and bring the project to fruition. We are especially grateful for the persistence and dedication of Lisa Frehill and Connie McNeely, and also of Alice Abreu, Jann Adams, Sybrina Atwaters, Josephine Beoku-Betts, Lisa Borello, J. McGrath Cohoon, Catherine Didion, Wendy Hansen, Marta Kisilevsky, Robert Lichter, Anne MacLachlan, Mariko Ogawa, Anne Pépin, Cheryl de la Rey, Diane Wilcox, and Kathrin Zippel.

The chapters have been improved enormously by comments from a distinguished group of external reviewers. We are grateful to the following individuals for their critical feedback: Anna Baron (University of Colorado, Denver, US), Geesje van den Berg (University of South Africa), Sylvia Bozeman (formerly Spelman College, US), Cinda Sue Davis (University of Michigan, US), Charmaine Dean (University of Waterloo, Canada), Joan Frye (US National Science Foundation), Yolanda George (American Association for the Advancement of Science, US), Angela Ginorio (University of Washington, US), Linda Grant (formerly University of Georgia, US), Wendy Hansen (United Nations University, Maastricht, The Netherlands), Sandra Hanson (Catholic University, US), Kaye Husbands Fealing (Georgia Institute of Technology, US), Maki Kubo (Okinawa Institute of Science and Technology, Japan), Val Kuk (formerly of Bell Labs, US), Kong-Ju-Bock Lee (Ewha Woman's University, South Korea), Anne MacLachlan (University of California, Berkeley, US), Carol Muller (Stanford University, US), Mia Ong (TERC, US), Cheryl de la Rey (University of Pretoria, South Africa), Terrence Russell (formerly Association for Institutional Research, US), Yu Tao (Stevens Institute of Technology, US), and Jungwon Yoon (Seoul National University, South Korea).

We express our deep appreciation to our collaborators who took their valuable time to participate in this labor intensive and time consuming effort. The collaborators represent diverse geographical regions: Americas, Africa, Asia, Europe, and Oceania. Additionally, a number of individuals were instrumental in recommending chapter and vignette contributors and reviewers. We thank the following individuals for their assistance: Anna Baron (University of Colorado, Denver); Betsy DiSalvo (Georgia Institute of Technology); and Luis Tenorio (Colorado School of Mines).

We thank Nicholas Philipson of Springer for immediately recognizing the value of this book, and Nitza Jones-Sepulveda for her help in bringing it to press. The views expressed in the book are solely those of the authors, and not those of their

institutional affiliations nor of the US National Science Foundation. Finally, we credit the strengths of this volume to the insight, knowledge, and skill of the authors in addressing the tasks requested of them and to the enormous support of our colleagues. However, we take full responsibility for any errors that remain.

Atlanta, GA, USA	Willie Pearson, Jr., Ph.D.
Washington, DC, USA	Lisa M. Frehill, Ph.D.
Fairfax, VA, USA	Connie L. McNeely, Ph.D.

Contents

Part I Cross-Cultural Foundational Issues

Part II Exemplar Disciplines

Part III Policies and Programs

Chapter 1

An International Perspective on Advancing Women in Science

Lisa M. Frehill, Connie L. McNeely, and Willie Pearson, Jr.

Many countries have implemented policies to increase the number and quality of scientific researchers as a means to foster innovation and spur economic development. In many cases, policy interventions have sought to increase participation by those who have traditionally been underrepresented in science, with particular reference to women. Today, even in countries with persistently strong patriarchal regimes, the extension of educational opportunities to women has been framed as a means of making better use of the potential pool of science and engineering innovators (Bielli et al. 2004; UNESCO 2007, 2010; CNRS 2004; NRC 2011). Women and, also, in many countries, members of ethnic minority groups traditionally have been limited in access to high-quality education, with concomitant occupational outcomes. Positing the importance of education to development and progress, universal primary education is one of the United Nation's Millennium Development Goals. However, participation in the scientific workforce necessitates education far beyond the primary level—an expensive enterprise, and one in which girls and women have been persistently disadvantaged.

This volume constructs bridges across different perspectives on related issues by weaving together three expanded and critical strands of research on women's

---

L.M. Frehill (✉)
Energetics Technology Center, 10400 O'Donnell Place, Ste 202,
St. Charles, MD 20603, USA
e-mail: lfrehill@etcmd.com; lisa.frehill@gmail.com

C.L. McNeely
School of Policy, Government, and International Affairs, George Mason University,
3351 Fairfax Drive, MS-3B1, Arlington, VA 22201, USA
e-mail: cmcneely@gmu.edu

W. Pearson, Jr.
School of History, Technology, and Society, Georgia Institute of Technology,
Bobby Dodd Way, Old Civil Engineering Building 221, Atlanta, GA 30332-0225, USA
e-mail: willie.pearson@hts.gatech.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_1

participation in science to articulate a comprehensive treatment of cross-national similarities, differences, and interactions. The three strands are

- Globalization
- The social organization of science
- Gendered societal relations

First, *globalization* is especially relevant, particularly in reference to the transformation of systems of production. The relative place of an economy within the global world system, the pace of change and historical conditions, and the capacity of individual countries to deploy resources to build a science enterprise have implications for women's participation and status in science, and vice versa. The increasingly global science enterprise shapes national labor markets and opportunities for scientists in general and women scientists in particular as knowledge workers.

Second, social science research on the *social organization of science* is foundational for understanding the conduct of science at the global, regional, and national levels. This point also highlights the importance of policy interventions and governments as supporters of science and the fundamental changes that have been wrought in the locus of scientific work. Moreover, the conduct and movement of science and its further stratification across sectors—academia, government, and industry—speaks to variation in how science is organized cross-nationally even as institutional isomorphism drives similarity.

Third, research on *gendered societal relations* impacts the structural and cultural interactions and dynamics of scientific work itself. Horizontal and vertical dimensions of occupational sex differentiation and segregation impact the career prospects of women in the sciences. Although the representation of women varies within and across scientific fields, it is still the case that, in most fields and in most contexts, women are consistently underrepresented in effective decision-making and leadership positions, even in fields in which they reflect high levels of degree attainment and scientific expertise. Gender bias often still outweighs competency and skill in many venues, especially those in scientific communities in which practice and decision-making are dominated by privileged elites. Despite apparent gains in the numbers of women in some science fields, the larger structure of marginalization persists, as women continue to be systematically barred from authoritative positions with decision-making power.

Taken together, the three research strands—globalization, the social organization of science, and gendered societal relations—as explored in this book, represent key social forces and offer an analytical framework within which to address foundational issues affecting women's participation in science. By interactively engaging the strands, this volume seeks systemic solutions to the challenge of building an inclusive and productive scientific workforce capable of creating the innovation needed for economic growth and prosperity.

The productive relationships and resources of science are organized largely as disciplinary communities. While the boundaries among disciplines may be blurring with the advent of more inter-, multi-, and trans-disciplinary work, disciplines continue to wield substantial power in prescribing behavior and conferring status within scientific communities. For example, scientists, as do other professionals, exercise discipline-based control over entrance into the community, now defined largely via the global university system (Drori et al. 2003; Frank and Gabler 2006).

Along the same lines, disciplines and scientific communities also span national borders. International collaboration across employment sectors—with academia actually lagging the private sector—has become normative for scientists and engineers (e.g., Falkenheim and Kannankutty 2012). Scientists' status and prestige within their fields are increasingly bound up with the ability to build an international, rather than a strictly national, reputation. Also, as has been the case for the past 20 years, graduate students and postdoctoral researchers often cross national boundaries to obtain credentials, with many remaining in the country of training after they have completed studies (National Science Board 2014; Finn 2012; Hamilton et al. 2012). Furthermore, multinational industries locate research and development centers across the globe in search of production advantages and to exploit and tap the diversity of human talent, along with strengthening collaborative ties with universities (Thursby and Thursby 2006).

This volume also includes chapters focused primarily on women's participation in the chemical sciences, mathematics, statistics, and computing, as four such disciplinary sites and communities that maintain independent organizing structures but also involve intersecting material interests. Many important works on women in science have employed a high level of aggregation (e.g., UNESCO 2007; AAUW 2010; IAC 2006; INAS 2013), the result of which is that the experiences of those in the largest general field of science, the life sciences (a field with a high level of women's participation at all educational levels), often dominate the discourse about women's status in science, missing important variations in the educational and occupational realities for women in fields with proportionately fewer women.[1] Such aggregation can obscure specific disciplinary contexts, functional tasks, and the socio-historical conditions that can vary markedly across fields.

Given the powerful force of globalization of labor and capital, attention to disciplines such as the chemical sciences and computer science can shed important light on likely trends that also will occur in other science and engineering fields. Along with these disciplines, the foundational nature and cross-sector applications of mathematics and statistics offer crucial insights into the extent to which occupational hierarchies within disciplines and social hierarchies like gender and nationality operate in tandem. Each of these four disciplines provides different types of opportunities for individuals with varied types and levels of postsecondary training ranging from certifications to doctorates. As the degree level increases in each of these fields, the intellectual content of the work also increases, with less time spent manipulating things and more time spent manipulating ideas and data. In addition, these higher-level manipulations often involve synthesizing information from multiple sources and producing knowledge rather than things. Therefore, while workers are needed at all educational levels, the most powerful roles in these fields typically are played by those with more advanced training. The challenges highlighted in this

---

[1] Some studies also include the social sciences, which reflect different representational patterns.

volume provide a mirror for the problems generally understood as relevant to the participation of women in science and, also, offer a promising framework for more detailed and comparative investigation of gendered relations and outcomes in other disciplinary contexts.

The volume is divided into three parts. Each chapter includes additional pieces—case studies, profiles, and reflections—contributed by scholars and analysts from around the world, which call attention to the importance of context in understanding women's participation in science. Just as the overall volume explores the interplay among individual, national, and international aspects, so too do these "vignettes" offer insights into multiple levels of analysis in answering questions about women in science. The cross-national insights offered by these pieces provide additional depth to the material in each chapter, adding to an understanding of both the role of gender as an organizing principle of social life and the relative position of women in science within national and international labor markets.

The chapters in Part I lay the foundation for the book, providing an overview of trends in women's representation in science education by global regions, analytical techniques for examining gender in the workforce, and a review of available data on gender and science. Francisco O. Ramirez and Naejin Kwak (Chap. 2) examine 40 years of women's enrollments in science and engineering fields in 69 countries that are aggregated to six world regions. They find that, while women's participation in science and engineering has increased, the terms of that inclusion are still subject to wide variation and debate. Lisa M. Frehill, Alice Abreu, and Kathrin Zippel (Chap. 3) provide a critical literature review and overview of relevant work that has been done to date by demographers, sociologists, and economists on occupational segregation, as an important toolkit for gender analysis. Wendy Hansen (Chap. 4) offers a global perspective and assessment on applicable education and workforce data. Gaps in data collection are identified with an eye to informing policy decisions. Even with various international efforts dedicated to such issues, it is still the case that multiple sources of data must be consulted to "cobble together intelligence" for advocates and policy makers.

Part II considers each of the four exemplar disciplines. Women in the chemical sciences are discussed by Lisa Borello, Robert Lichter, Willie Pearson, Jr., and Janet L. Bryant (Chap. 5). Mathematics is covered by Cathy Kessel (Chap. 6) and statistics is considered by Lynne Billard and Karen Kafadar (Chap. 7). Finally, computing is addressed by Lisa M. Frehill and J. McGrath Cohoon (Chap. 8). While current data are included for illustration purposes, these chapters explore education and workforce situations in each discipline within the overall organizing framework for analytical reference and insight. Each discipline is examined relative to different outcomes and strategies that reflect and impact women's involvement in the given field and the structure and content of the work itself. By focusing in more detail on these disciplines, the specific aspects of the international labor market, distributional differences across national contexts, and within-field structures and relationships along gender lines are examined relative to the interplay of globalization, the social organization of science, and gender relations. As such, these chapters offer starting points for researchers to conduct more nuanced analyses of gender within each field (cf. Creager et al. 2001).

Part III examines the ways in which policies and programs can affect "who will do science." Daryl Chubin, Catherine Didion, and Josephine Beoku-Betts (Chap. 9) describe programmatic efforts as means to address issues of ethnic and gender equity in access and advancement within scientific professions. The authors caution us to be mindful of different expectations for programmatic interventions held by different stakeholders to understand the relative "success" of such interventions. Finally, Cheryl Leggon, Connie L. McNeely, and Jungwon Yoon (Chap. 10) engage related policy issues in terms of who needs to do what, when, how, and for how long to advance the representation and status of women in science. Rather than looking to the behaviors of individual women,[2] their focus is on institutions and governments as loci of intervention for increasing diversity and broadening participation. They point out that policy makers need to be informed by a more detailed understanding of the complex role of gender—as well as other dimensions of difference—in science education and workforce outcomes.

A postscript is offered at the end with thoughts about looking forward and building on the foundation provided by this volume. With multiple audiences in mind—scholars, educators, employers, analysts, policy makers, and other stakeholders—the postscript delineates an agenda for future research, policy, and activism associated with advancing women's participation in science around the world.

Acknowledgement Some of the research reported in this volume was supported in part by a grant from the US National Science Foundation (DRL-1048010). Related findings, conclusions, and opinions are those of the authors and do not reflect those of the National Science Foundation.

Chapter References

American Association for the Advancement of Women (AAUW). 2010. *Why So Few?: Women in Science, Technology, Engineering, and Mathematics*. Washington, DC: AAUW.

Bielli, A., A. Buti, M.V. Camino, M.E. Estébanez, T. Lascaris Comneno, H.M. Martins Lastres, H. Pereira de Melo, E. Pérez Sedeño, R. Robledo, M.T. Pin, M.L. Rodríguez-Sala, H. Vessuri, and J. Zubieta García. 2004. *Proyecto Iberoamericano de Ciencia, Technología y Género—GENTEC—UNESCO: Informe comparative regional e informes nacionales de Argentina, Brasil, Costa Rica, España, México, Paraguay, Uruguay y Venezuela,* http://api.ning.com/files/3wIypPzztSduT4Q6g5O8DZkdNgudKlow6TrCnNeQq-F-B5AwrJ42Jdwu3rT8RlkhkY5vbmuBO-EZK0Pu0qVZ6cDwbV180bSf/Reporte_FinalGENTEC.pdf (accessed 30 March 2014).

Centre National de la Recherche Scientifique (CNRS). 2004. *Les femmes dans l'histoire du CNRS,* http://www.cnrs.fr/mpdf/IMG/pdf/cnrs_femmes_histoire.pdf (accessed 30 March 2014).

Creager, Angela N.H., Elizabeth Lunbeck, and Londa Schiebinger (eds.). 2001. *Feminism in Twentieth Century Science, Technology, and Medicine*. Chicago, IL: University of Chicago.

Drori, Gili S., John W. Meyer, Francisco O. Ramirez, and Evan Schofer. 2003. *Science in the Modern World Polity: Institutionalization and Globalization*. Stanford, CA: Stanford University Press.

---

[2] As in volumes that use biographies of women to articulate how women as active agents have surmounted obstacles to gain success in science (e.g., Rossiter 1995; Tang 2006).

Falkenheim, Jacquelina, and Nirmala Kannankutty. 2012. *International Collaborations of Scientists and Engineers in the United States*. Arlington, VA: National Science Foundation, National Center for Science and Engineering Statistics. InfoBrief 12-323.

Finn, Michael G. 2012. "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2009, http://orise.orau.gov/files/sep/stay-rates-foreign-doctorate-recipients-2009.pdf (accessed 30 March 2014)].

Frank, David John, and Jay Gabler. 2006. *Reconstructing the University: Worldwide Shifts in Academia in the 20th Century*. Stanford, CA: Stanford University Press.

Hamilton, R.V., C.L. McNeely, and W.D. Perry. 2012. Foreign Doctoral Attainment in the Natural Sciences at U.S. Universities. *ERN Public Policy Institutes Research Paper Series* 4(2), http://dx.doi.org/10.2139/ssrn.1999816

InterAcademy Council (IAC). 2006. *Women for Science: An Advisory Report*. Amsterdam: IAC Secretariat.

Interamerican Network of Academies of Sciences (INAS). 2013. *Women Scientists in the Americas.*

National Science Board (NSB). 2014. *Science and Engineering Indicators 2014*. Arlington VA: National Science Foundation (NSB 14-01).

National Research Council (NRC). 2011. *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*. Washington, DC: The National Academies Press.

Rossiter, M.W. 1995. *Women Scientists in America: Before Affirmative Action, 1940-1972*. Baltimore: Johns Hopkins University Press.

Tang, J. 2006. *Scientific Pioneers: Women Succeeding in Science*. Washington, DC: University Press of America.

Thursby, M., and J. Thursby. 2006. Where is the New Science in Corporate R&D? *Science* 314: 8.

United Nations Educational, Scientific, and Cultural Organization (UNESCO). 2007. *Science, Technology, and Gender: An International Report*. Paris: UNESCO.

UNESCO. 2010. *UNESCO Science Report 2010: The Current Status of Science around the World.* Paris: UNESCO, http://unesdoc.unesco.org/images/0018/001899/189958e.pdf (accessed 30 March 2014).

Part I
Cross-Cultural Foundational Issues

Chapter 2
Women's Enrollments in STEM in Higher Education: Cross-National Trends, 1970–2010

Francisco O. Ramirez and Naejin Kwak

Much of the earlier literature on women and higher education emphasized the dearth of women therein. This phenomenon was problematized for three reasons: higher education was increasingly seen as an important determinant of individual adult success; the human capital developed in higher education was increasingly seen as necessary for national success; and, women were increasingly seen as individual persons with rights and with human capital potential. Numerous studies showed that one's life chances were improved as a function of higher education attainment. In sociology, occupational status attainment studies were replicated across a wide range of national contexts. A positive association between higher education attainment and occupational status was reported repeatedly (see for example the papers in Shavit and Blossfeld 1993).

A different but related line of research began to emphasize the importance of education for national economic development (see Harbison and Myers 1964 for an early study). Schooling, it was argued, was the key to developing more productive individuals, and in the aggregate, more productive countries. If individuals needed more schooling to better advance themselves, countries needed more educated individuals to further national progress. Thus, there was a sense that the individual self-interest and the public good of the national society were closely aligned. This new sensibility extended to higher education and undercut older fears about overeducated individuals and societies with too many dangerously underemployed graduates (Freeman 1976).

F.O. Ramirez (✉) • N. Kwak
Graduate School of Education, Stanford University,
485 Lasuen Mall, Stanford, CA 94305, USA
e-mail: Ramirez@stanford.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_2

Not surprisingly, the earlier studies did not include women in the samples of individuals whose life trajectories were examined. A traditional gendered vision of society, with men in the workforce and women at home, still had some currency in the decades after World War II. But the world was changing albeit slowly. Women's social movements had earlier led to their gaining the franchise throughout the world (Ramirez et al. 1997). These movements globalized women's issues long before the term globalization became ubiquitous in the social sciences. Issues of women's rights increasingly centered on access to domains that were once monopolized by men. Access to higher education became one such important issue (Sewell 1971; Karen 2000). As women gained greater access to higher education, the status attainment and the human capital research traditions evolved to examine the influence of women's higher educational attainment on their subsequent occupational attainment and earnings. Earlier studies of the impact of women's education on their husbands' occupational attainment would not be replicated. The traditional line of research on the effect of women's education on the welfare of their children would continue, but more research now examines the influence of women's education on their own life chances, their wages, and their health, for example. As a gendered vision of society fades, women enter into these studies as individuals rather than as wives or mothers.

These issues are now revisited with a strong focus on women in science, technology, engineering, and mathematics (STEM). In one sense, these are not new issues: the publication of "A Nation At Risk" (1983) dramatized the relatively lower standing of American students in international mathematics tests. A more recent publication of "Rising Above the Gathering Storm" (2007) is also centered on STEM domains. There is considerably less interest in how American students fare in reading tests or in the mastery of foreign languages. Mathematical and scientific literacy are clearly privileged in the national crisis discourse that permeates both of these government reports. A general emphasis on higher education is now shifting to a more specific focus on STEM. The underlying assumption is a straightforward extension of the earlier logic regarding higher education: individuals and societies will both benefit from the enhanced competency and the greater number of students in STEM.

The scholarship, consequently, turned their attention from women in higher education to women in STEM. This is true not only in the United States but also throughout the world. In the West, for instance, it is argued that women have a right to expanded access to STEM and that it is in the national interest to develop policies to improve access to STEM for women. This is an equity issue: what is good for men is good for women. But it is also an efficiency issue: the underutilization of female human capital undercuts national development. Thus, the European Technology Assessment Network (2000) invokes both themes of equity and efficiency in making the case for mainstreaming gender in science policies. Much of the literature on women in STEM is country specific (but see Ramirez and Wotipka 2001; Wiseman et al. 2009). The literature addresses individual and organizational factors that influence the likelihood of women entering into and graduating from these fields of study. This literature is important in its own right and its core finding is that fewer women in these fields are not due to lower ability (Riegle-Crumb et al. 2012). However, it does not directly address the changing global context within which the issues of women in STEM have been generated. In what follows, we briefly sketch a macro-sociological world society perspective and its implications for understanding the worldwide changing status of women. This perspective informs the questions this chapter addresses regarding women in STEM and our discussions of cross-national trends that constitute our basic data.

2.1 World Society and Women's Status

The idea that nation-states operate in a global environment is now almost a commonplace understanding in the social sciences. It is widely understood that nation-states are subject to a large number of transnational influences and that, as a result, there are growing similarities among nation-state structures and policies (Meyer et al. 1997). These transnational influences are applauded when they lead to an expansion of the rights of persons, as in the human rights literature (Hafner-Burton 2013). But they are critiqued when seen as undermining national autonomy and integrity, often found in critiques of the impacts of the International Monetary Fund (IMF) on education, for example (Beech 2011). The problem, of course, is that some of what adds up to national or cultural autonomy may be precisely what impedes the extension of rights to women. For instance, local male dominant cultures may restrict women's educational opportunities through harassment practices that make it dangerous for girls to go to schools and universities, in Taliban-dominated areas, for example.

Globalization has been discussed as a force that has led to nationalism, an invention that diffused around the world as blueprints of nation-building and lead to more similar forms of imagining oneself as a territorially based national entity. From the outset, what now appear to be natural nation-states forged their common identities with transnational blueprints in mind:

> …the independence movements in the Americas became, as soon as they were printed about, 'concepts,' 'models' and indeed 'blueprints.'…Out of the American welter, came these imagined realities: nation-states, republican institutions, common citizenships, popular sovereignty, national flags and anthems, etc. … . In effect, by the second decade of the nineteenth century, if not earlier, a 'model' of the independent national state was available for pirating (Anderson 1991: 81).

This is the first premise that motivates the world society perspective: nation-states derive their identity and their legitimacy from world models of the nation-state. The second premise is that the individual person is increasingly placed at the center of attention within the nation-state (Beck 2002). The idealized nation-state is one that incorporates more diverse segments of its people, transforming them into national citizens. This logic of inclusion can be viewed as an extension of the category of individuals who have rights. It can also be viewed as an expansion of the category of individuals whose development counts toward national development. The patriotic and productive citizen is thus linked to the idealized nation-state.

The third premise is that schooling arises and expands as a favored mechanism for the production of patriotic and productive citizens. Through schooling, peasants become Frenchmen, the working class becomes English or German, and so forth. Mass schooling spreads worldwide, and more recently higher education becomes more accessible to a broader array of individuals. The ideal nation-state is expected to expand schooling and to enact policies that make education a centerpiece of national policy.

The status of women changes in a world where they are increasingly seen as persons and citizens and where women's development is seen as their right as well as an important part of the national interest. Women's movements gain legitimacy from world models of the legitimate nation-state, and at the same time, these movements reinforce and modify the models, highlighting gender-related issues. Thus, various types of gender inequalities are likely to be viewed as inequities and become the object of intense public scrutiny. A growing number of changes in access to education, health, and work are facilitated by global egalitarian standards. In fact, there is ample evidence of changes in the direction of greater gender equality across many domains, including education, mortality, economic activity, and political representation (Ramirez et al. 1997; Paxton et al. 2006; Dorius and Firebaugh 2010).

From the world society perspective, one would expect to find that women have increased their numbers in higher education in general and in STEM fields in specific. But is this indeed the case? This chapter describes cross-national trends in women's share of science, technology, engineering, and mathematics enrollments for about 70 countries between 1970 and 2010. We do so to answer two questions: (1) what is the overall global trend regarding women's entry into these fields of study, and (2) are some fields more women accessible than others?

In what follows, we first examine cross-national trends to answer these questions. We then discuss the main findings. In doing so, we link these findings both to the world society perspective and to feminist arguments that distinguish between women in science and women and science. The core assumption underlying these arguments is that there is more to gender equality than increased female access to domains formerly dominated by men (e.g., Stromquist 2013).

2.2 Cross-National Trends

To describe worldwide historical trends in women's enrollments in STEM fields of study in higher education, six indicators are examined in this chapter. First, to depict a broad picture of women's participation in higher education, we examine (1) women's enrollments in higher education divided by the appropriate postsecondary education age cohort, and (2) women's enrollments in higher education divided by total enrollments in higher education. The first indicator reflects the degree to which women relative to their age appropriate population are enrolled in higher education. National policies that emphasize the need for fully utilizing human capital typically focus on the first indicator. The second indicator captures the degree to which women's presence is increased in higher education relative to men. Scholarly discussions about gender equity often pay attention to this indicator.

Given that much of the current literature is now focused on women in STEM, we next examine (3) women's enrollments in STEM fields of study divided by total enrollments in the fields. Although the natural sciences and engineering may share attributes that make them different from other fields of study, each also has a distinct academic culture, possibly leading to divergent female enrollment trends. Thus, we further examine natural sciences and engineering separately by using (4) women's enrollments in natural sciences divided by total enrollments in natural sciences, and (5) women's enrollments in engineering programs divided by total enrollments in engineering programs. Lastly, we present additional information on (6) total enrollments in STEM programs divided by total enrollments in all programs. We do so to see whether the STEM share of higher education is on the rise and whether that is related to changes in women's share of STEM over time.

The data on women's enrollments in higher education by sex, field, and country were gathered from various volumes of the UNESCO Statistical Yearbook for earlier years (UNESCO 1970–1998) and the online database of the UNESCO Institute for Statistics for more recent years (UNESCO 1999–2010). UNESCO uses the International Standard Classification of Education (ISCED) system to categorize higher education institutions by levels and students by fields of study (i.e., STEM). Three levels of higher education (i.e., vocational, university, and postgraduate) are all included in our analyses. With regard to fields of study, we took into account some changes in the ISCED system during the period under our examination. For example, in some years, the enrollment data on math and computer science programs were collected separately from natural science. We kept the measures of women's enrollments in science and engineering consistent by including math and computer science in natural science throughout the 40 years. There is another issue to note in using the UNESCO data. In some years, a small number of countries provided the overall enrollment information on natural science and humanities together. These cases were coded as missing.

In what follows we first examine historical trends of female participation in higher education in general, and then focus on women in science and engineering fields of study. The sample includes 69 countries throughout the world from 1970 to 2010.[1] UNESCO collects higher education enrollment data from national governments around the world on a yearly basis, but not all governments have participated in data collection every year. The countries missing any indicator listed above for more than 3 years out of the five time points (1970–2010) were eliminated from the sample. This led to the inclusion of 52 to 68 countries in the sample over the four

---

[1] Our analyses are based on five data points largely around 1970, 1980, 1990, 2000, and 2010. If data were missing, we went on to use information from adjacent years. More than 90% of the data were collected within a five-year window.

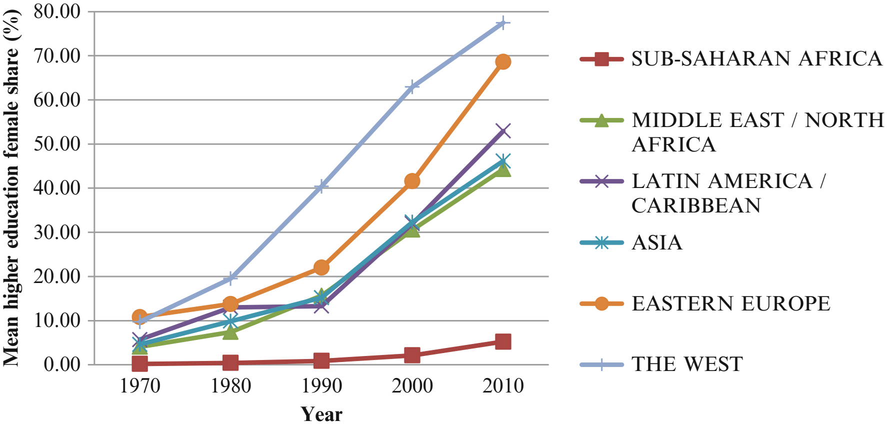


Fig. 2.1 Women's participation in higher education, 1970–2010. *Note*: Data are from various volumes of the UNESCO Statistical Yearbooks (1970–2010). Women's participation in higher education was calculated by dividing the total enrollment of women in higher education by the appropriate school age population

decades.[2] Whereas the general enrollment data were available for a large number of countries throughout 1970–2010, the enrollment data broken down by fields of study were found in a fewer number of countries, particularly in the 1980s and 2000s. Although the West (including Australia and New Zealand) is overrepresented, the countries in the sample vary by level of economic development, type of political regime, and other sociocultural characteristics. The sample covers a wide range of national entities across different regions.[3] The complete list of countries in the sample can be found in the Appendix.

Figure 2.1 plots the degree to which women in the appropriate school age cohort are enrolled in higher education. Regional means are reported for each time point, from 1970 to 2010. We find that there has been a significant growth of female participation in higher education throughout the world for the past four decades. In every region of the world, the percentage of women in higher education in 2010 is greater than that in 1970. This finding is consistent with prior studies that showed a worldwide growth of women's participation in higher education in earlier decades (Kelly 1989; Bradley and Ramirez 1996; Ortega 2008). To be sure, there are some cross-regional differences: women in Sub-Saharan African countries undergo a more modest increase relative to the marked gains in the other regions. As of 2010, more than 40% of women in the tertiary age cohort are enrolled in higher education in countries in every region except Sub-Saharan Africa.

---

[2] For example, the United States is excluded from the sample because, for the 1980s, 1990s, and 2000s, the US enrollment data were not reported to UNESCO.

[3] The regional categories in the analyses speak more to sociocultural rather than strictly to geographical categorization.

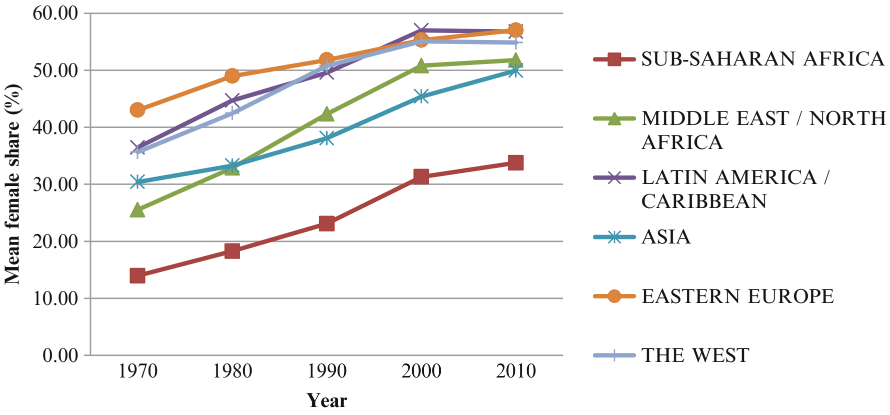


Fig. 2.2 Women's share of higher education, 1970–2010. *Note*: Data are from various volumes of the UNESCO Statistical Yearbooks (1970–2010). Women's share of higher education was calculated by dividing the total enrollment of women in higher education by the total enrollment (of men and women) in higher education

Some scholars have pointed out that the dramatic increase in women's participation in higher education is partially a function of the massive expansion of all of higher education in these periods (Schofer and Meyer 2005). This then raises the question of whether women's gains are comparable to those of men. If men are entering into higher education at a higher rate than women, then despite their overall increases in participation, women would still be losing ground in terms of their overall share of higher education enrollments.

In Fig. 2.2, however, we see that there has been a steady increase in women's share of higher education.[4] In every region of the world, women's share of higher education in 2010 is greater than that in 1970. More specifically, in 1970, women's share of higher education varied from as little as approximately 17% in Sub-Saharan Africa to as large as roughly 43% in Eastern Europe. By 2010, women's share varied roughly from 34% in Sub-Saharan Africa to 57% in Eastern Europe. Except for Sub-Saharan Africa, women around the world are now enrolled in postsecondary education at a level that is comparable to or higher than men, hovering around 50–60%. That is, this remarkable improvement of female participation in higher education is a worldwide phenomenon.

This impressive growth of the female share of higher education was not anticipated in the earlier social science literature that emphasized a wide range of barriers against women's entry into higher education. The empirical question is whether the increased women's share of higher education is solely due to the increased women's

---

[4] To keep our sample comparable throughout the analyses, we limited our analyses of women's participation in higher education to the set of countries that have information on enrollment by fields of study. Our results are similar to what Ramirez and Riddle (1991) found earlier with a larger sample of countries (79–119).

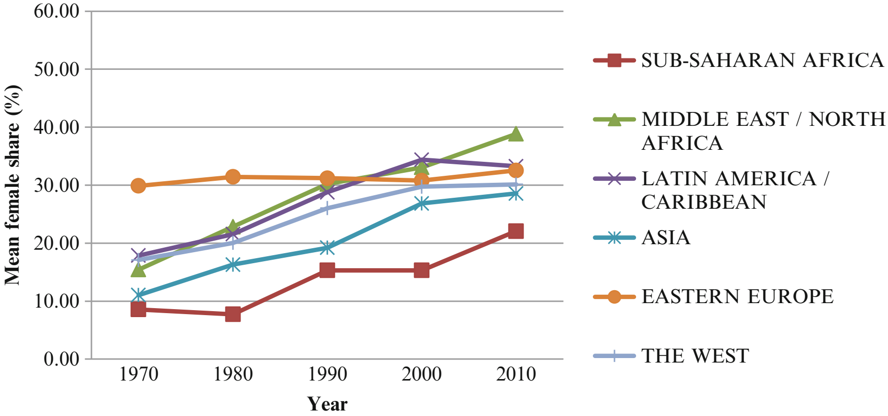


Fig. 2.3 Women's share in science and engineering: 1970–2010. *Note*: Data are from various volumes of the UNESCO Statistical Yearbooks (1970–2010). Women's share in science and engineering fields was calculated by dividing the total enrollment of women in science and engineering fields by the total enrollment (of men and women) in science and engineering fields

share in non-STEM fields such as education, humanities, or social sciences. Or, alternatively, whether women have also expanded their share of higher education enrollments in STEM.

Figure 2.3 displays historical trends in women's share of STEM fields. Overall, lower women's share is found in STEM fields throughout the five time points than that of higher education as a whole. However, the historical trends also indicate that women around the world have made some progress in entering these fields. Compared to the 1970s, when they made up only 10–20% of science and engineering majors, women now comprise 30–40% of science and engineering majors. In every region, women's share of STEM in 2010 is greater than it was in 1970. In fact, there are only four countries in 2010 with female shares lower than those in 1970; Bulgaria (42.7% in 1970 to 35.2% in 2010), Finland (from 27.3 to 24.7%), France (from 33.9 to 30.4%), and Hungary (from 24.7 to 23.1%). The growth of women's share seems to slow down in more recent years in some regions such as Latin America, the Caribbean, and the West while it continues to go on in other regions. In particular, the Middle East and North Africa has witnessed a substantial and consistent growth in female share of STEM fields. It appears that the growth is greater in regions that started with lower female shares of STEM, suggesting a catch-up with the rest of the world dynamic.

Although natural sciences and engineering share many traits in common that make them distinct from other fields of study, they may be different from each other in certain aspects. For example, the two fields may have divergent disciplinary cultures, career prospects and pathways, professional development opportunities, academic prestige, and so on, leading to potentially dissimilar enrollment patterns by gender. Therefore, it is worth examining cross-national variation in natural sciences and engineering programs separately. Figures 2.4 and 2.5 demonstrate the historical

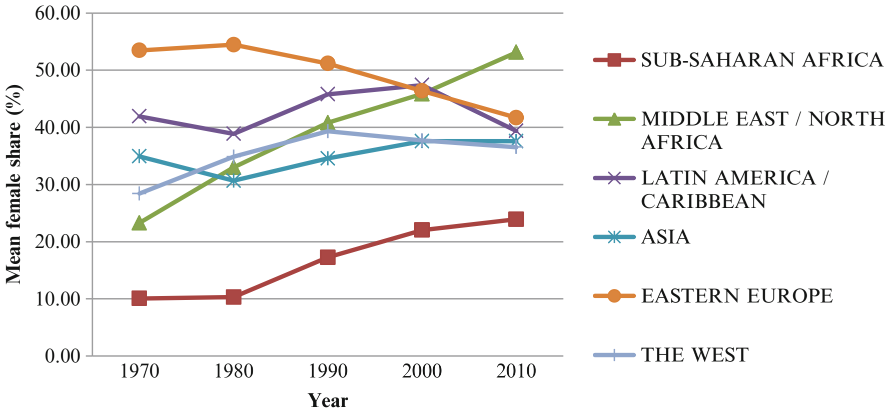


Fig. 2.4 Women's share of natural science, 1970–2010. *Note*: Data are from various volumes of the UNESCO Statistical Yearbooks (1970–2010). Women's share of natural science was calculated by dividing the total enrollment of women in science fields by the total enrollment (both men and women) in science fields. Natural science includes math and computer science

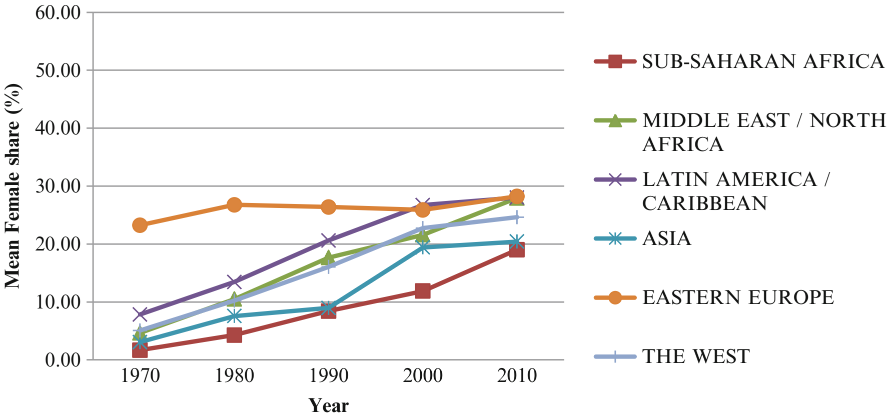


Fig. 2.5 Women's share in engineering, 1970–2010. *Note*: Data are from various volumes of the UNESCO Statistical Yearbooks (1970–2010). Women's share in engineering was calculated by dividing the total enrollment of women in engineering programs by the total enrollment (both men and women) in engineering programs

progression of women's enrollment in the natural sciences, including math and computer science, and in engineering, respectively.[5]

Figure 2.4 shows trends in women's share of natural science programs by world region. In four out of six regions, women's share of natural sciences is greater in 2010 than that in 1970. Interestingly, we find somewhat diverging trends in women's representation in natural science programs. The most noticeable pattern is

---

[5] Medicine and health-related fields and agriculture programs are not included.

found in Eastern Europe. Unlike any of the other regions, more women were represented in natural sciences than men in Eastern Europe in 1970 than today. This trend may reflect the collapse of the Communist regimes and their central planning agendas that were less open to individual choice as regards fields of study (Bradley 2000). These regimes were formally committed to gender equality, assumed strong links between science and engineering and development, and controlled access to STEM fields through strict meritocratic criteria. Thus, women who demonstrated aptitude for STEM fields were channeled into these fields. The collapse of these regimes did not slow down women's entry into higher education as a whole (see Figs. 2.1 and 2.2), but in the absence of a mobilizing regime, women began to opt for other fields of study.

The continuing growth of the female share in the Middle East and North Africa is also notable. Women in these regions have not only made impressive and steady advancement in their representation in natural sciences, they are now surpassing men in their enrollment rates in natural science programs. Albeit at a much lower level, Sub-Saharan Africa also witnessed a slow but steady increase in women's share of natural science. In the West, women's share of natural sciences increased to about 40% in the early 1990s, and then started leveling off in the later periods. On the other hand, Latin America and the Caribbean, and Asia show common patterns with a dip in the 1980s followed by an increase in the later periods.

What does the overall pattern look like in engineering? In the United States, women's access to engineering seems more limited than in the natural sciences (Jacobs 1995; Charles and Bradley 2002; England and Li 2006). How do cross-national patterns compare to those in the natural sciences? Figure 2.5 presents trends in women's share of engineering. As in the United States, women's share of engineering is generally lower than their share of natural science enrollments. This is true for all regions of the world throughout the periods, which suggests that engineering is indeed a less accessible field of study for women.

However, even in what appears to be a male bastion, there is evidence of increasing female enrollments. That is, women's share of engineering has steadily grown around the world. In most regions of the world, women's share of engineering programs was below ten percent in 1970. In 2010, the shares vary from 20 to 30%. There has been relatively little change in Eastern Europe, where women's share of engineering was much higher than those in other parts of the world in the 1970s. In sum, even the most female-resistant field of study, engineering, has become relatively more inclusive to women.

We noted earlier that higher education as a whole is on the rise everywhere. Given the enormous emphasis national policy makers place on the study of science and engineering, one might expect that the growth of higher education is fueled by a rising wave of science and engineering enrollments. Figure 2.6, however, reveals that this is not uniformly the case. In fact, in most regions we find a slightly downward trend or an absence of change. This finding is consistent with prior studies, which suggest that growth in the social sciences is the driving force behind the overall higher educational growth (Drori and Moon 2006; Frank and Gabler 2006).

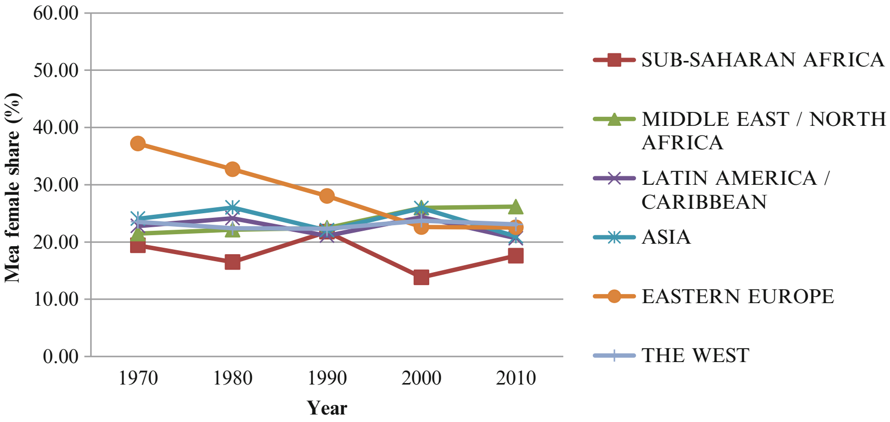


Fig. 2.6 STEM Fields' share of higher education, 1970–2010. *Note*: Data are from various volumes of the UNESCO Statistical Yearbooks (1970–2010). STEM fields' share of higher education was calculated by dividing the total enrollment of men and women in science and engineering programs by the total enrollment (of men and women) in all higher education programs

Either due to lower student demand or more stringent entry criteria, science and engineering enrollments are not increasing as much as non-STEM enrollments are. Taken as a whole, Figs. 2.3–2.6 indicate that the increase in women's share of STEM is not due to an explosion of enrollments in STEM fields. Quite the contrary, it appears that women are increasing their relative presence in fields that are both seen as pivotal for national development and for individual advancement, but the fields themselves are not growing significantly. We return to this point in the discussion that follows.

2.3 Discussion

There are two main inferences that one can draw from these cross-national trends. First, women's share of higher education and their enrollments in science, technology, engineering, and math fields have both expanded worldwide between 1970 and 2010. The growth rate, not surprisingly, is greater in the regions where women's share was relatively lower in the earlier time period. That is, the further the female share is from the 50% gender parity target at the initial time point, the greater its growth. The overall pattern of growth, however, suggests that in this era distinctive national structures and cultures may matter less than universal world pressures on nation-states to make their higher education more accessible to women as citizens and persons. The same worldwide pressures may directly affect women who are now more likely to imagine the possibility of entering into fields of study once monopolized by men.

On the other hand, STEM fields are increasingly regarded as the key to future national development. The "nation at risk" and "gathering storm" rhetoric centers on the importance of improving achievement in STEM fields in lower levels of schooling as well as higher education. In the United States and in other countries, the message is that the country needs more people with greater competence in STEM. Thus, women emerge in national policy discourse both as rights-bearers and as needed human capital. A similar kind of message is also articulated by subnational and international women's nongovernmental organizations. Expanded female access to both natural sciences and engineering in higher education appears to be a response to world, societal, and organizational pressures.

This worldwide advancement of women in STEM fields is inconsistent with theories that privilege distinctive national structures and cultures. Regions of the world where women's opportunities have been limited by religious or cultural traditions favoring men in the public sphere have nevertheless experienced a growth in women's share of STEM enrollments. Economically underdeveloped countries where there may be fewer jobs requiring STEM skills have also seen a growth of the female share in these fields of study. The world society perspective implies that these global changes are in good part driven by the triumph of world models of nation-states that facilitate national policy and collective action. The exceptions to the worldwide pattern are few (e.g., Eastern Europe as regards natural science enrollments).

The second main inference is that throughout the time period, women's share of STEM is lower than their overall share of higher education. Women's share of engineering enrollments is also generally lower than that of the natural sciences. These findings account for the research and policy focus on women in STEM, a focus that carries global currency. That is, we should expect to see that national, regional, and world conferences on women in higher education will increasingly highlight underrepresentation of women in STEM and encourage women's participation in these fields. Some of these conferences will continue to discuss access issues as regards women in STEM, but we expect that theory and research will veer in the direction of focusing on women *and* STEM, rather than women *in* STEM.

This direction is part of a broader feminist critique of institutions and organizations: the crucial questions are not about access per se but about structures themselves and whether the structures privilege men (Stromquist 2013). The chilly climates perspective, which argues that women are often made to feel unwelcome in male-dominated fields, builds on the distinction between access and experience. The growing emphasis on graduates, distinguished from enrollees, presupposes that there will be a gender gap between enrollees and graduates because STEM fields are more difficult for women to successfully navigate. Some of the problems women face may simply be due to their underrepresentation in STEM. These issues were identified and addressed by Kanter (1977) in her analysis of women and their career paths in corporations. Her main thesis is that as the number of women increases in a corporation, women will be less burdened by sticking out. When few women are in a group, they are more likely to be viewed as tokens. The author argued that female tokens often end up downplaying gender differences so that the dominant majority, or men, can cheerfully conclude, "you really are one of us!" Or, alternatively, tokens can be burdened with the expectation that they need to furnish the woman's point of view on all sorts of issues. Either side of the dilemma leads to interpersonal dynamics that undercut the achievement and advancement of tokens. The same logic can be applied to women in STEM—concerns over sticking-out increase the likelihood of opting-out.

But the current concerns over women-in-STEM are based on other aspects of the structures as well, such as curriculum and pedagogy. Some of the literature suggests that the taken-for-granted curriculum and pedagogy in these domains may be especially negative for females (Boaler 1997). Reforms in mathematics and science education that emphasize contextualized learning or integrated instruction often refer to their advantages for girls (Boaler 1999) and women (Stage and Kinzie 2009). More traditional approaches are criticized for compartmentalizing knowledge and for structuring assessments in competitive terms, emphasizing inherent talent rather than sustained effort. These approaches are viewed as gender biased because they evoke stereotypes that cast females as inherently less talented in STEM fields (Spencer et al. 1999; Cheryan et al. 2009; Good et al. 2012). From this perspective, the question is not simply who gets into STEM but what STEM is. At its core are calls for the de-masculinization of STEM. Adding more women to the mix is, of course, a plus. But the favored policies are two pronged and call for both more women in STEM and the de-masculinization of STEM. Efforts to strip STEM from gender bias include the production of textbooks and curricula in which science is done in everyday contexts, not just in labs by men with white coats (McEneaney 1998). Furthermore, these efforts tend to emphasize science production as a process involving collaboration within and between groups of individuals rather than as competition between a few charismatic male leaders.

It is obviously easier to simply increase the number of women in STEM than to question the terms of inclusion. We are, in fact, witnessing a growth of the inclusion of women in STEM, as well as an increase in the questions raised regarding their terms of inclusion. The increasing number of women in the field better positions women to challenge their being incorporated into a man's world. This may seem odd to those who assume that their incorporation simply results in an acceptance of the status quo, or what the more critically inclined might deem co-optation. But, in fact, what we see is part of a global shift from debates about who is eligible for inclusion to debates over the terms of inclusion. It is precisely because the logic of inclusion has outcompeted exclusionary logics, de-legitimating the latter across a wide range of domains, that the terms of inclusion debates are now possible. The transformation of women into more included citizens, persons, and workers empowers women to contest the terms of inclusion, that is, to challenge the gendered character of the institutions and organizations in which women now have expanded access. More women in STEM lead to more questions about women and STEM.

2.4 Appendix: Countries Included in the Sample (in Alphabetical Order)

Albania
Algeria
Argentina
Australia
Austria
Bangladesh
Belgium
Benin
Brazil
Bulgaria
Burundi
Cameroon
Central African Republic
Chile
Colombia
Cuba
Cyprus
Czech Republic
Denmark
Ecuador
Egypt
El Salvador
Ethiopia
Finland
France
Ghana
Greece
Guyana
Honduras
Hong Kong
Hungary
Iceland
Iran
Ireland
Israel
Italy
Japan
Jordan
Lebanon
Macedonia
Madagascar

Malaysia
Malta
Mexico
Morocco
Nepal
Netherlands
New Zealand
Norway
Panama
Philippines
Poland
Portugal
Republic of Korea
Romania
Saudi Arabia
Senegal
Slovakia
Spain
Sri Lanka
Sweden
Switzerland
Thailand
Trinidad and Tobago
Tunisia
Turkey
Uganda
United Kingdom
Uruguay

Chapter References

Anderson, Benedict. 1991. *Imagined Communities: Reflections on the Origins and Spread of Nationalism*. London: Verso.

Beck, Ulrich. 2002. *Individualization: Institutionalized Individualism and its Social and Political Consequences*, vol. 13. London: Sage.

Beech, Jason. 2011. *Global Panaceas, Local Realities: International Agencies and the Future of Education*, vol. 22. Frankfurt am Main: Peter Lang.

Boaler, Jo. 1997. Reclaming School Mathematics: The Girls Fight Back. *Gender and Education* 9(3): 285–305.

Boaler, Jo. 1999. Participation, Knowledge and Beliefs: A Community Perspective on Mathematics Learning. *Educational Studies in Mathematics* 40(3): 259–281.

Bradley, Karen. 2000. The Incorporation of Women into Higher Education: Paradoxical Outcomes? *Sociology of Education* 73(1): 1–18.

Bradley, Karen, and Francisco O. Ramirez. 1996. World Polity and Gender Parity: Women's Share of Higher Education, 1965–1985. In *Research in Sociology of Education and Socialization*, vol. 11, ed. Aaron M. Pallas, 63–91. Greenwich, CT: JAI Press.

Charles, Maria, and Karen Bradley. 2002. Equal but Separate? A Cross-National Study of Sex Segregation in Higher Education. *American Sociological Review* 67(4): 573–599.

Cheryan, S., V.C. Plaut, P.G. Davies, and C.M. Steele. 2009. Ambient Belonging: How Stereotypical Cues Impact Gender Participation in Computer Science. *Journal of Personality and Social Psychology* 97(6): 1045–1060.

Dorius, Shawn F., and Glenn Firebaugh. 2010. Trends in Global Gender Inequality. *Social Forces* 88(5): 1941–1968.

England, Paula, and Su. Li. 2006. Desegregation Stalled: The Changing Gender Composition of College Majors, 1971–2002. *Gender and Society* 20(5): 657–677.

European Technology Assessment Network. 2000. *Science Policies in the European Union: Promoting Excellence Through Mainstreaming Gender Equality*. Luxembourg: European Union.

Drori, G.S., and M. Hyeyoung. 2006. The Changing Nature of Tertiary Education: Neo-Institutional Perspective on Cross-National Trends in Disciplinary Enrollment. In *The Impact of Comparative Education on Institutional Theory*, ed. D. Baker and A. Wiseman. Oxford: Elsevier Science.

Frank, David, and Jay Gabler. 2006. *Reconstructing the University: Worldwide Shifts in Academia in the 20th Century*. Stanford: Stanford University Press.

Freeman, Richard B. 1976. *The Overeducated American*. New York: Academic.

Good, Catherine, Aneeta Rattan, and Carol S. Dweck. 2012. Why Do Women Opt Out? Sense of Belonging and Women's Representation in Mathematics. *Journal of Personality and Social Psychology* 102(4): 700–717.

Hafner-Burton, and M. Emilie. 2013. *Making Human Rights a Reality*. Princeton, NJ: Princeton University Press.

Harbison, F.H., and A.M. Charles. 1964. *Education, Manpower, and Economic Growth: Strategies of Human Resource Development*. New York: McGraw-Hill.

Jacobs, Jerry. 1995. Gender and Academic Specialties: Trends Among Recipients of College Degrees in the 1980s. *Sociology of Education* 68(2): 81–98.

Kanter, Rosabeth M. 1977. Some Effects of Proportions on Group Life: Skewed Sex Ratios and Responses to Token Women. *American Journal of Sociology* 82(5): 965–990.

Kelly, Gail P. 1989. Achieving Equality in Education-Prospects and Realities. In *International Handbook of Women's Education*, ed. Gail R. Kelly, 547–69. Westport, CT: Greenwood Press.

McEneaney, Elizabeth. 1998. *The Transformation of Primary School Science and Mathematics: A Cross-national Analysis of 1900-1995* (Ph.D. dissertation, Department of Sociology, Stanford University).

Meyer, John W., John Boli, George M. Thomas, and Francisco O. Ramirez. 1997. World Society and the Nation-State. *American Journal of Sociology* 103(1): 144–181.

Ortega, Moreiça Allana-Kim. 2008. *Global Change, Regional Trends, and National Indicators: Shifting Gender Composition and the Worldwide Expansion of Female Enrollment in Higher Education: 1970-2000* (Ph.D. dissertation, School of Education, Stanford University).

Paxton, Pamela, Melanie M. Hughes, and Jennifer L. Green. 2006. The International Women's Movement and Women's Political Representatives, 1893–2003. *American Sociological Review* 71(6): 898–920.

Ramirez, Francisco O., and Phyllis Riddle. 1991. The Expansion of Higher Education. In *International Higher Education: An Encyclopedia*, ed. Philip Altbach, 91–106. London: Garland.

Ramirez, Francisco O., Yasemin Soysal, and Suzanne Shanahan. 1997. The Changing Logic of Political Citizenship: Cross-National Acquisition of Women's Suffrage Rights, 1890 to 1990. *American Sociological Review* 62(5): 735–745.

Ramirez, Francisco O., and Christine Min Wotipka. 2001. Slowly but Surely? The Global Expansion of Women's Participation in Science and Engineering Fields of Study, 1972–92. *Sociology of Education* 74(3): 231–251.

Riegle-Crumb, Catherine, Barbara King, Eric Grodsky, and Chandra Muller. 2012. The More Things Change, the More They Stay the Same? Prior Achievement Fails to Explain Gender

Inequality in Entry into STEM College Majors Over Time. *American Educational Research Journal* 49(6): 1048–1073.

Schofer, Evan, and John W. Meyer. 2005. The Worldwide Expansion of Higher Education in the Twentieth Century. *American Sociological Review* 70(6): 898–920.

Sewell, William H. 1971. Inequality of Opportunity for Higher Education. *American Sociological Review* 36(5): 793–809.

Shavit, Yossi, and Hans-Peter Blossfeld (eds.). 1993. *Persistent Inequality: Changing Educational Attainment in Thirteen Countries*, Social Inequality Series. Boulder, CO: Westview.

Spencer, Steven J., Claude M. Steele, and Diane M. Quinn. 1999. Stereotype Threat and Women's Math Performance. *Journal of Experimental Social Psychology* 35: 4–28.

Stage, Frances K., and Jullian Kinzie. 2009. Reform in Undergraduate Science, Technology, Engineering, and Mathematics: The Classroom Context. *The Journal of General Education* 58(2): 85–105.

Stromquist, Nelly. 2013. Women's Education in the Twenty-First Century. In *Comparative Education: The Dialectic of the Global and the Local*, ed. Robert F. Arnove, Carlos Alberto Torres, and Stephen Franz, 175–200. Lanham, MD: Rowman & Littlefield.

Wiseman, Alex, David Baker, Catherine Riegle-Crumb, and Francisco O. Ramirez. 2009. Shifting Gender Effects: Opportunity Structures, Mass Education, and Cross-National Achievement in Mathematics. In *Gender, Equality and Education from International and Comparative Perspectives*, ed. David Baker and Alice Wiseman, 395–422. Amsterdam: Elsevier.

Vignette 2.1

Road to 2015: Pre-college Gender Parity and UNESCO's Millennium Development Goals

Katie Seely-Gant

Fourteen years ago, UNESCO adopted eight Millennium Development Goals (MDGs), targeting areas essential to international development such as clean water access, reduction of worldwide poverty, and increased equality and accessibility to primary and secondary education. As we near the 2015 "deadline," it is fitting to stand back and assess the effectiveness of the MDGs, as well as barriers to their implementation, particularly in relation to closing the gender gap in primary and secondary education.

It is also appropriate to address gender parity in pre-college STEM education in this context. Similar to primary and secondary education on the whole, pre-college education in STEM fields was historically dominated by males, although gender gaps have narrowed significantly in both the United States and other developed countries. While there has been considerable improvements toward gender parity in both STEM education and later the STEM workforce, efforts to encourage women and girls in these fields remain worthwhile. STEM education can provide women with a wealth of funding opportunities to attend postsecondary education and eventually open up a wide and profitable job market.

Low rates of gender parity in precollegiate education coupled with low, although rising, STEM recruitment rates of women create a perfect storm for imbalances in the workforce, worldwide. There is a great deal of research and resources poured into developing the STEM workforce and higher education opportunities for women, however, without fixing the earliest leaks in the STEM pipeline created by inequitable access to pre-college education, efforts that seek to address imbalances further downstream are likely to be in vain (van Lagen and Dekkers 2005).

K. Seely-Gant (✉)
Energetics Technology Center, 10400 O'Donnell Place, Ste 202, St. Charles,
MD 20603, USA
e-mail: kseelygant@gmail.com

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_2

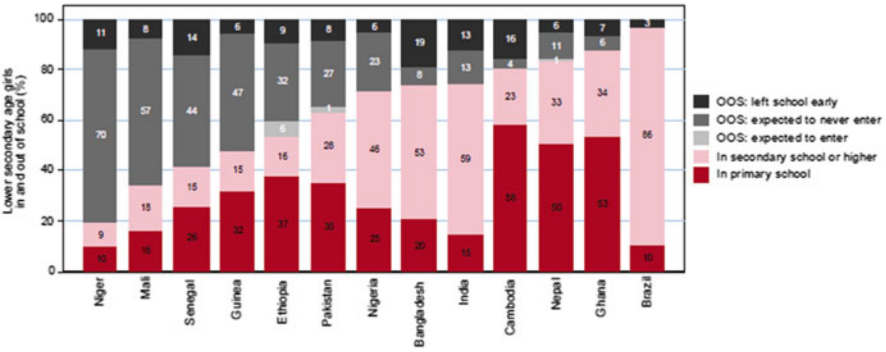


Fig. 2.7 Percentage of lower secondary school-age girls who are in and out of school (OOS) for selected countries, most recent year available (UNESCO Institute for Statistics based on household survey data: Bangladesh Multiple Indicator Cluster Survey (MICS) 2006, Brazil Pesquisa Nacional por Amostra de Domicílios (PNAD) 2009, Cambodia Demographic and Health Survey (DHS) 2005–2006, Ethiopia DHS 2005, Ghana DHS 2008, Guinea DHS 2005, India DHS 2005–2006, Mali DHS 2006, Nepal DHS 2006, Niger DHS 2006, Nigeria DHS 2008, Pakistan DHS 2006–2007, and Senegal DHS 2005)

In 2010, the UNESCO Institute of Statistics (UIS) reported that over 57-million children were missing out on primary education (UIS 2010). While this number has drastically improved since 2002, when UIS reported 95 million out-of-school primary students, it seemed that UNESCO was far from reaching a foundational MDG, universal access to education (UNESCO 2012). The UIS data showed that enrollment and retention problems were affecting girls and young women at a far greater rate than males, which set the stage early-on for gender disparity. Figure 2.7 depicts statistics for lower secondary age girls in selected countries. These countries were selected as they depict both ends of the spectrum. Here, countries like Brazil and India serve as exemplars, with high percentages of girls enrolled in lower secondary schools. On the other end are countries, like Niger and Mali, which show as little as nine percent of lower secondary aged girls enrolled in schools.

While UNESCO data show that primary education programs around the world are making progress toward gender parity, the gap in secondary school remains wide in most areas of the world (UIS 2010). Some regions, such as East Asia, Latin America, and Europe have made great strides, and many countries in those regions exhibit the highest rates of gender parity. But for other regions, such as South Asia and Sub-Saharan and West Africa, there has been little improvement in closing the gender gap (Abu-Ghaida 2002). For example, in Senegal, according to 2010 UNESCO data, a girl from a household meeting the national average income still had less than a 30% chance to finish primary school, let alone attend secondary school (UNESCO 2013).

These data beg the question, what makes these "at-risk" regions so different than others? Why is a girl starting school in Latin America better off than a girl starting school in South Asia? After debating this very question, UNESCO's 2012 report, "Access to Equality: Empowering Girls and Women through Literacy and Secondary Education," reaches an unfortunate but not unexpected answer: poverty (UNESCO 2012). In low socioeconomic status families, several factors are considered when choosing whether or not to send a daughter to school. In these situations, a daughter may be more valuable as a caretaker for younger siblings or as an income contributor. Families may be unable to justify the long-term investment in education and thus many girls are pulled-out of school before primary education is completed, or not enrolled at all (UNESCO 2012).

Another issue is the perceived conflict between traditional cultural norms and expectations for women and education (Abu-Ghaida 2002). Parents or guardians may worry that secondary education will pull their daughters away from traditional values, usually resulting in girls not being permitted to enroll in further education. Classes also often interfere with household duties expected of girls such as cleaning, cooking, and child care. This clash in values means that women who do seek secondary education often receive little support, financial and otherwise, from family. The lack of access to education that plagues low-income families often creates a "vicious cycle" of poverty for these women as secondary education is increasingly necessary as an important determinant in future social mobility (Lewin 2007).

Tied in with UNESCO's Education for All (EFA) initiative is the push for better qualified teachers. Studies have cited lack of classroom resources, namely qualified and informed teachers, as one of the key issues in retention of female students in STEM fields, as well as retention in school on the whole, in all levels of education. As a piece of the MDGs and EFA initiative UNESCO has pledged to increase the pupil-tech ratio in schools, specifically in at-risk regions, as well as increase the number of female teachers (UIS 2010).

Due to limitations in UNESCO data, it is difficult to know the extent of STEM exposure in primary and secondary education, worldwide. A test administered to OECD countries, called the Program for International Student Assessment (PISA), aides in measuring student achievement in reading, math, and science. Even in low-performing countries, girls continue to perform on par or above boys in all three subjects, according to 2012 data. Although most of the seriously at-risk regions are not included in these data, this report still offers an important benchmark for pre-collegiate STEM achievement for girls (OECD 2012). Figures 2.8, 2.9, and 2.10 display the gender difference in performance on the mathematics, reading, and science assessments on the 2012 PISA Test, by mean score, for selected countries. These numbers represent the mean score for boys minus the mean score for girls; therefore a negative number represents higher mean score for girls while a positive number represents higher mean score for boys (OECD 2012). These countries were selected based on gender parity in their region. Brazil and Argentina typically exhibit high gender parity, in line with Latin American region averages as recorded by UIS. Countries representing both Central/Eastern Europe and South Asia were also selected, as these regions suffer low gender parity. The OECD average is provided as a benchmark. By selecting these countries, we can gain additional insight into the affect of gender gaps on achievement.

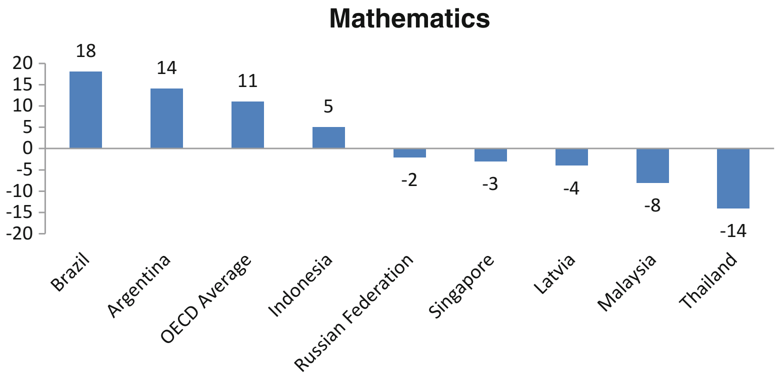


Fig. 2.8 Gender differences in performance in Mathematics on 2012 PISA (Data in Figs. 2.8–2.10 obtained through OECD's Education GPS Indicator Explorer access via http://gpseducation.oecd.org/IndicatorExplorer)

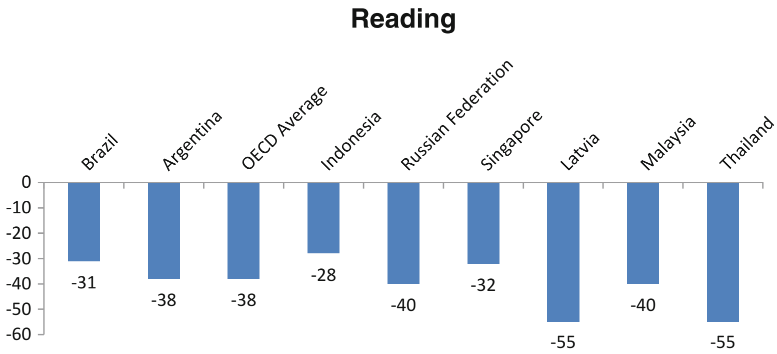


Fig. 2.9 Gender differences in performance in reading on 2012 PISA

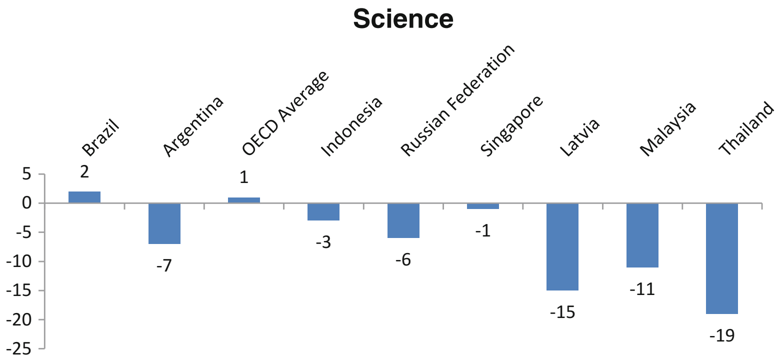


Fig. 2.10 Gender differences in performance in science on PISA 2012

These data show that even in countries with poor gender parity, such as Indonesia, girls in secondary education continue to perform on par or above their male peers. There is still room for progress in mathematics, however, which is a critical STEM field. Overall the 2012 PISA results are promising. Educational performance for girls continues to rise, even in countries where gender parity is low.

In the 14 years since UNESCO's adoption of the MDGs, many regions have made great strides toward gender parity in pre-college education and PISA scores show girls typically outperforming male students in both science and reading on the secondary level. But even with all this progress, there is still a ways yet to go. In many low-performing regions girls receive only the most basic education, if any at all, and often remain illiterate. While strides have been made the road to 2015 still appears fraught with obstacles.

References

Abu-Ghaida, Dina and Stephan Klasen. The Costs of Missing the Millennium Development Goal on Gender Equity. *Munich Discussion Paper No. 2003-1*, http://epub.ub.uni-muenchen.de/2/

Bing, Wu Kin. 2009. Education and Inequality in the Developing World. In *Inequality in Education: Comparative and International Perspectives*, ed. Donald B. Holsinger and W. James Jacob, 86–127. Comparative Education Research Centre: Hong Kong, www.springer.com/series/5731.

Brotman, Jennie S. and Felicia M. Moore. 2008. Girls and Science: A Review of Four Themes in the Science Education Literature. *Journal of Research in Science Teaching* 14(9): 971–1002, http://adsabs.harvard.edu/abs/2008JRScT..45..971B

Cherng, Hua-Yu Sebastian and Emily C. Hannum. 2013. Community Poverty, Industrialization, and Educational Gender Gaps in Rural China. *Gansu Survey of Children and Families Papers,* http://works.bepress.com/emily_hannum/33/

Lewin, K. 2007. Improving Access, Equity and Transitions in Education: Creating a Research Agenda. Project Report, Consortium for Research on Educational Access, Transitions and Equity (CREATE), http://sro.sussex.ac.uk/1828/

The Organization for Economic Co-operation and Development (OECD) PISA. 2012. Results in Focus: What 15-Year-Olds Know and What They Can Do With What They Know: Key Results from PISA 2012. *PISA Report,* http://www.oecd.org/pisa/keyfindings/pisa-2012-results.htm

Power, Colin. 2011. Addressing the UN Millennium Development Goals. *International Education Journal: Comparative Perspectives* 10(1): 3–19, http://iejcomparative.org.

Rihani, May A, Lisa Kays, and Staphanie Psaki. 2006. Keeping the Promise: Five Benefits of Girls' Secondary Education. Project Report, Academy for Educational Development, http://www.iywg.org/resources/keeping-promise-five-benefits-girls-secondary-education

Sadler, Philip M., Gerhard Sonnert, Zahra Hazari, and Robert Tai. 2012. Stability and Volatility of STEM Career Interest in High School: A Gender Study. *Science Education* 96(3): 411–427, http://onlinelibrary.wiley.com/doi/10.1002/sce.21007.

UNESCO 2012. From Access to Equality: Empowering Girls and Women Through Literacy and Secondary Education *UNESCO Report*, http://www.uis.unesco.org/Education/Pages/gender-education.aspx

_____. 2013. Education for All Global Monitoring Report (Figure 1.5.2) *UNESCO Report*, http://www.unesco.org/new/en/education/themes/leading-the-international-agenda/efareport/reports/2013/gmr-2013-figures/

UNESCO Institute for Statistics. 2010. Gender Parity in Primary and Secondary Education. *UIS Fact Sheet No. 4,* http://www.uis.unesco.org/FactSheets

Van Lagen, Annemarie and Hetty Dekkers. 2005. Cross-National Differences in Participating in Tertiary Science, Technology, Engineering, and Mathematics Education. *Comparative Education* 41(3): 329–350, http://www.tandfonline.com/toc/cced20/41/3

Vignette 2.2

Historical Perspectives on Women in Chemical Sciences, Computer Science, and Mathematics

Mariko Ogawa and Lisa M. Frehill

Women have been rare, but not completely absent from the chemical sciences, computing and mathematics. While the chemical sciences date back to alchemy, there have been fewer female chemists in history than female mathematicians. Maria Sklodowska Curie (1867–1934) and her daughter, Irène Joliot-Curie (1897–1956) won Nobel Prizes in Chemistry in 1911 and in 1935. With such notable women, it was not long before the Women's Committee of the American Chemical Society in the United States was founded (some 85 years ago). In the time since the Curies won Nobel prizes, chemistry has been able to successfully attract women to undergraduate study in many nations.

The nature of laboratory work in chemistry has posed special challenges for women's participation. Without access to equipment, supplies, and space, performing chemistry experiments can be problematic. So if academic institutions and chemical industry employers do not hire women—as was the case prior to World War I and again after the immediacy of war needs no longer prevailed—then women who are trained in chemical sciences in college have few options to practice in the field. Instead, they will likely seek work in which a science background is useful, but for which laboratory resources are not required. Henry Etzkowitz's (2009) idea of a "Vanish Box" whereby highly trained women who disappeared from academic bench science subsequently reappeared in technology transfer offices at the interface between science and economy is an example of this process.

M. Ogawa (✉)
Mie National University, 3-21 Nijigaoka, Meitou-ku,
Nagoya 465-0078, JAPAN
e-mail: ogawa@human.mie-u.ac.jp

L.M. Frehill
Energetics Technology Center, 10400 O'Donnell Place Ste 202,
St. Charles, MD 20603, USA
e-mail: lfrehill@etcmd.com; lisa.frehill@gmail.com

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_2

The nature of work in mathematics, however, differs compared to chemistry. That is, mathematics work involves few resources, often merely paper and pencil. Indeed, in the eighteenth and nineteenth centuries, women enjoyed solving mathematical problems as contests. *The Ladies Diary* was designed specifically for the amusement and entertainment of women with an appendix of curious and valuable mathematics papers for use by students (Perl 1979; Costa 2000, 2002).

The LADIES Diary:
OR, THE
Woman's ALMANACK,
For the Year of our LORD, 1725.
Being the Firſt Year after LEAP-YEAR.
Containing many Delightful and Entertaining *Particulars*,
Peculiarly Adapted for the *Uſe* and *Diverſion* of the
FAIR-SEX.

Being the Twenty ſecond ALMANACK ever Publiſh'd of that kind.

1. HAIL! happy LADIES of the *BRITISH* Iſle.
On whom the GRACES and the MUSES ſmile.

2. LONG had your lovely *Shape*, and matchleſs *Mein*,
The Wonder of our Neighb'ring Nations been;

3. NATURE to make your *Triumph* more compleat,
To peerleſs CHARMS has added piercing WIT.

4. NO [illegible] HOST,
Nor their SEMIRAMIS th' *Aſſyrian's* Boaſt:
WIT joyn'd to BEAUTY, *Fame* ſhall now record;
Which lead more Captive than the Conquering Sword

Printed by *A. Wilde*, for the Company of *Stationers*, 1725.

There were many women who have been recognized for their excellence in mathematics as students. For example, Philipa Fawcett (1868–1948), at Newnham College, Cambridge in 1890 was ranked above the Senior Wrangler, achieving the highest mark in mathematics. While there were other female Wranglers, no other ranked as senior nor as second. Grace Chisholm Young (1868–1944), who studied at Girton College, Cambridge and marked almost equivalent to a Senior Wrangler in 1892, received her Ph.D., magna cum laude, from Göttingen in 1895.

Seven examples in the history of famous women mathematicians are traditionally noted; their accomplishments prove that women can be highly skilled mathematicians (Osen 1974; Alic 1986). These exemplars include:

- Hypatia of Alexandria (about AD 370–415) Alexandrian mathematician and philosopher. Teacher at the Neoplatonic School, Alexandria.

- Maria Gaetana Agnesi (1718–1799) Italian mathematician. Honorary professor of mathematics and philosophy at University Bologna.
- Émilie du Châtelet (1706–1749) Who translated into French, with commentary, Isaac Newton's work Principia Mathematica.
- Sophie Germain (1776–1831) French mathematician, who also made an important contribution to applied mathematics of acoustics and elasticity.
- Mary Somerville (1780–1872) Scottish popular science writer: her talent was highly appreciated though she lacked scientific originality.
- Sofia Vasilyevna Kovaleskaia (1850–1891) Russian mathematician. Professor at University of Stockholm.
- Emmy Noether (1882–1935) German mathematician, unofficial associate professor (1922–1933) at University of Göttingen, visiting professor (1933–1935) at Bryn Mawr College, and lecturer (1933–1935) at Princeton Institute of Advanced Study.

Sometimes Caroline Herschel (1750–1848) is added to this list of seven female mathematicians. The presence of such notable women contradicts the common myth that women are not good at mathematics.

The "math myth" however, has proved rather intractable even today. Witness, for example, the world's most popular doll, Barbie, and her Japanese sister, Licca. Both dolls have issues with mathematics. Licca is poor at mathematics but good at art and music. And when Barbie finally spoke in 1992, one of the first phrases programmed in for her 800 million young owners to hear was "math class is tough" (Schiebinger 1999: 67). So, despite the low resource requirements necessary to perform mathematical work, persistent gendered stereotypes have thwarted women's participation in the field in some cultures.

While computer science is a much newer discipline, some its foundations were established by two notable women. Mathematician, Augusta Ada Byron, Countess Lovelace (1815–1852) was the first developer of conceptual programming for Charles Babbage's Analytical Engine. The Ada programming language in the Pentagon is named after her. Grace (Brewster Murray) Hopper (1906–1992) worked for the US Navy and was engaged in the development of the first BINAC and later UNIVAC. She was mainly involved in designing software for digital computers; the COBOL programming language made her name famous.

In summation, then, when we look at women's participation in the chemical sciences, mathematics and computer science, we are able to point to some notable women in each field, yet women's pursuit of these fields as a profession has been affected by larger social forces. In mathematics, women had access to the field as a recreation and to study mathematics at universities in England. The chemical sciences' resource-intensive nature of work stood as a barrier to women's participation. When employers had labor shortages, such as during the First World War, and again during the Second World War, women chemists were able to locate work. But when they were no longer needed, women were pushed out of the laboratory. Finally, some elements of computer science are like mathematics with a lower need for expensive resources, so it is a field that could have been able to attract women who could have been inspired by the achievements of women like Grace Hopper and Ada Byron.

So far, our emphasis has been on notable women in chemistry, computer science, and mathematics in the developed world, specifically, Europe and North American. When we turn our attention to developing a history of these fields and women's participation in the developing world, there are many challenges. Much literature is from Western Europe and North America therefore there is a need to engage with multilingual literature for broader global coverage. Furthermore, science is in the early stages of development in many developing countries, therefore information can be difficult to locate. In addition, the colonial past and path to independence hold many implications for women's participation in science. There is a body of work about women's participation in agriculture that was impacted by colonial processes and that, now, has provided a backdrop against which women become involved in science (Sachs 1996). Finally, the chemical industry, which is capital intensive, has also been rather mobile in the twentieth century. Hence, as the capital resources for the chemical sciences move to new locations, new labor forces must be developed. In such cases, there is a need to consider the interaction of gender within these contexts.

Acknowledgement This work is based on an earlier work: Ogawa, M., Frehill, L.M., and Huyer, S. (2012). "Historical Perspectives on Women in Chemistry, Computer Science, and Mathematics" pp. 73–76 in Frehill, L.M., Didion, C. and Pearson, Jr., W. (rapporteurs) *Blueprint for the Future*: *Framing the Issues for Women in Science in a Global Context*; *Summary of a Workshop* (Washington, DC: National Academies Press).

References

1997. *Licca chan hausu no hakurankai* (Exhibition of Licca's House) (in Japanese, Tokyo: INAX).

Alic, Margaret. 1986. *Hypatia*'*s Heritage.* Boston: Beacon Press.

Costa, S. 2000. *The Ladies*' *Diary*: *Society*, *Gender and Mathematics in England*, *1704–1754* (Ph.D. dissertation, Cornell University).

_____. 2002. The Ladies' Diary: Gender, Mathematics and Civil Society in Early Eighteenth-Century England. *Osiris* 17: 49–73.

Etzkowitz, Henry. 2009. Vanish Box. *Research EU*: *The Magazine of the European Research Area* (Special Issue, April): 23.

Julian, Maureen M. 1990. Women in Crystallography. In *Women of Science*: *Righting the Record,* ed. G. Kass-Simon and P. Farnes. Bloomington, IN: Indiana University Press, 335–383.

Perl, T. 1979. The Ladies' Diary or Woman's Almanack, 1704–1841. *Historia Mathematica* 6: 36–53.

Osen, Lynn M. 1974. *Women in Mathematics.* Cambridge: MIT Press.

Sachs, Carolyn. 1996. *Gendered Fields*: *Rural Women*, *Agriculture*, *and Environment.* Boulder, CO: Westview.

Schiebinger, L. 1999. *Has Feminism Changed Science*? Cambridge: Harvard University Press.

Vignette 2.3

Color.less.Edu: A Statistical Overview of the Status of Women of Color in US Higher Education at the Baccalaureate Level of S&E

Sybrina Y. Atwaters

Globally, enrollment trends in higher education have remained relatively flat for some countries, while others have shown steady increases. Higher education enrollment trends for women in France, Japan, Germany, Italy, and the United Kingdom have remained level between 1998 and 2008 (see Fig. 2.11). Enrollments in the Russian Federation generally trended upward until 2005 when enrollment seems to have stabilized. Comparatively, US enrollments have been continuously trending upward.

Science and engineering (S&E) degrees awarded to women in the United States also increased significantly between 1998 and 2008, from 190,474 to 249,449. By 2010, US women earned 17.6% of all S&E degrees awarded to women globally and 50.3% of all S&E degrees in the United States, with social and behavioral sciences ranked highest and engineering ranked lowest among all fields.[6] The recent steady increases in women's enrollment and degree awards within the United States offers a rich context for understanding the complexities of underrepresentation in S&E for women.

Several policies and programs have been implemented in the United States to increase the participation of women in S&E (Best 2004; Leggon 2006; National Science Board 2004; National Science Foundation 2008; Perna et al. 2008). Panels, workshops, mentor and undergraduate research programs, targeted research funds, diversity trained reviewers at funding agencies, evaluation and accountability mechanisms, and analysis of best practices and programs are among the strategies implemented by institutional leaders and policy makers. Yet, many of these initiatives, aimed at broadening the participation of women, are developed in response to

---

[6] See National Science Foundation (2014), Table 2-38.

S.Y. Atwaters (✉)
Georgia Institute of Technology,
Atlanta, GA 30332, USA
e-mail: syatwat@gatech.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_2

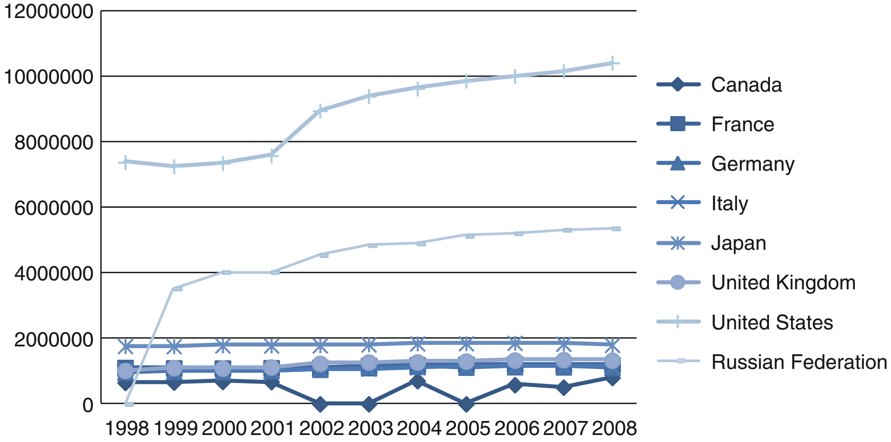


Fig. 2.11 Women's enrollment in higher education (ISCED5A&ISCED5B) for select countries, 1998–2008 (*Source*: OECD 2010. Tertiary-type A programs (ISCED 5A) are generally equivalent to the US bachelor's degree, while the type B programs are equivalent to technologies and US associate's degrees. Data not available for Russian Federation 1998, Canada 2002–2003, 2005.)

gender dynamics observed when race is not equally considered. Once women's S&E enrollment and degree data are disaggregated by race/ethnicity, interesting trends emerge that raise new issues and concerns for broadening participation amidst an increasing minority US population.

2.4.1 Status of Women of Color

In a review of over 40 years of empirical research, covering 1970–2009, Ong et al. (2011) found that women of color were largely missing from S&E research agendas, leaving a significant portion of the population an untapped resource for science and engineering innovation. With the lack of focus in research agendas it is not surprising that the participation of women of color in S&E higher education within the United States is staggeringly low. For example, in 2010, African American, Asian, and Hispanic women represented 8.5%, 2.9%, and 8%, respectively, of the total females enrolled at the baccalaureate level. In contrast, White women represent 56.7% of the total women enrolled.[7]

However, from 2001 to 2010 women of color represent larger proportions of baccalaureate enrollment than their male counterparts in their respective ethnic groups. African American women have the highest gender representation with 63% of all African American baccalaureate enrollments.

---

[7] *Note*: total female enrollment include women of two or more races, American Indians, Native Hawaiians, Pacific Islanders as well as temporary residents. For Data percentages, see National Science Foundation 2013, Table 2.1.

Table 2.1 Degrees awarded to women by field and race/ethnicity, 2001, 2005, and 2010

Fields and race/ethnicity	Bachelor			Doctorate		
	2001 (%)	2005 (%)	2010 (%)	2001 (%)	2005 (%)	2010 (%)
Science						
All women (number)	190,752	233,087	250,590	8,686	10,103	11,596
Asian	8.3	8.5	9.2	6.4	6.5	7.4
Black or African American	10.7	10.9	10.7	4.4	4.9	4.7
Hispanic	7.7	8.5	9.8	4.8	5.0	4.8
American Indian or Alaska native	0.7	0.8	0.8	0.4	0.5	0.4
White	65.9	63.0	59.5	60.8	55.2	49.9
Engineering						
All women (number)	11,912	13,203	13,693	921	1,222	1,815
Asian	14.1	15.5	14.0	8.5	7.4	9.6
Black or African American	8.6	8.2	5.9	3.3	2.4	2.9
Hispanic	8.1	8.8	9.8	2.7	2.3	3.6
American Indian or Alaska native	0.5	0.6	0.6	0.3	0.0	0.1
White	59.2	55.6	57.3	34.6	26.6	28.0

Data Source: National Science Foundation (2013), Table 5-4, 7-2, and 7-7.

Degree trends are also complex when S&E data is disaggregated by gender and race. In 2010 women received 55.6% of science degrees and 18.4% of engineering degrees awarded at the baccalaureate level.[8] African American women represent the largest group of color (10.7%) of bachelor's degrees awarded to women in science (Table 2.1). Asian women, in comparison, were awarded the greater percentage (14%) of baccalaureate engineering degrees earned by women of color. White women received over half of all S&E baccalaureate degrees awarded to women between 2001 and 2010.

Interestingly, minority racial/ethnic groups have a higher percentage of women's representation in both science and engineering than do Whites (Fig. 2.12). White women receive 53.5% of bachelor's degrees awarded to Whites in science, while Asian, African American, Hispanic, and American Indian women receive 55.2, 66.4, 61.0, and 58.5% of science degrees awarded within their respective racial/ethnic groups.

The status of women of color also varies by disciplines within S&E fields. Chemistry and chemical engineering produce the greatest percentage of Asian Americans among women bachelor's degree recipients, while computer science

---

[8] National Science Foundation 2013, Table 5.4.

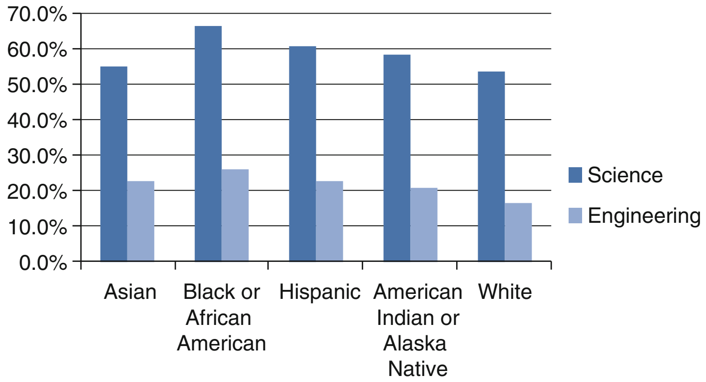


Fig. 2.12 2010 Women's representation of S&E Bachelor's degree recipients within total race/ethnicity (*Data Source*: National Science Foundation, 2013, Table 5.3 and 5.4. Science includes Agricultural sciences, Biological sciences, Computer sciences, Earth, atmospheric, and ocean sciences, Mathematics and statistics, Physical sciences, Psychology, and Social sciences as defined by the National Science Foundation.)

reflects a higher saturation of African American degree recipients. Hispanic women receive the lowest percentage of degrees awarded to women in computer science, mathematics, and chemistry.

2.5 Conclusion

The statistical trends emphasize that additional research is needed to understand the intersections and interdependencies of racial and gender barriers across disciplines in S&E higher education. Women of color may have access to gender focused as well as racially focused initiatives that enhance their persistence in science and engineering when compared to their male counterparts. Women of color access to gender as well as racially focused initiatives within US higher education may lead to a higher gender representation of women among minority racial/ethnic groups. However, these programs often divide women of color S&E experiences into categories of gender or race which does not attend to the double bind effect of their experiences at the intersection of gender and race.[9] Consequently, women of color remain significantly underrepresented among US higher education S&E enrollment and degree awards recipients. As the United States continue to celebrate, promote, and analyze the increasing status of women in S&E there must also be concentrated

---

[9] The double bind effect refers to the impact of minority women's unique experiences on their persistence in STEM, due to the simultaneous confrontation of sexism and racism (see Ong et al. "Inside the Double Bind," 2011; see also Malcolm et al. "The Double Bind," 1976).

efforts to ensure that the impact of the policies and programs implemented do not create a colorless women higher education population amidst a growing racial minority US population.

References

Building Engineering & Science Talent (BEST). 2004. *A Bridge for All*: *Higher Education Design Principles to Broaden Participation in Science*, *Technology*, *Engineering and Mathematics*, http://www.bestworkforce.org/PDFdocs/BEST_BridgeforAll_HighEdFINAL.pdf (accessed 9 March 2013).

Leggon, C. 2006. Women in Science: Racial and Ethnic Differences and the Differences They Make. *Journal of Technology Transfer*, 31: 325–333.

Malcom, S., Hall, P., & Brown, J. 1976. The Double Bind: The Price of Being a Minority Woman in Science. Washington, DC: American Association for the Advancement of Science.

National Science Board, National Science Foundation. 2004. *Broadening Participation in Science and Engineering Research and Education*: *Workshop Proceedings*, Special Report NSB 04-72, http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsb0472 (accessed 10 November 2012).

National Science Foundation, National Center for Science and Engineering Statistics. 2013. *Women*, *Minorities*, *and Persons with Disabilities in Science and Engineering*: *2013*. Special Report NSF 13-304. Arlington, VA, http://www.nsf.gov/statistics/wmpd/ (accessed 8 January 2014).

National Science Foundation. 2014. *Science and Engineering Indicators.* Arlington, VA (NSB 14-01) | February 2014.

OECD. 2010. Education Database: Students Enrolled by Type of Institution. *OECD Education Statistics* (database).

Ong, M., Wright, C., Espinosa, L., and Orfield, G. 2011. Inside the Double Bind: A Synthesis of Empirical Research on Undergraduate and Graduate Women of Color in Science, Technology, Engineering, and Mathematics. *Harvard Educational Review*, 81(2): 172–208.

Perna, L., et al. 2009. The Contribution of HBCUs to the Preparation of African American Women for STEM Careers: A Case Study. *Research in Higher Education*, 50, 1–23.

Vignette 2.4
Women's Participation in Higher Education: An Indian Scenario

Sarita Khandka

India has a total population of 1,270,272,105 (1.27 billion), with 48.4% being female.[10] The literacy rate of the country as a whole is 74.04%, with female literacy rate pitching at 65.46% (Indian Census 2011). If education in the knowledge society is an effective indicator of its development, then educated women in the society reflect the stage of its development. Education for women is the basis of their empowerment and has multiplier effect on the role of women in the society (Prakash et al. 2010; Godbole 2002). Educated women not only add to the human resources but also nurture a healthy society by being the nucleus of their families (Rani 2010). Higher education is also of paramount importance as it leads to knowledge generation and skill development in specialized fields. This in turn is responsible for the economic and social well-being of the society (Moon 2002). Realizing its importance, soon after Independence in 1947, the Indian government focused on this by setting up the University Education Commission (1948). The importance of higher education for women in particular was also realized and the first two 5-year plans considered the problems that women face while pursuing higher education. However, a more focused approach was adopted after the report of the committee on Education of Women in 1959 and, later, the Kothari Commission (1964–1966) emphasized providing equal educational opportunities for women in India. With the report on the "Status of Women" in 1974, the issue gained momentum and was included in the framework of developmental issues of the 5-year plans. These were

---

[10] http://www.indiaonlinepages.com/population/india-current-population.html

S. Khandka (✉)
Sam Higginbottom Institute of Agriculture,
Technology and Sciences, (Formerly Allahabad Agricultural Institute)
Deemed University, J-13, Fifth Floor, Sonal Apartment,
Near Jagat Taran Degree College, A.N. Jha Marg, George Town,
Allahabad 211002, Uttar Paradesh, India
e-mail: saritakh@rediffmail.com; sarita_khandka@yahoo.co.in

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_2

Table 2.2 Participation of women in higher education, India (UGC, India, Annual Report. 2006–2012)

S. No.	Year	Total enrollment	Women enrollment	Women enrollment in science and technology (S&T)[a]
1	2006–2007	11,612,505	4,708,871	1,265,000
2	2007–2008	12,376,718	5,024,945	1,423,062
3	2008–2009	13,641,808	5,649,102	1,628,636
4	2009–2010	14,624,990	6,080,373	1,937,820
5	2010–2011	16,976,000	7,049,000	2512000
6	2011–2012	20,327,478	8,672,431	2,663,321

[a] Science and Technology (S&T) includes Science, Agriculture, Medicine, Engineering and Technology, and Veterinary faculties

further cemented in a later five year plan, stressing the need for greater participation of women in higher education, and in the National Perspective Plan (1988–2000).

Presently, there are ample and equal opportunities of education available for women in the country. The government laid special emphasis on the participation of women in higher education and launched various programs for attracting women in higher education. Among these are the scholarships provided to the single girl child for higher education and to the women scientists who have breaks in their career due to family responsibilities and are willing to return to the mainstream. India has the third largest higher education system in the world and the participation of women in it also has been increasing steadily (Chauhan 2011). Table 2.2 provides data on the participation of women in higher education from 2006 to 2012.

In the last 6 years, the enrollment of women in higher education has steadily increased, from 40.6 to 42.7%. Also, an important trend that is observed in the last 6 years is that out of the total number of women pursuing higher education, the percentage of women's participation in Science and Technology (S&T) has increased except in the year 2011–2012. This reflects the increasing participation of women in S&T in the country (Fig. 2.13). In the past also, women's participation in higher education has seen a steady increase, as it rose from a mere 10% participation in 1950–1951 to 42.7% in 2011–2012. A similar steady increase in women's participation has also been found in the State Science Congress of Uttarakhand in India (Khandka et al. 2013). This is an encouraging sign and reflects the awareness and empowerment of women in the country over the past seven decades.

Another aspect of women in higher education is their choices of field of study. Table 2.3 provides data on women's participation and the status of choices for higher education made by women in India from 2007 to 2012. Traditionally in India, arts faculty is considered the forte of women's education and now there also is maximum enrollment in arts faculty (Table 2.3). However, the data gives clear indication that more and more women are opting for Science and Technology faculties for higher education, and it also is encouraging to find that enrollment in S&T faculties has seen a steady increase. Although women's participation in higher education

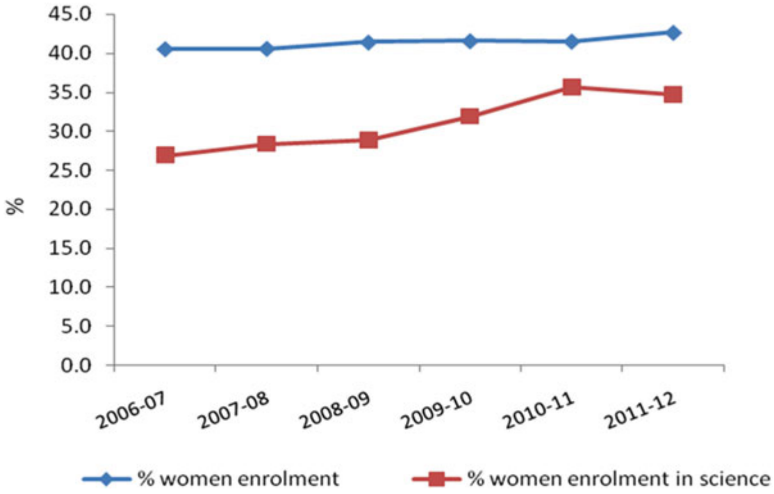


Fig. 2.13 Women's participation in higher education, India

Table 2.3 Women's enrollment (higher education) in various faculties

Faculty	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012
Arts	2,562,219	2,772,580	2,776,289	2,905,000	3,634,876
Science and Technology	1,423,062	1,628,636	1,937,820	2,512,000	3,003,321
Commerce and Management	827,608	915,719	967,392	1,137,000	1,414,804
Education	92,961	180,771	224,974	324,000	428,660
Law	82,409	89,256	84,517	84,000	107,825
Others	36,686	62,140	89,381	87,000	82,945

Source: UGC, India. Annual Report

has increased by only 2.1% in the last 6 years, increase in S&T faculties has been around 7.7%. However, this increase was more marked from 2008 to 2011. This clearly indicates that now women are increasingly inclined toward the Science and Technology faculties. This in turn reflects the availability and acceptance of women in Science and Technology faculties.

This is a very positive trend for development of the higher education system in India, with the statutes of equal opportunity in education for women now showing results after 50 years of their institutionalization in 1964–1966 by the Kothari Commission. This is of further importance as the country in the past has been plagued by gender issues in education. However, if the data reflecting the present scenario of women in higher education is any indication, we can conclude that women are not only getting opportunities for higher education, they are being accepted in the bastion which was earlier considered alien to them.

References

Chauhan, C.P.S. 2011. Participation of Women in Higher Education: The Indian Perspective. *Analytical Reports in International Education* 4(1): 67–86.

Godbole, R. 2002. Being a Women Physicist: An Indian Perspective. *AIP Conference Proceeding* 628: 107–111.

Khandka, S, R. Dobhal, and N. Jeelani. 2013. Women Participation in Science and Technology: A Case Study from Uttarakhand, India. *Journal of Women and Minorities in Science and Engineering* 19(1): 87–94.

Moon, U. 2012. Women Participation in Higher Education of India: The Enrolment Scenario. *International Journal of Education Economics and Development* 3(1): 79–96.

Prakash, N, B. McLellan, and B. Wejnert. 2010. *Empowerment of Women Through Science and Technology Intervention*, New Delhi: NAM S&T Centre.

Rani, G.S. 2010. Women's Education in India—An Analysis. *Asia-Pacific Social Science Review* 2(1):106–124.

Vignette 2.5

The Impact of Burundian Customs and Mores on the Scientific Careers of Burundian Women

Rachel Akimana

This is a case study on the position of Burundian women in scientific careers, as in universities, higher education institutes, research centers, etc. This position is determined in comparison with that of men living in the same condition and with the same age. To be sure that we have men and women under similar conditions, I consider individuals from the same family, and address this question: Why, in the same family, most probably does a boy, rather than his sister, pursue long studies? Before going any further, let's discuss the relationship between a scientific career and long studies. Here we can assume that a scientific career requires at least a Ph.D. diploma. In Burundi, if we consider, as an example, the University of Burundi, most lecturers obtained their Ph.D. diplomas after their thirties. As children begin school when they are seven years old, we can say that a Ph.D. diploma requires at least 23 years of studies. This is what I refer to as "long studies."

The fact is that, in Burundi, the ratio of women doing scientific careers is far below that compared to men under the same conditions. As there is no scientific evidence proving that men are more intelligent that women in the same conditions, I consider the cause of this fracture in Burundian customs and mores.

2.5.1 Some Words on Burundi

Burundi is a landlocked country of 27,834 km square located in the eastern part of Africa. The population of Burundi is around ten million, and the majority of Burundians are farmers. Concerning the current topic, Burundian law does not make any discrimination toward woman. At least it seems to encourage women to

---

R. Akimana (✉)
Faculty of Sciences, University of Burundi, P.B. 2700, Bujumbura, Burundi
e-mail: akimanarac@yahoo.fr

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_2

do long studies. Another important thing to note in relation to the topic is the fact that in Burundi, it is not mandatory to send children to school. The figures below show the evoked fracture.

Diploma	Total (%)	Male (%)	Female (%)
None	69.5	68.0	71.0
Primary certificate	26	27	25.3
A4	0.5	0.5	0.4
A3	1.2	1.1	1.3
A2	1.9	2.2	1.7
Bachelor’s	0.3	0.3	0.2
Master’s	0.6	0.9	0.3
Ph.D.	0.1	0.1	0.0

The figures (from the 2008 census on the Burundian population) show that the fracture begins far early at the primary school stage and is exacerbated level by level. In the following, I discuss this in two environments: the rural area and the city.

2.5.2 *Situation in Rural Areas*

The majority of Burundians living in rural area are farmers with generally a low level of education and generally with low revenues (less that USD1 per day). Rural parents have long made a distinction between the education of boys and of girls. On one hand, in the education of boys, parents focused on their preparation to be representative of the family and many investments were done in studies for boys. On the other hand, in the education of girls, parents prepared them to be able to take care of their family and house with the assumption that this role does not require long studies. As a consequence, the fact that girls generally do “short studies” affects negatively the ratio of women following scientific careers. Another factor is that women in rural areas get married earlier and afterwards face economic problems as they are, in many cases, jobless. In this situation, their brothers are called to substantially assist them, which constitute a supplementary charge to the brother’s family. The case of my father is illustrative of this situation in rural area.

In the family of my father, they were two boys and four girls. My grandparents had received no formal schooling or instruction. None of the girls attended school. My uncle went to school and obtained a primary certificate. However, he was not able to continue his schooling. My father went to school and obtained three A4 diplomas (law, sanitation, and construction). He worked as assistant in sanitation, with my mother as nurse in a local hospital. All his life he was called to assist his sisters, who were married. He regretted the fact that his sisters had not been to school. The good consequence of this situation was the fact that my sisters and I were encouraged to pursue long studies in order to avoid being a charge of our brothers. We are three daughters in my family and my younger sister is Doctor of Medicine and my youngest sister has an M.B.A.

2.5.3 Situation in the City: The Case of Bujumbura, the Capital of Burundi

Note in the first place that the majority of the youth in Bujumbura are at most from the second or the third generation of parents originating from rural areas. Here, consider the fact that, even though local customs and mores are attenuated in towns, they still are there. They are attenuated by contact with foreign customs via television and incoming and outgoing travel. As a consequence, parents and youth are aware that women can play an important role in the development of their country. But this requires women to do long studies. That is why parents and girls are more motivated to go to school and do attend to scientific careers. Unfortunately, the customs stating that a girl is only good to be married is still there, even in the city. That is why women with high diplomas generally find it difficult to get married.

2.6 Conclusion

The figures presented in this case study show that, in Burundi, girls go to school but do not attend to long studies. As a consequence, it is almost impossible to find women following scientific careers. In Burundi, the majority of women with education have A4 diplomas and that is not enough to have a scientific career.

Chapter 3
Gender, Science, and Occupational Sex Segregation

Lisa M. Frehill, Alice Abreu, and Kathrin Zippel

Over the past 20 years, policy makers have been increasingly connecting science and technology to innovation and economic growth. Many nations have made increased public investments in science and technology, as reflected in GDP (National Science Foundation 2012). Simultaneously, the role of diversity within the innovation process, in general, and the potential contributions of women, in particular, to national science and technology enterprises, has received much attention in many nations and international organizations (see, for example, efforts by UNESCO, APEC, the European Union and OECD).

As part of a larger volume, this chapter is meant to provide general audiences that include advocates of women's participation in science, individuals with science backgrounds, and social scientists who study these areas, with a description of the methods, tools, and approaches of occupational sex segregation as applied to understanding issues for women in science. The larger volume within which this chapter appears focuses attention on four science disciplines: chemical sciences, computing, mathematics, and statistics; hence we have attempted to incorporate examples from these specific disciplines, when possible (Fig. 3.1).

L.M. Frehill (✉)
Energetics Technology Center, 10400 O'Donnell Place, Ste 202,
St. Charles, MD 20603, USA
e-mail: lfrehill@etcmd.com; lisa.frehill@gmail.com

A. Abreu
Federal University of Rio de Janeiro, Rua Anibal de Mendonça 28 Apto 501,
22410-050 Rio de Janeiro, Brazil
e-mail: alicepabreu@gmail.com

K. Zippel
Department of Sociology and Anthropology, Northeastern University,
201 Ren Park, 360 Huntington Avenue, Boston, MA 02210, USA
e-mail: k.zippel@neu.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_3

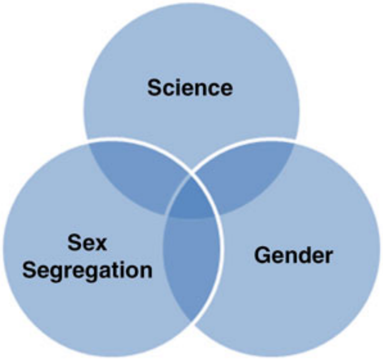


Fig. 3.1 Three research literatures

The attention to four specific disciplines is important within a larger framework of occupational analysis. Many treatments generalize across science, which is problematic because women's representation varies across science fields, the local and global labor markets in science fields varies, and the very nature of the work (material conditions of production) that scientists do varies within and across fields.

This chapter brings together three concepts that have often been pairwise connected but which we propose to integrate. To date, little work on the representation of women in science has deployed the tools of segregation analysis. The most recent edition of *She Figures* (European Commission 2013), though, includes a discussion of the D, the index of dissimilarity, which we will discuss in this chapter. By tools, we mean both the measurement methods and the theoretical models that enable us to understand the processes of sex segregation and allow us to make comparisons across units, such as nations, as might be of interest to those who wish to understand the status of women in international chemistry, computer science, and mathematics and statistics. By using segregation measures, we are able to effectively normalize data within a specific context—for example, nations—so that valid cross-national comparisons are possible. Such comparisons could offer useful insight about the extent to which science disciplines are gendered and how this shapes the larger context for women in science. Further, if we are interested in examining trends over time in the level of segregation within a particular context (e.g., within a nation over time or across disciplines, Frehill 2006), segregation measures permit such analysis.

This chapter will provide an overview of occupational sex segregation in science at three levels of analysis. The first section looks broadly at the concepts and tools of occupational sex segregation analysis at the macro or labor market level. Next, we discuss how the institutional processes of qualification, training, recruitment, and retention within scientific careers are impacted by the social institution of gender. At this level the emphasis is on how social relations are gendered and how social processes are deeply influenced by gender, as well as race and generation, resulting in very different positions for men and women in the scientific world (Galerand and Kergoat 2013). Finally, at the individual level, we discuss the concept of "choice." To what extent do differences in the occupational structures and careers reflect choices made by active agents and to what extent are choices constrained by gender as a social institution? How do individuals navigate through scientific careers within these larger contexts?

We use Brazil as a case to illustrate gender differences in science because as one of the BRIC nations, which also include Russia, India, and China, it has one of the largest and strongest scientific and technological systems in Latin America. Brazil is also spends more than 1% GDP on science and technology (S&T) and has a consolidated graduate program in the majority of S&T areas, with a systematic and overall evaluation process in place. The participation of women in the educational and capacity building sectors is also impressive and detailed figures are available.

3.1 Science Labor Markets and Measuring Occupational Sex Segregation

To date, literature that implements an occupational sex segregation framework to understand the structure of scientific labor markets has been relatively sparse. There is much literature at the intersection of science and gender and another robust literature at the intersection of gender and segregation, including an extensive literature on the sociology of work, which, in the past quarter century, has had more content related to gender and work (Maruani 2013). There is also quite a bit of work that examines segregation of occupations or educational fields in cross-national perspective (Chang 2004; Charles 1992; Charles and Bradley 2002; European Commission 2009; McDaniel 2010), without explicit focus on science. The literature on science and gender includes many anecdotal accounts (i.e., usually first-person narratives) along with standard social science using both qualitative and quantitative approaches. The literature on gender and segregation has a long research tradition. Demographers' tools and techniques originally developed to understand spatial segregation patterns (e.g., Duncan and Duncan 1955, and Massey and Denton 1993) have been applied to measuring occupational segregation by race/ethnicity (e.g., Frehill 1996; King 1992) and occupational sex segregation (e.g., Anker 1998; Blackburn et al. 2000; Charles and Grusky 2004; Melkas and Anker 2001).

Literature that connects all three areas—science, gender, and sex segregation—has been less common. To some extent this is due to differences in data availability and cross-national variation in educational structures and labor markets. To another extent, science, as an enterprise, tends to represent a proportionately small segment of the overall labor force within a nation. In the United States, for example, approximately 5–6% of the workforce is classified as scientists or engineers, 24% of which is women (Author's analysis of U.S. Bureau of Labor Statistics 2013). In the European Union, it has become more common to refer to "knowledge intensive activities" (KIA); 35% of workers in the EU-27 across the EU are in KIA jobs of which about one-third are women. In other international reports, such as data on science and technology indicators produced by the Organisation for Economic Development and Cooperation, data are provided on the number of researchers such as the number of researchers per 1,000 members of the economy's workforce. In 2011, the highest ratio was in Finland, where there were 14.8 researchers per 1,000 workers and the lowest was in Mexico at 0.9. The European Commission's most recent edition of *She Figures* reports that in 2009, researchers represented about one-third of the EU-27 workforce, with women's representation varying from 21% in Luxembourg and 52% in Latvia (European Commission 2013).

These occupations are important to study because these jobs are often advantaged and respected, commanding (usually) decent salaries and providing a modicum of career satisfaction and, within many contexts, job security. From a policy perspective, too, many nations have embraced the notion that science is an engine of economic development and advancement particularly for "knowledge economies:" so it is imperative to ensure that the field taps all potential human resources, including women.

What does it mean to say that an occupation is segregated by gender? The term and measures are derived from the US racial residential segregation literature; therefore, it is common for some see "segregation" as implying "intentionality." But such a view conflates measurement and explanation. We argue that the observed differences in the distributions of women and men into different occupations reflect the outcomes of many social forces, operating at the social, institutional/organizational, individual levels, some of which may have intentionally sought to disadvantage women, while others result in different treatment patterned by gender as unintended consequences. As such, we use the term "segregation" simply as macro-level measurement of the difference in women's and men's occupational distributions. The intentionality of the social forces that lead to segregation is a matter of much debate, to which we are encouraged to attend once we engage in the comparative analyses associated with the metrics.

Segregation refers to the tendency for members of different socially defined groups to be in different types of jobs. Segregation can be described along both horizontal and vertical dimensions. Figure 3.2 gives an example of horizontal

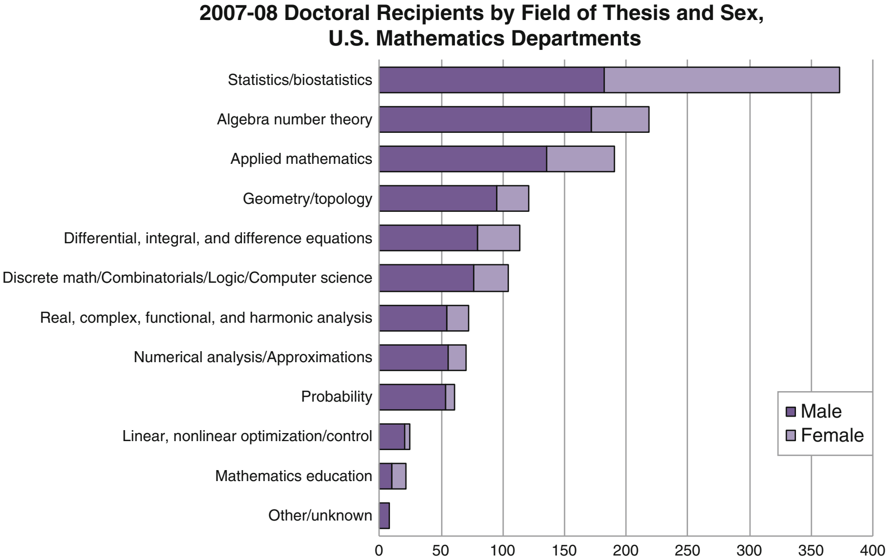


Fig. 3.2 Illustration: horizontal segregation

segregation, drawn from data published annually by the American Mathematical Society based on that organization's survey of departments of mathematics in the United States. These data show how women and men are distributed across various subfields within mathematics. Women accounted for just over half of all doctorates awarded to mathematicians who specialized in statistics or biostatistics. Women also accounted for half of those who specialized in mathematics education, although, as shown in the graph, this was a far smaller subfield than statistics/biostatistics was. Women were least represented in probability (12%) and in linear, nonlinear optimization/control (17%).

A customary way to describe horizontal segregation is to compare the extent to which groups of interest are concentrated in a specific set of fields. Here, for example, we would find that 44% of the 435 women who earned doctoral degrees in US mathematics departments specialized in statistics/biostatistics. While about one-in-five men who earned doctoral degrees also specialized in this area, it is noteworthy that men are much more "spread" across subfields than are women. Women's concentration in the statistics/biostatistics area raises a number of questions associated with the larger relationship between sex/gender and mathematics. For example, how do the subfields in mathematics vary in status, visibility, and resources such as positions grant funding, salaries etc.? To what extent are those who specialize in statistics/biostatistics advantaged or disadvantaged within mathematics? Are rewards such as earnings and prestige similar in this versus other fields? As has occurred in other fields (see, for example, Reskin and Roos 1990), will statistics/biostatistics "tip" and become even more female-dominated within mathematics and what are the implications of this change?

Vertical segregation looks at a particular occupation, or set of occupations, to see how people from different social groups occupy different levels within that occupation. For example, in most fields of science, women are often more highly represented among those at lower educational and occupational levels, with men more highly represented at higher levels. The So-called scissors diagrams, such as the one shown in Fig. 3.3, show women's representation along stages of science careers, is a common way to illustrate vertical segregation.

The Fig. 3.3 example is based on data from the European Union's *She Figures 2012*. In this particular case, the slight overrepresentation of women at the lower levels of tertiary study leading to academic careers and men's increasing overrepresentation at higher levels result in lines that cross like a pair of scissors. The extent to which the scissors widen reflects the extent to which men are more advantaged at higher levels. In some national or occupational settings, such as in many African nations, the lines do not cross, because girls/women have not reached parity even at the lower levels of education. Segregation indices, which we discuss next, provide a way of measuring this gap to permit systematic analysis that goes beyond looking at graphs and to enable more rigorous comparative analysis within and across contexts.

The stacked bar chart in Fig. 3.4 shows another illustration of vertical segregation. As with Fig. 3.2, this example is drawn from US mathematics, in this case, showing the representation of women and men at different academic levels. Derived

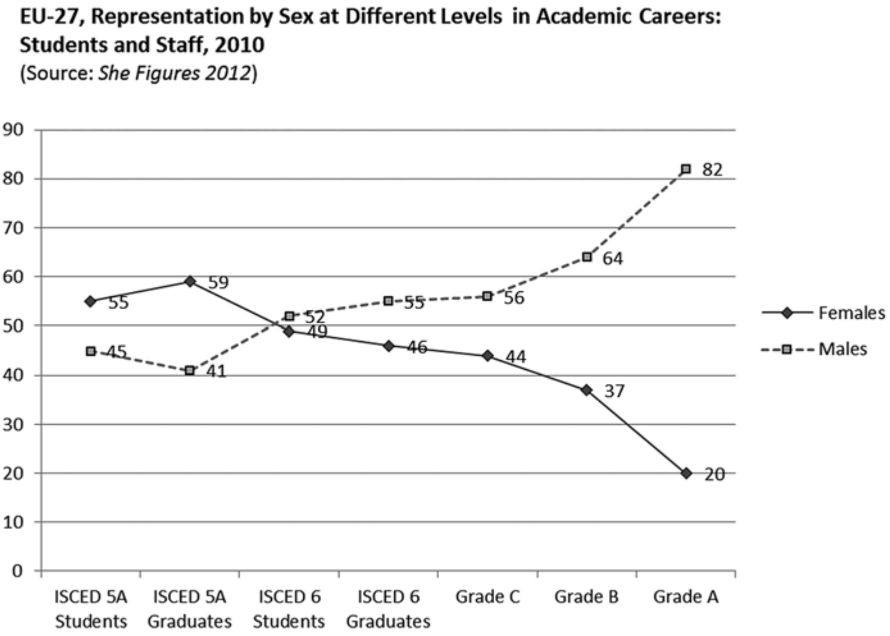
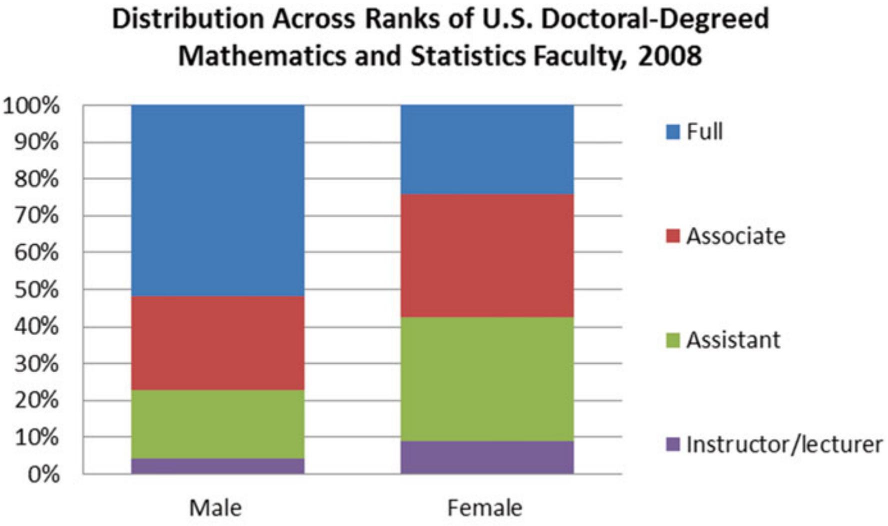


Fig. 3.3 Example scissors diagram: European Union Academic Pipeline. *Source*: Frehill, Lisa M., analysis of data from European Commission. 2013. *She Figures 2012*



Source: author's analysis of data in National Science Foundation. 2012. *Characteristics of Doctoral Scientists and Engineersin the United States, 2008, Detailed Statistical Tables*, NSF13-302.

Fig. 3.4 Illustration: vertical segregation from data from the National Science Foundation's Survey of Doctorate Recipients, each stratus in the stacked bar chart shows the within-sex proportion of faculty in each of four academic ranks for doctoral-degreed mathematicians.[1] The figure shows, what is now, common knowledge: women are far less likely than men to be in the highest rank (i.e., full professor) and are more likely than men to be in the more marginalized rank of instructor/lecturer, which is generally untenured and often lacking in job security and prestige within US academia.

The occupational sex segregation literature provides metrics and theoretical models with which to understand differences in women's and men's participation in science and enable disaggregation of science into more specific fields. The framework suggests a need to look at factors associated with both men and women, with the various ways in which gender is constructed with respect to these fields in different places at different times, and the benefits that accrue to men and women who conform to these societal norms. The role of power is critical here. All-too-often the literature to date on gender and science—with the exception of the clearly feminist research in this area—has been devoid of any meaningful power analysis.

3.1.1 Measures of Segregation

The most common segregation measure is the Index of Occupational Dissimilarity, originally developed by Duncan and Duncan (1955) to describe residential segregation. This relatively simple measure ranges from 0 to 1, with 0 indicating perfect equality of two occupational distributions and 1 indicating complete inequality. The computed ratio is interpreted as the percentage of workers who would have to change jobs in order for the distributions of the two groups into jobs to be the same.

$$D = \frac{1}{2}\sum_{j=1}^{J}\left|\frac{F_j}{F} - \frac{M_j}{M}\right| \times 100$$

The difference in the within-gender percentage of women and men in each of the J occupations forms the basis for D. As Frehill (2006) explains: "The D-score enables comparisons of the structure of occupations over time (Bertaux 1991; Frehill 1996; Jacobs 1989, 1995) across different race by gender groups (Frehill 1996; King 1992; Semyonov et al. 2000), and across different labor markets, such as those in different nations (Chang 2004; Charles and Bradley 2002, 2009)"

---

[1] The U.S. Survey of Doctorate Recipients (SDR) population is drawn from the Doctoral Records File, which includes information about all recipients of doctoral degrees conferred by the US colleges and universities. This means that estimates based on the SDR exclude consideration of individuals who earned doctoral degrees at the non-US institutions.

Frehill (2006: 346).[2] For example, the D-score associated with the data shown in Fig. 3.4 is 0.24, which is slightly lower than the D-score of 0.27, which was computed for those same data in 2006. These D-scores suggest that between 24 and 27% of doctoral-degreed academically employed mathematicians/statisticians would need to change ranks in order for women and men to be evenly distributed by academic rank at US 4-year colleges and universities.

Concentration is another important dimension of segregation. Massey and Denton (1989) proposed this as one of five dimensions of racial residential segregation in their formulation of hyper segregation as an explanation for the continued significance of race as a determinant of class outcomes for African Americans in US major metropolitan areas. Concentration is generally computed in a straight-forward way as a percentage, but then additional interpretation is necessary to determine at what percentage level one might say that "concentration" exists or not. In the international occupational segregation literature, Anker (1998) has proposed:

> Female-concentrated occupations are thus defined as those having more than 1.5 times the mean percentage female, while "female-underrepresented" occupations are those having less than 0.5 times the mean percentage female. (Anker 1998: 87)

As illustrated in Figs. 3.2, 3.3, and 3.4, it is critical to explore both the vertical and horizontal dimensions of occupational segregation within science. Each analysis calls attention to different issues within and across fields and suggest different kinds of questions. The distribution of advantage described by vertical segregation reveals how sex is reflected in the structure of a specific occupation or discipline. The definitions, content and processes of advancement in each national context greatly vary.

Figure 3.4 reflects the US system in which full professors are at the top of academia, holding positions of greatest power and prestige within this economic sector. In other sectors, such as government or industry, these positions would be senior research scientists with large budges, spans-of-control, and decision-making authority about the scientific work that will be undertaken. Full professors in academic settings and senior research scientists in others are "gatekeepers" who make decisions about whether new entrants will be admitted (i.e., hiring decisions) and how and when individuals will advance in the field (i.e., tenure and promotion decisions). They make and enforce the rules within their field via their control of discipline-based professional organizations.

---

[2] See also Frehill (2006 pp. 346–347): "In recent years, the D-score has been critiqued as a measure of occupational segregation. Charles and Grusky (1995) developed a new measure, A, which is based on logistic regression modeling of occupational distributions. A has been proposed as a superior measure because it is truly marginal independent, unlike D or another version of D known as the standardized (D Charles and Grusky 1995; Grusky and Charles 1998). That is, A provides a measure that better accounts for the relative sizes of the male and female labor forces (e.g., women's participation in academic science and engineering is quite a bit lower than that of men's) as well as the relative sizes of the different occupational groupings (e.g., there are fewer industrial engineers employed in academia than there are mathematicians)."

At the other end of the academic spectrum are those who hold doctoral degrees but are in instructor or lecturer positions, which tend to be nontenure track. Tenured and tenure track faculty are advantaged in academic settings, while those who are not on the tenure track are disadvantaged with respect to power, privilege, and access to resources. Likewise, scientists in government and industrial settings who lack a doctoral degree are often relegated to lower-level positions, which carry less discretionary decision-making authority and control.

3.2 Theories of Occupational Segregation and Levels of Analysis

The previous section discusses the macro-level measurement of sex segregation. While there are a number of decisions about measurement that reflect theoretical points of view, theories to explain the observed differences in men's and women's distribution into the occupational structure attempt to determine the causes and meaning behind the patterns noted using these quantitative, macro-level measures. There are many excellent discussions of the theories of occupational segregation (see, for example, Charles and Grusky 2004; Anker 1998; Reskin and Hartmann 1986). One way of summarizing this vast literature is via the concepts of supply-side and demand-side factors and with attention to the level of analysis.

On the supply-side, individual level decisions that men and women make about occupations result in the sorting of workers into occupations based on gender. The logic associated with these choices may vary: individuals, for example, may focus on the human capital investments necessary to pursue specific careers or they may focus on the extent to which they view careers as suitable or unsuitable within the context of the other constraints within their lives, which may be associated with gender.

On the other hand, demand-side explanations focus on employers' actions. Employers may engage in discrimination based on group membership (where groups are defined by gender or a host of other dimensions salient in a given society). In the more benign formulations, employers merely reflect the values of a society in which they are located. In less benign formulations, competition from the less powerful group threatens the advantages of those currently at the top of occupational hierarchies, who implement subtle and covert strategies that exploit institutional structures to prevent the encroachment by the newcomers. This institutional analytical level suggests it is important to understand how scientists' careers are structured within a larger disciplinary context, which is often defined by work organizations and disciplinary associations. In some contexts, disciplinary associations are private, in others they are part of the state apparatuses, and in others there are honorary societies that bestow status and privilege upon "chosen" scientists. Institutional processes, therefore, can be highly resistant to changes that may be perceived as threatening the hegemony of science, reflecting the interests of an entrenched group.

3.2.1 Understanding Occupational Segregation: The Gendering of Social Relations in Science

Key to understanding how sex segregation works to funnel women and men into different scientific occupations are the institutional processes of qualification, recruitment, retention and advancement. In the last 40 years, extensive social science research has clarified the role that these processes play in limiting women's access to science careers and, especially, to leadership positions in science. A global effort to address these issues has been underway with numerous synthesizing reports produced by international organizations in the first decade of the twenty-first century (European Commission 2002; Organization of Iberoamerican States—OEI 2004; Organization of American States—OAS 2005; Inter Academy Council 2006; OECD 2006; Third World Organization for Women in Science (TWOWS) 2007; UNESCO 2007; European Commission 2008; European Commission 2009a, 2009b; Caprile et al. 2012). These multiregional findings consistently point to a range of factors to explain the persistent underrepresentation of women, emphasizing the role of specific institutional and national contexts.

In this section we look at the underlying complex, institutional processes associated with horizontal and vertical segregation. A gendered perspective is essential to understand the complex social processes that shape scientists' careers, which have been metaphorically referred to as the "leaky pipeline," the "crystal labyrinth," and the "glass ceiling" for women. The processes of qualification and training, recruitment, retention, and advancement all occur within various scientific workplaces and educational settings, the institutional sites that shape large-scale segregation outcomes.

3.3 Qualification and Training

One of the most important issues related to women in science is how to attract girls and young women to scientific disciplines. While there has been much progress made in girls' education in many parts of the world, there are still some important differences within and across nations in terms of the likelihood that girls and women will stay on academic pathways that will lead to successful careers in science.

While women now constitute a majority of university students in many regions, including North and South America and Europe, sex segregation across fields of study is persistent. Women's representation is higher in the social and biological sciences; women's participation lags that of men in other areas of science and varies across levels for those who work in science occupations (see Figs. 3.2–3.4 for examples). Among the four disciplines we are focused on, women's representation in the chemical sciences has seen an important increase in many nations and there have been modest increases in women's participation in mathematics and statistics. Computer science, however, remains elusive for women in many countries, yet, as

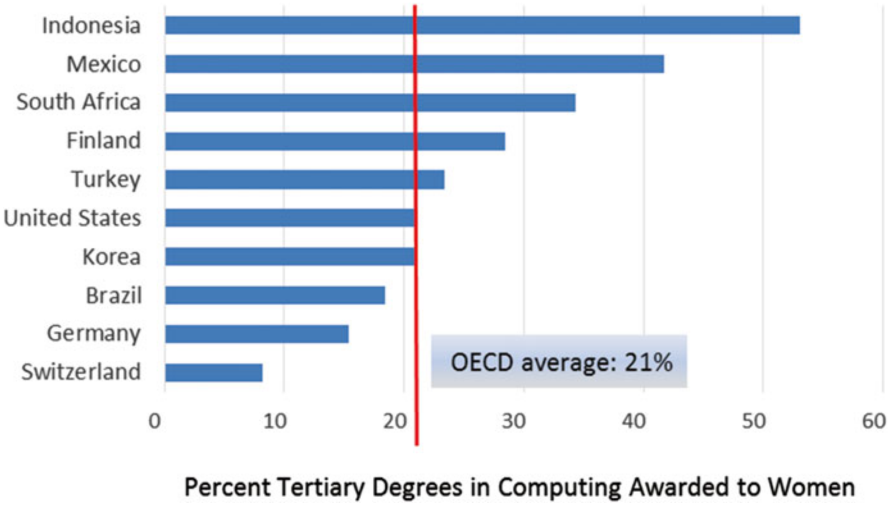


Fig. 3.5 Women as a percent of computing tertiary degrees, selected countries. *Note*: Tertiary includes both A level and advanced research programs. *Source*: Frehill, Lisa M. analysis of OECD. 2012. "Indicators of Gender Equity in Education, 2012" Gender Data Portal, online at www.oecd/els/gender

shown in Fig. 3.5, women's representation varies greatly cross-nationally. The lowest level of representation was in Switzerland at 8%, while in Mexico women account for 42% and in Indonesia, just over half (53%) of tertiary degrees in computing were awarded to women in 2010. The substantial cross-national variation suggests that essentialism offers an inadequate explanation for the observed gender differences of these fields.

Of course, in some other parts of the world attaining a university education remains a significant barrier for women who aspire to careers in science. In areas such as parts of Asia, Africa, and the Arab countries, women often lack access to careers in science, which generally require university training and, quite often, post-baccalaureate training as well.

There are many pivotal moments that influence the participation of women and girls along the scientific career trajectory, including some that parallel the life course processes of childbearing and rearing. Such issues have long been viewed as key in attempting to understand placement and success in science careers. For example, in some fields, a bachelor's (hereafter, B.S.) or a master's degree (hereafter, M.Sc.) is a suitable qualification for occupational entry, while in others the Ph.D. continues to be the requisite entry credential, with a concomitant devaluation of the B.S. and M.Sc. Likewise, in some science fields, the M.Sc. is a stepping stone along the pathway to a Ph.D., providing a useful set of career/life balance options.

While many reports point to the challenges associated with the lengthy career training process this simply is not a robust explanation. In spite of lengthy training, in many countries—not only the developed countries—there has been a notable increase in recent years in the presence of women among Ph.D. graduates and in some countries they are the majority (see Vignette 1.1: *Focus on Brazil*). In other disciplines with long and arduous training time, such as medicine, women now predominate. The increased prevalence and advancement of women in some careers suggests that it is *possible* for institutions to adapt to women's life course needs. The many organizations that constitute scientific discipline establish and enforce normative behavior for those who wish to be considered members. Many work organizations have implemented policies to enable employees to attend to family matters. Women continue to bear a larger share of responsibility for family care giving, but recent research indicates that younger men are also interested in workplaces that enable employees to balance work and family life. The burden of adaptation, however, appears to continue to fall upon individuals. The key question, though, is what actions do organizations take—or do not take—that enable women to manage advancement into and through science careers within the context of life course plans? Which opportunities do they create for women, in general, to counter disadvantage in their careers independently of family responsibilities?

3.4 Recruitment, Retention, and Advancement: Leaky Pipelines and Crystal Labyrinths

Institutional processes associated with recruitment, retention, and advancement often vary from country to country and within different economic sectors. Recruitment systems and specific criteria for advancement vary, although some indicators of productivity, such as publications and research funding for doctoral-degreed scientists, are prevalent in most contexts. Expectations for performance within these systems vary as do the extent to which scientists' careers are influenced by state policies that may or may not provide supports or resources for scientists. Transparency in these processes can produce more equitable outcomes, but the level of transparency varies across institutional contexts.

3.4.1 Recruitment

As Rees (2004: 115) summarizes the ETAN report (Osborn et al. 2000): [W]hatever the country […], whatever the discipline, and whatever the proportion of women among the undergraduate population […], men are selected disproportionately to their numbers in the recruitment pool at every stage on the career ladder. Many reasons have been given for this persistent state of affairs. Although the majority of Western countries now have equal employment laws that attempt to block overt discrimination, "covert or perceived discrimination that discourages women" (OECD 2006) is persistent.

Narrow job advertisements are one issue in recruitment, which may have a disparate gender impact. Women are unlikely to apply for positions for which they do not see an immediate match to their qualifications, but in some contexts, men are more likely to apply regardless of their qualifications (NRC 2010). Further, the narrower the job advertisement, the narrower the potential pool of recruits; with the rapid changes in science, such restrictions seem to be inefficient.

Even when women apply for positions, the many incremental subjective judgments embedded within selection processes may disadvantage women. Again, many institutions, led by those that had ADVANCE awards from the U.S. National Science Foundation, have implemented institutional policies to improve search processes via: (1) wider and more open advertisement of positions; (2) articulation of criteria for new hires and careful assessment of all candidates on all of these criteria; (3) training of department chairs and faculty about unconscious bias; and (4) oversight of hiring processes. Such interventions often had a positive impact on the likelihood that women would be hired (Bilimoria and Liang 2012).

In other countries, where the entry point in the scientific career might be by other forms of recruitment, such as public competition for example, networks are nevertheless still important in the subsequent steps of the career ladder. Women's limited access to networks continues to disadvantage them relative to their male colleagues within the hiring process. A study by the US National Research Council (2010) found that women were less likely than men to apply for academic positions, particularly in fields in which women are underrepresented. Further, as shown by Wenneräs and Wold (1997) women are held to higher performance standards than are men: they must work twice as hard to gain half the recognition of equivalent male colleagues. Advocates for women in science often refer to these higher standards for women as "raising the bar" for women candidates (Moody 2005).

3.4.2 Retention and Advancement: Leaky Pipelines and Crystal Labyrinths

Advancement in science is another process that has been a challenge for women. As bluntly put by Caprile et al. (2012) "the existence of a "'glass ceiling'" or "'sticky floor'" for women trying to progress to senior positions is well documented and affects all occupational sectors," regardless of the level of women's representation. Christine Williams (1992) documents that even in occupations that are numerically dominated by women such as nursing, gender privilege for men translates into a "glass escalator," suggesting that larger numbers of women, alone, are unlikely to alter the likelihood of achieving top positions in a field. While the glass ceiling is problematic for women in all sectors, it appears to be more pronounced in science (EC 2006; OECD 2006). According to a 2006 OECD report, institutional factors play an important role in women's career advancement. First, women's professional networks differ from those of men. Second, the workplace culture and organizational structures associated with promotion practices and the selection and allocation of research funding disadvantage women (OECD 2006: 11–12).

Professional networks are important for career advancement; they are a source of information for workers and provide access to the informal work culture, in general, and a key means by which scientists form collaborative relationships within and across work settings. Sveva Avveduto's (2015) discussion of women's participation in science in Italy suggests that such networks, "relationship-building tools for encouraging exchanges," have been instrumental in the increase in women's participation. In addition, networks provide newly minted scientists with access to mentors and guides who can assist with navigating the often-difficult path to tenure in academic settings and to career advancement in government and private industry. The lack of transparency associated with these career paths and the differential access to mentors has produced a crystal labyrinth for many women scientists (Eagly and Carli 2007).

Subtle gender biases and societal norms that regulate interactions between men and women impact the extent to which women can access the right networks to ensure successful career transitions. For men, it is almost "natural" that a more experienced scientist takes a new male scientist under his wing to ensure that he makes all the proper acquaintances. Women, however, do not seem to have the same opportunities. The general lack of women in leadership positions, and the scarcity of a mentoring culture in many countries have led to a relative scarcity of opportunities for women students. In the United States and in the European Union more formal mentoring structures are now seeking to address this inequality in both universities and professional associations, but in other countries mentoring is still in its infancy.

Access to key resources—research funding, materials, students or junior researchers, and space—is critical to scientists' career success. Such resources are more crucial in capital-intensive science (e.g., bench sciences like the chemical sciences) than in areas that are less capital-intensive (e.g., mathematics). A report of the European Commission (2009) on the "gender challenge in research funding" confirms that access to research funds by men and women scientists can show an important disparity, but also emphasized the situation varied much between the European countries under analysis. A number of innovative national policies which affect research funding were noted. Such policies include, for example: establishing targets for the proportion of women funded; giving preference to women in the case of candidates assessed to have equal merit; implementing programs and policies to address career phases or groups of researchers; and facilitating work/life balance for researchers (Husu and de Cheveigné 2010). In addition, a few aim at institutional transformation in a dialogue with universities (EC 2009: 25–27; Bilimoria and Liang 2012).

Other research has shown that women tend to have smaller funds and projects. In a study of the U.S. National Institutes of Health (NIH) US women represented 25% of the awards in 2004, and their awards remained at about 80% of the size of men's research grants (Hosek et al. 2005). In the UK, Blake and La Valle (2000) found that "not only women apply for fewer grants than men, but they are less likely to apply as the principal applicant, generally apply for grants of shorter duration and for lower levels of funding." (p. 51). Funding structures could contribute to both horizontal and vertical sex segregation. If women have less access to funding, overall, the result might be that women will be more likely to be in fields that require less funding (horizontal). A study of the German Research Foundation showed that women's rate of success in winning grants was higher in male-dominated fields than in fields with higher percentages of women (Hinz, Findeisen, and Auspurg 2008).

How resources are made available, the ways that scientists obtain these resources, and the role of gender within these processes is key in understanding the persistent difficulties that women face with the glass ceiling or the sticky floor. In general, too, the extent to which these processes are transparent and involve universalistic criteria versus the extent to which they are organized as pre-bureaucratic forms or in which particularistic criteria continue to operate as a means by which resources would be allocated. In general, then, two inter-related gendered mechanisms tend to disadvantage women and advantage men in resource allocations: the assessment of excellence in science settings and negotiation as a means of obtaining resources.

Assessing Excellence: The mechanisms for the construction of excellence in science, critical for advancement to the highest positions in the system, involves numerous "gatekeepers": full professors or senior research scientists, members of national science and technology councils, members of evaluation committees and panels, external reviewers, science editors, and many others. The research evidence is clear that, in most countries, power, decision-making, and other gatekeeping activities continue to be dominated by men, in many cases, overwhelmingly so. According to Feller (2004), in the analysis of gender bias in scientific excellence it is important to distinguish conceptually between: (1) The ways in which scientific excellence is defined and measured and (2) The specific procedures for assessing scientific excellence. The definition of scientific excellence and the measurement of scientific production have both been shown to be constructed on models that are still clearly masculine. "This meritocratic system strengthens unequal starting points and has particularly damaging results for many women and some men who do not meet the model of success defined as standard" (Caprile et al. 2008, cited by EU Seventh Framework Programme 2008: 19; Bailyn 2003; Knights and Richards 2003; Valian 1998).

On the other hand the increasing dependence on bibliometric measures of scientific production has been debated, including within a gender framework. Women scientists have often been considered less productive than men because they published fewer papers. Evidence shows, however, that "productivity is not an independent characteristic of individuals but rather a reflection of their positions in the academic hierarchy and the access to resources that those positions make possible. When academic position, available resources, type of institution, and other personal and institutional factors are held constant, men and women scientists are equally productive." (NRC 2007: 113)

Negotiation: The extent to which adversarial negotiation processes are used to obtain institutional resources plays an important role in gender differences in advancement. In those national contexts and institutional settings where negotiation is the principal method by which space, students, salaries, travel funds, and other resources essential to the conduct and dissemination of scientific research, women are likely to be disadvantaged relative to men. As discussed by Babcock and Laschever (2009), women are less likely to demand the same resources as men. But merely asking does not, necessarily, improve women's success, as being demanding is stereotypically a male trait in many cultures; so when women violate this gendered norm, administrators respond to their request differently, hence women risk being negatively evaluated. Instead, the processes by which individuals secure resources must be made more transparent and less particularistic in order to provide a level playing field for all.

3.5 The Pay Gap: Economic Resources over the Life Course

The pay gap persists between women and men; in all countries where this information is available, women earn less than men. Historically, men have been concerned when women start to move into "their" fields for fear that women's entrance will erode the status and prestige of the field as well as the pay. The specter of diminishing pay—and potentially concurrent decreases in status and prestige of a field—represents a key interest that entrenched majorities would seek to preserve by barring entry to women.

Similar to the mechanisms that produce disparate career advancement outcomes for women in science, segregation is related to pay along both the vertical and horizontal dimensions, which can make the gendered social forces that produce the pay gap more difficult to reveal. Along the horizontal segregation, different areas of science have different pay rates. Women have often been observed to be more highly represented in the lower-paid fields while men are more highly represented in the higher paying fields. For example, biologists often earn far less than computer scientists or engineers; women are more highly represented in biology than in CS or engineering. Employment sector is another dimension of horizontal sex segregation: pay is often far higher in private industry than in academia. As Etzkowitz et al. explain, in some fields like computer science women tend to work in universities while men take better paying positions in industry (2000: 204).

In addition, vertical segregation also has important implications for the pay gap; as one gains more seniority and/or moves up positions in the status hierarchy, one expects increased earnings over the life course. The glass ceiling, therefore, imposes differential rates of access to higher-status jobs and this accounts for women's lower average earnings relative to men's. However, there is also evidence that women in positions equivalent to male peers also earn less than men, especially those that lack transparency and expect allow individuals to negotiate. In pay systems with less room for negotiation, however, gender differences are likely to be smaller since position (including rank in academic settings), experience, etc. will be more of an objective measure. Government systems or those in which labor unions play an important role, for example, can diminish wage inequality when compared to more *laissez faire* systems. These processes that lead to horizontal and vertical segregation funnel more men but less women into higher-status and higher-paid jobs, so that over the career-course, the pay gap widens.

3.6 The Cloister Culture of Science

When examining the work content of science, the traditional scientific career model was more accurately a "two-person career" that assumed that family and non-work issues were taken care of by someone else, traditionally a wife, allowing the male scientist to have a total commitment to work, with long hours. Such highly dedicated men could also be expected—within this social context—to be highly mobile in pursuing career opportunities, often in multiple countries. This model is increasingly untenable for both men and women; calling into question the traditional structures that guided scientific career paths. The extent to which family responsibilities may be a factor in women's career disadvantage in science varies across countries. The availability of childcare varies from publically funded to inexpensive childcare and household labor that allows parents to "outsource" these tasks. National and local contexts for childcare, therefore, provide different tools with which dual-career families may balance childcare, producing different patterns of career attainment. In countries with little (institutional) supports for childcare, the dynamics of work/life balance are intensified for scientists with children. For many women, childcare responsibilities have led to career breaks, which can hinder career success (CATALYST studies, Etzkowitz et al. 2000; Gupta et al. 2004; Kemelgor and Etzkowitz 2001; Osborn et al. 2000). Such studies have pointed to the need for "on-ramping" programming for women who may have had such breaks to re-integrate into their careers.

Of course, children will not always have a negative impact on careers. Some researchers have challenged the notion that women's advancement in science is thwarted by childcare and family responsibilities. Mary Frank Fox (2005) has shown that US women with children who stay in academia are more productive than their counterparts without children. Frehill and Zippel (2011) find that the presence of children did not affect US-based women's participation in international collaboration. Work by the European Commission, however, indicates that childcare responsibilities continue to limit women's career outcomes in the highest levels of science (<>*She Figures* 2012).

3.7 Institutional Processes

In this section, we have reviewed a number of processes within the institutions that comprise the presumed meritocratic objectivity of scientific communities, including the workplaces within which scientists work, that lead to patterned differences in the career outcomes for men and women. Women experience barriers to advancement in science both within educational institutions and scientific workplaces. The scissors diagrams, which have become an omnipresent visualization tool, are clear in showing women's declining representation at higher levels of science education and occupations and men's concurrent increasing representation, especially women's rarity in top leadership positions in science.

The so-called "blind" processes of peer review, in which faith has been grounded as an efficient and fair means of evaluating the merits of scientific research, have been shown time and again and across national contexts to be fraught with some persistent bias against women. While women might benefit overall from "blind" evaluation processes, the persistence of gender biases, even if they are not as overt as previously, can hinder women's access to and advancement in science. The accumulation of small disadvantages produces disparate outcomes over the course of individuals' careers (Valian 1998).

Finally, particularistic institutional processes that treat individuals differently, which reward men for gender-appropriate aggressive behavior and may punish women for gender-inappropriate behavior (i.e., aggressiveness) disadvantage women, who are placed in an untenable, no-win situation necessary to access resources that are critical to career success. The subtle ways in which gender is woven into these processes provides institutions with a way to deflect attention away from institutional actions and, instead, to women's own behaviors as the reason for persistent gender disparities in resource allocation, advancement, and pay.

3.7.1 The Calculus of "Choice": The Individual Level

In this section, we move further down into the social world to the level of individuals. At this level we are particularly interested in the calculus of choice. Here we reach a dilemma; to paraphrase Karl Marx, people make their own history, but they do so under circumstances directly encountered, given, and transmitted from the past. While individuals may be viewed as active agents of their own lives, especially in Western cultures, the extent to which individuals encounter opportunities and constraints, which can be patterned by a number of characteristics, which can serve to channeled individuals into some areas or block them out of others. Further, evidence from non-Western cultures suggests that individualism is less important in determining career outcomes. Rather, in these cultures (notably Indian and China), students' early performance on tests in mathematics and science and family wishes play a far larger role in the career selection process. In this volume, the ways in which the institution of gender shapes individuals' choices, even though they may believe that these are freely made, results in the macro-level patterns of the sex segregation.

Norms, values, policies, and practices are patterned by gender channel individuals towards choices in relatively predictable ways. In addition, the information that individuals possess and the specific situations in which they find themselves also impact choices. The personal comments by Diane Wilcox (2015) about advancing in South African academic science provide an illustration of personal choices as they are embedded and constructed in a larger set of gendered practices.

Many researchers on gender and science today agree that there are multiple factors associated with variations in women's representation in science. In general, both women and men select themselves out of and into sex segregated fields and believe that these are freely chosen pathways. Yet, we will show here, cross-national differences in how young women and men embark on studies and careers in science reveal the significance of context for these choices. Indeed, that these gender differences in career interests are not fixed, but vary greatly cross-nationally, reflects the influence of complex social forces in social, organizational, institutional settings, and cultural beliefs that shape individuals' choices.

3.8 Gender Stereotypes

The Institutional Context of Mathematics Choice and Sex Segregation

Mathematics is the basis of many fields of science. Imagine the difference between growing up in a country in which in secondary school around the age of 13–14, individuals are asked, do you want to continue taking advanced math classes? And compare this situational "choice" to that in another educational system where the option for continued mathematics education is delayed until college. If mathematics is believed to be connected to gender, then those of the gender viewed as inferior at mathematics might be permitted to opt out of mathematics in the first situation, making it more difficult to pursue math-intensive majors later in college. This example illustrates how the educational systems' context can have profound influences on gendered achievements and potentially closing the gender gap in math.

The social construction of gender varies cross-nationally, across cultural groups within a nation, across time, and across the individual's life course. Gender stereotypes are cultural beliefs about what it means to be a male or a female: these are learned from the moment of birth. In general, stereotypes of any kind are embedded in a society and influence individuals' behaviors. Counter examples do not upset the conceptual framework of stereotypes, as these are viewed as "exceptions to the rule," therefore, stereotypes can prove difficult to change.

Beliefs, for example, such as "girls are not good at mathematics," despite the weight of evidence against this proposition, are commonly asserted as fact because stereotypes need no evidence to be taken at face value. Given the foundational role of mathematics in science, this particular stereotype is particularly problematic in those nations that hold this stereotype.

Spencer et al. (1999) explored stereotype threat as a factor affecting women's mathematics performance. The original concept of stereotype threat had been developed by Claude Steele and Joshua Aronson (1995) to understand why African American youth performed poorly on standardized tests in the United States. Steele found that under conditions of stereotype threat—a situation in which subjects were told that a test measured ability—African Americans performed substantially worse than Whites, while in a non-stereotype threat condition, African American scores were slightly higher than Whites. Many psychologically oriented researchers and engineering and mathematics educators have taken the phenomenon of stereotype threat seriously, and have devised testing protocols (i.e., specific sets of instructions) that serve to create a non-stereotype threat environment in testing contexts (Steele 1997).

At the heart of the matter, the United States, along with other Western-European cultures, frames mathematics as an innate ability, with an uneven gender distribution of talent (i.e., girls are viewed as less likely than boys to be "good at math"). In Asian cultures, however, mathematics is culturally defined as a skill, which, like any other skill, requires practice to master. Therefore, the concept of stereotype threat, while salient in those nations where mathematics is a gendered ability, may be less relevant in those nations where mathematics is conceptualized as a skill.

Another way in which stereotypes affect the calculus of choice is the subtle biases that creep into decision processes. Peer review and evaluation, the most prevalent system of assessment and widely believed to be the most effective and efficient means of maintaining highest standards, does not completely preclude social prejudices, such as gender stereotypes, which disadvantage women and advantage men. The earlier-cited works by Wenneräs and Wold (1997) for Sweden and Cotta et al. (2009) for the case of Brazil make it clear that peer evaluations can be biased. Further, social psychological studies point to the persistence of implicit bias against women in science which can seep into the evaluation of their work (Nosek and Riskind 2012) and that often these biases are held by both men and women as they are inextricably woven into the fabric of social life.

3.9 Gendered Norms

In the case of stereotypes, solutions can be developed that pull back the curtain to reveal the fallacy of the belief. New instructions can be devised for testing and more careful methods of review can be implemented to ensure that women and men are treated equitably in peer review processes. More difficult, however, are gendered norms, which are merely expectations for behavior based on gender. As indicated, above, these vary cross-nationally, over time, and cross-culturally (e.g., by ethnicity, religion, social class) within a nation. Norms guide behavior in predictable ways as an element of social order. Enforcement of norms tends to be informal: those who violate appropriate rules of behavior associated with their gender might be punished, while those who conform may be rewarded, as was the case with negotiation, discussed in the previous section. But these punishments and rewards are not always codified nor are the sanctions. In addition, the punishments and rewards associated with violating or conforming to norms may not be consequential to a given individual. Hence, the calculus of choice within the context of gendered norms is rather complicated even as these norms do channel individuals into "gender-appropriate" fields.

Norms and Major Choice: When girls and boys make individual choices in school to major in specific subjects, later in university and finally for their career choices, gender norms affect their choices. As discussed above, stereotypes can serve as strong signals to girls and boys about the appropriateness of fields and careers. But the operation of gendered norms can often be more subtle.

For example, students now in the United States may refer to biology as an intuitive, "soft" and easy field because of the preponderance of women in this major over the past 30 years. This means that biology as a field is more accessible to women, since women can fit in without creating dissonance between their self-image and that of a scientist. By contrast, mathematics and physics are constructed as difficult, "hard" sciences, which are more consistent with masculine norms, which attract men. Within the hegemonic construction of masculinity (Connell 1995), men shun fields associated with women/femininity and seek fields in which their sense of themselves as men can find expression.

Gender and the Life Course: Gendered norms are particularly important in defining appropriate behaviors within family structures: wives and husbands, sons and daughters, and mothers and fathers. In China and India, for example, there has been a strong male-child preference because of beliefs about the roles of sons and daughters. In these countries, daughters are expected to marry into another family, with sons remaining and viewed as carrying on the family name and family responsibilities, which become more onerous as parents age.

Family obligations and the gendered expectations associated with these obligations pose different consequences for women and men along the science career pathway. Employment choices are gendered, with long lasting influence of careers paths including pay and status, and, again contribute to observed gender segregation in labor markets. Consider the situation of a German woman with young twins who went back to get a master's degree in computer science. She started a job in an almost all-male IT start-up company with little flexibility and high demands for working overtime. She did not feel that this was a good "fit" for her. Instead, she chose teaching at a local high school and has been satisfied for the past several years.

While the woman might believe that she has made a "free choice" between two career paths, when we look at the institutionalized features of the positions, "gendered" organizational features become visible. The high school offered her a gender-mixed environment of colleagues and students, in contrast to the almost all-male (IT) one she left. The working hours at school matched her children's school and vacation schedule, hence enabling her to maximize time with her children. For her, this flexibility was particularly important because her husband had a job with high time demands and little flexibility, much like positions in start-up companies.

Hence, her "choice" between these two careers needs to be contextualized by the features of these two positions, the gendered workplace culture of the jobs as well as the availability of childcare beyond limited school hours in the German system.

If we carry this example a step further, we can also see a way in which individual-level choices, driven by organizational contexts, result in the macro-level pay gap. In this case, teaching pays less than IT work for those with the same education. But the work context in the IT start-up leaves little time for a worker to pursue much life outside the workplace. Teaching, however, is very consistent with work/life balance—at least on the surface—so it is not surprising that this woman was funneled into teaching and away from IT. Over time, her husband will see increases in his pay and could continue to reap the financial rewards that come from long hours of paid employment. The woman is likely to work more hours than her husband, but will split her time between the lower-paid teaching job and the unpaid work of caring for her family. In addition, she will also now have an IT career discontinuity that she would have to explain—if she is even given a chance to do so—making it rather difficult for her to move back into a full-time IT job even when her children are older.

Gender, *the Life Course*, *and Science Careers*: The decision to get an advanced degree in science and the choice of a work setting can be shaped by how individuals make choices within the context of the culture of science disciplines that are patterned by gender. As illustrated by the example, above, individuals make choices within the context of their family situations and beliefs about appropriate behavior within the family setting. The German woman, above, who opted for a lower-paying job that provided her with more time to spend enacting the gendered role of "mother" might not have had that same freedom of choice if she did not have a partner who was not well employed. Likewise, if her husband had wished to spend more time with the children and less in the paid labor force, would his "choice" to take a lower-paying job be seen as acceptable?

Advanced science degrees, especially at the doctoral level, prepare students for academic careers and open doors in industry and government for professional careers with high status and leadership opportunities. When we compare disciplines and countries we easily see how these decisions are not just shaped by personal motives, but also by a whole set of complicated factors. The availability of work for people in labor markets varies by degree field level and individuals' careers may not match their level of formal education. For example, a US individual who holds a B.S. in chemistry but progresses within her/his career as a result of on-the-job training to positions of higher level research responsibility may find that without a formal educational credential it would not be possible to be hired to do the same work at another US firm or at a laboratory in another country (e.g., Germany). Particular subfields in the German chemistry workforce are deemed more open to women such as food-chemistry, which has less status and pay than other chemistry subfields (Kahlert 2012).

In addition, regulations and practices of workplace protections that people take for granted can further constrain women's career choices. For example, in Germany pregnant women are not allowed to work in laboratories that might expose them to "dangerous" substances, which has obvious implications for women's ability to work in fields like the chemical sciences. Hence, women who intend to have children in Germany may avoid chemistry jobs with such restrictions and take jobs in other areas of chemistry. Gendered policies that most individuals take for granted further obscure the role of gender in shaping career choices.

3.10 Individual-Level Choices

Individuals are active agents but they are not atomistic. They are connected to significant others and, as members of cultures, sensitive to the norms that regulate social behavior. Gendered norms are woven throughout cultures, often in subtle ways, so that individuals may believe that the pathway choices they make are entirely independent of gendered considerations when, indeed, gendered factors have shaped these choices all along the way to produce the macro-level separation of women and men into different occupations. Individuals who choose to challenge, ignore, or violate the gendered norms within their culture run the risk of being evaluated negatively or, in extreme cases, of being targeted by gunmen as was Malala Yousafzai, the 14-year-old Pakistani girl who advocated for girls' access to education. On the other hand, conforming to gendered norms may produce rewards, such as when men can choose to accept opportunities for advancement because someone else is responsible for taking care of their children.

3.11 Conclusion

In this chapter, the horizontal and vertical dimensions of occupational segregation were discussed. Women and men often pursue different areas within the sciences (horizontal segregation). The role of education in preparing individuals for careers in science and the mechanisms by which entry is patterned by gender, therefore, produce differences in women's and men's entry to different fields of science. Further women are less likely to be at the pinnacle of scientific careers in positions of power and are more likely to be concentrated in lower-level positions (vertical segregation). The large cross-national variation in women's representation across fields reveals the importance of social factors—versus innate biology—as the reason for gender variation. The social institution of gender, itself, plays a pivotal role in women's representation both across different fields of science and in advancement within science. Gender as an integrated set of social norms, values, roles, expectations, and practices, shapes behavior and patterns opportunities in subtle ways, so that the average individual typically fails to acknowledge the role of gender in producing educational and occupational outcomes.

Expectations for performance within these systems vary and scientists' careers can be influenced by state policies that may or may not provide supports or resources for scientists. Transparency in these processes can produce more equitable outcomes, but the level of transparency varies across institutional contexts. The extent to which individuals negotiate within these systems and the extent to which negotiation is gendered hold further implications for women's advancement in science.

A number of processes within the institutions that comprise the presumed meritocratic objectivity of scientific communities were reviewed. The omnipresent scissors diagrams clearly illustrate women's lower representation at higher levels of science education and occupations and men's concurrent higher representation, especially women's rarity in top leadership positions in science. Such stratification holds implications for women's access to key resources in science and maintains men's control of scientific organizations, thereby replicating the gendered status quo.

Second, the so-called "blind" processes of peer review have been shown to be fraught with bias (Wenneräs and Wold 1997). The accumulation of small disadvantages produces disparate outcomes over the course of individuals' careers (Valian 1998). Further, particularistic institutional processes that reward men for gender-appropriate aggressive behavior in the allocation of resources disadvantage women, who are placed in an untenable, no-win situation where aggressive behavior may result in sanctions.

Much more research is needed to understand how these processes vary between countries. The cross-national variation is a potentially rich source of "natural experiments" to examine the way gender operates to impact education and career outcomes. The D-scores that quantify the level of segregation—both horizontal and vertical—are one metric that can aid in these analyses; these metrics are also useful for the analysis of the segregation of science within a nation over time. Robust analyses should drill down to better document the institutional and institutional-level processes by which gender is salient in the careers of scientists. Within national contexts, it would be useful to examine if these processes impact women differently based on the level of women's participation in science. For example, are women more or less likely to advance in male or female-dominated fields? Some evidence suggests that that even in fields in which women account for the majority of occupants, men are privileged and "ride the glass escalator" to higher positions of authority (Williams 1992).

There are a number of other research avenues in which attention to the horizontal and vertical dimensions of segregation and the social, organizational, and individual-level mechanisms could prove fruitful. First, the recent worldwide economic crisis increased competition for jobs across labor markets in most nations. To what extent were women in science likely to suffer adverse career impacts, either because of men's assertion of gender privilege or due to "last in-first out" processes?

Second, intersectionality also bears more careful scrutiny. In this chapter, we focused almost exclusively on deploying the tools and analytical strategies of sex segregation to understand the relative status of women in four science fields in international perspective. Other bases of differentiation, including birth cohort (or generational effects), race/ethnicity, immigration status, sexual orientation, etc. have been increasingly incorporated into more nuanced analyses of gender differences to provide a richer understanding of the segregation outcomes and cross-national differences that might be observed. Scientists are an internationally mobile workforce; so, for example, to what extent does gender and national origin (i.e., immigrant/nonimmigrant) impact individuals' science careers?

Additional research on women's science careers outside of academic settings in cross-national perspective is also needed. There are vast differences across nations in the level and quality of data about workforce participation. Data on women in industrial and government science workplaces is often very difficult to obtain, despite the efforts by international organizations like OECD to standardize occupations and industrial classification systems.

Much of the international effort focused on improving the status of women (e.g., UNESCO) often focuses on such basic needs for health and sanitation, that increasing women's participation in science seems remote in comparison. That is, as illustrated by recent events, the need to address outright violence against women when they attempt to go to school or work may be a more pressing priority versus opening doors to women to what is generally a small segment of the larger labor force (i.e., science).

In closing, the relationship between scientific credentials, careers, and larger social and economic forces must attend to gender as an often subtle factor that affects all of these processes. The social organization of science and the ways this might vary across national contexts should also find a place on social scientists' research agenda. The worldwide discourse that suggests that science is critical for economic development and continued technological advancement implies that women have an important stake in being full participants in science.

Chapter References

Anker, Richard. 1998. *Gender and Jobs: Sex Segregation of Occupations in the World*. Geneva: International Labour Office.

Aaveduto, Sveva. 2015. Greetings from Italy: What Is Changing for Women and Science and Research Careers. In *Advancing Women in Science: An International Perspective*, ed. W. Pearson Jr., L.M. Frehill, and C.L. McNeely. New York: Springer.

Babcock, Linda, and Sara Laschever. 2009. *Women Don't Ask: Negotiation and the Gender Divide*. Princeton, NJ: Princeton University Press.

Bailyn, Lotte. 2003. Academic Careers and Gender Equity: Lessons Learned from MIT. *Gender, Work & Organization* 10: 137–153.

Bertaux, Nancy E. 1991. The Roots of Today's "Women's Jobs" and "Men's Jobs": Using the Index of Dissimilarity to Measure Occupational Segregation by Gender. *Explorations in Economic History* 28: 433–459.

Bilimoria, Diana, and Xiangfen Liang. 2012. *Gender Equity in Science and Engineering: Advancing Change in Higher Education*, vol. 15. New York: Routledge.

Blackburn, R.M., Jennifer Jarman, and Bradley Brooks. 2000. The Puzzle of Gender Segregation and Inequality: A Cross-National Analysis. *European Sociological Review* 16: 119–135.

Blake, Margaret, and Ivana La Valle. 2000. *Who Applies for Research Funding?: Key Factors Shaping Funding Application Behaviour Among Women and Men in British Higher Education Institutions*. London: National Centre for Social Research.

Caprile, Maria, ed., B. Sánchez, N. Vallès, A Gómez, J Potrony, E Sixto, D Herrera, M Oleaga, M. Amate, and I. Isasa. 2008. *Monitoring Progress Towards Gender Equality in the Sixth Framework Programme*. European Commission, Directorate for Research.

Caprile, Maria, coord., Elisabetta Addis, Cecilia Castaño, Ineke Klinge, Marina Larios, Danièle Meulders, Jörg Müller, O'Darchoai, Robert Alain Plasman, Seppo Roivas, Felizitas Sagebiel, Londa Schiebinger, Nuria Vallès, and Susana Vazquez-Cupeiro. 2012. *Meta-Analysis Gender and Science Research: Synthesis Report*. Bruxelles: ULB—Universite Libre de Bruxelles.

Chang, Mariko Lin. 2004. Growing Pains: Cross-National Variation in Sex Segregation in Sixteen Developing Countries. *American Sociological Review* 69: 114–137.

Charles, Maria. 1992. Cross-National Variation in Occupational Sex Segregation. *American Sociological Review* 57: 483–502.

Charles, Maria, and Karen Bradley. 2002. Equal but Separate? A Cross-National Study of Sex Segregation in Higher Education. *American Sociological Review* 67: 573–599.

_____. 2004. *Occupational Ghettos: The Worldwide Segregation of Women and Men*. Stanford: Stanford University Press.

Charles, Maria, and David B. Grusky. 2004. *Occupational Ghettos: The Worldwide Segregation of Women and Men*. Stanford: Stanford University Press.

CNPq. 2013. *Diretório dos grupos de pesquisa no Brasil. Censos a partir de 2000 e base corrente* (Directory of Research Groups of Brazil. Census from Year 2000 and Current Base).

Connell, R.W. 1995. *Masculinities*. Oakland: University of California Press.

Correll, Shelley J., Stephen Benard, and In Paik. 2007. Getting a job: Is There a Motherhood Penalty? *American Journal of Sociology* 112: 1297–1338.

Cotta, Monica Alonso, Marília J. Caldas, and Marcia C. Barbosa. 2009. Climbing the Academy Ladder in Brazil: Physics. *AIP Conference Proceedings* 1119: 87.

Duncan, Otis Dudley, and Beverly Duncan. 1955. A Methodological Analysis of Segregation Indexes. *American Sociological Review* 20: 210–217.

Eagly, Alice H., and Linda Lorene Carli. 2007. *Through the Labyrinth: The Truth About How Women Become Leaders*. Boston, MA: Harvard Business School Press.

Etzkowitz, Henry, Carol Kemelgor, and Brian Uzzi, eds. 2000. International Comparisons. In *Athena Unbound: the Advancement of Women in Science and Technology*. Cambridge: Cambridge University Press, 203–224.

European Commission. 2002. *National Policies on Women and Science in Europe: A Report About Women in and Science in 30 Countries by Professor Teresa Rees*. Brussels: EC.

_____. 2006. *She Figures 2006*. Brussels: EC.

_____. 2008. *Mapping the Maze: Getting More Women to the Top in Research.* Luxembourg: Office for Official Publications of the European Communities.

_____. 2009. *The Gender Challenge in Research Funding: Assessing the European National Scenes*. Brussels: EC.

_____. 2013. *She Figures 2012. Gender in Research and Innovation. Statistics and Indicators. Office for Official Publications of the European Communities.* Brussels: EC.

European Commission, Directorate-General for Research Science, Economy and Society, ed. 2009b. *Women in Science and Technology: Creating Sustainable Careers*. Luxembourg: EUR-OP.

European Science Foundation (ESF). 2009. *Research Careers in Europe. Landscape and Horizons. A Report by the ESF Member Organisation Forum on Research Careers*. Strasbourg: ESF.

European Union Seventh Framework Programme. 2008. *Meta-Analysis of Gender and Science Research*. CIREM.

Feller, Irwin. 2004. Measurement of Scientific Performance and Gender Bias. *Gender and Excellence in the Making* 35.

Fiske, Susan T. 1998. Stereotyping, Prejudice, and Discrimination. In *The Handbook of Social Psychology*, ed. D.T.F. Gilbert, T. Susan, and G. Lindzey, 367–411. New York: McGraw-Hill.

Fiske, Susan T., J.C. Amy, Peter Glick Cuddy, and Xu. Jun. 2002. A Model of (Often Mixed) Stereotype Content: Competence and Warmth Respectively Follow from Perceived Status and Competition. *Journal of Personality and Social Psychology* 82: 878–902.

Fox, Mary Frank. 2005. Gender, Family Characteristics, and Publication Productivity Among Scientists. *Social Studies of Science* 35: 131–150.

Frehill, Lisa M. 1996. Occupational Segmentation in Kansas and Nebraska, 1890-1900. *Great Plains Research* 6: 213–244.

Frehill, L.M., and K. Zippel. 2011. Gender and International Collaborations of Academic Scientists and Engineers: Findings from the Survey of Doctorate Recipients, 2006. *Journal of the Washington Academy of Sciences* 97(1): 49–69.

_____. Measuring Occupational Sex Segregation of Academic Science and Engineering. *The Journal of Technology Transfer* 31: 345–354.

Galerand, Elsa, and Danièle Kergoat. 2013. Le travail comme enjeu des rapport sociaux (de sexe). In *Travail et genre dans le monde L'état des savoirs*, coord. Margaret Maruani, 44–51. Paris: La Découverte.

Grusky, David B., and Maria Charles. 1998. The Past, Present, and Future of Sex Segregation Methodology. *Demography* 35: 497–504.

Gupta, Namrata, Carol Kemelgor, Stephan Fuchs, and Henry Etzkowitz. 2004. The 'Triple Burden': A Cross-Cultural Analysis of the Consequences of Discrimination for Women in Science. In *Gender and Excellence in the Making*, ed. European Commission, 41–50. Luxembourg: Office for Official Publications of the European Communities.

Hanson, Sandra L., Maryellen Schaub, and David P. Baker. 1996. Gender Stratification in the Science Pipeline: A Comparative Analysis of Seven Countries. *Gender & Society* 10: 271–190.

Hinz, Thomas, Ina Findeisen, and Katrin Auspurg. 2008. *Wissenschaftlerinnen in der DFG. Förderprogramme, Förderchancen, Funktionen (1991–2004)*. Weinheim: Wiley-Verlag.

Hosek, Susan D., Amy G. Cox, Bonnie Ghosh-Dastidar, Aaron Kofner, Nishal Ramphal, Jon Scott, and Sandra H. Berry. 2005. *Is There Gender Bias in Federal Grant Programs?* Santa Monica, CA: RAND.

Husu, Liisa, and Suzanne Cheveigné. 2010. Gender and Gatekeeping of Excellence in Research Funding: European Perspectives. In *Gender Change in Academia*, ed. B. Riegraf, B. Aulenbacher, E. Kirsch-Auwärter, and U. Müller, 43–59. Wiesbaden: VS Verlag für Sozialwissenschaften.

Inter Academy Council. 2006. *Women for Science. An Advisory Report*.

Jacobs, Jerry A. 1989. Long-Term Trends in Occupational Segregation by Sex. *The American Journal of Sociology* 95: 160–173.

_____. 1995. Gender and Academic Specialties: Trends Among Recipients of College Degrees in the 1980s. *Sociology of Education*, 68: 81–98.

Kahlert, Heike. 2012. Was kommt nach der Promotion? Karriereorientierungen und -pläne des wissenschaftlichen Nachwuchses im Fächer- und Geschlechtervergleich. In *Einfach Spitze? Neue Geschlechterperspektiven auf Karrieren in der Wissenschaft*, ed. S. Beaufaÿs, A. Engels, and H. Kahlert. Campus: Frankfurt am Main [u.a.].

Kemelgor, Carol, and Harry Etzkowitz. 2001. Overcoming Isolation: Women's Dilemmas in American Academic Science. *Minerva* 39: 153–174.

King, M.C. 1992. Occupational Segregation by Race and Sex, 1940-88. *Monthly Labor Review* 115: 30–38.

Knights, David, and Wendy Richards. 2003. Sex Discrimination in UK Academia. *Gender, Work & Organization* 10: 213–238.

Maruani, Margaret, coord. 2013. Travail et genre dans le monde. L'état des savoirs. Paris: La Découverte.

Massey, Douglas S., and Nancy A. Denton. 1989. Hypersegregation in U.S. Metropolitan Areas: Black and Hispanic Segregation Along Five Dimensions. *Demography* 26(3): 373–91.

Massey, Douglas S., and Nancy A. Denton. 1993. *American Apartheid: Segregation and the Making of the Underclass*. Cambridge, MA: Harvard University Press.

McDaniel, Anne. 2010. Cross-National Gender Gaps in Educational Expectations: The Influence of National-Level Gender Ideology and Educational Systems. *Comparative Education Review* 54(1): 27–50.

Melkas, Helina, and Richard Anker. 2001. Occupational Segregation by Sex in Nordic Countries: An Empirical Investigation. In *Women, Gender and Work: What Is Equality and How Do We Get There?* ed. M.F. Loutfi, 189–213. Geneva: International Labour Office.

Moody, Joann. 2005. Rising above Cognitive Errors: Guidelines to Improve Faculty Searches, Evaluations, and Decision-Making.

National Science Foundation. 2012. *Science and Engineering Indicators*. Arlington, VA: National Science Board.

Nosek, Brian A., and Rachel G. Riskind. 2012. Policy Implications of Implicit Social Cognition. *Social Issues and Policy Review* 6: 113–147.

National Research Council (NRC). 2007. *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering*. Washington, DC: The National Academies Press.

_____. 2010. *Gender Differences at Critical Transitions in the Careers of Science, Engineering and Mathematics Faculty*. Washington, DC: National Academies Press.

Organization of American States (OAS). 2005. Gender Equity and Equality in Science and Technology. *Policy Proposals for the Americas*. Washington, DC.

Organisation for Economic Cooperation and Development. 2006. *Women in Scientific Careers: Unleashing the Potential*. Paris: OECD.

OEI—Organización de los Estados Iberoamericanos y UNESCO SAP. 2004. *Proyecto Iberoamericano de Ciencia, Tecnología y Género—GENTEC—UNESCO*. Informe comparativo regional e informes nacionales de Argentina, Brasil, Costa Rica, España, México, Paraguay, Uruguay y Venezuela.

Osborn, M., T. Rees, M. Bosch, C. Hermann, J. Hilden, J. Mason, A. McLaren, R. Palomba, L. Peltonen, C. Vela, D. Weis, A. Wold, and C. Wennerås. 2000. *Science Policies in the European Union: Promoting Excellence Through Mainstreaming Gender Equality*. Luxembourg: Office for Official Publications of the European Communities, European Commission.

Rees, Teresa. 2004. Measuring Excellence in Scientific Research: The UK Research Assessment Exercise. In *Gender and Excellence in the Making.* Luxembourg: Office for Official Publications of the European Communities, 115–120.

Reskin, Barbara, and Heidi I. Hartmann. 1986. *Women's Work, Men's Work: Sex Segregation on the Job*. Washington, DC: National Academy Press.

Reskin, Barbara, and Patricia A. Roos. 1990. *Job Queues, Gender Queues: Explaining Women's Inroads into Male Occupations*. Philadelphia: Temple University Press.

Semyonov, Moshe, Yitchak Haberfield, Yinon Cohen, and Noah Lewin-Epstein. 2000. Racial Composition and Occupational Segregation and Inequality Across American Cities. *Social Science Research* 29: 175–187.

Spencer, Steven J., Claude M. Steele, and Diane M. Steele. 1999. Stereotype Threat and Women's Math Performance. *Journal of Experimental Social Psychology* 35: 4–28.

Steele, Claude M. 1997. A Threat in the Air: How Stereotypes Shape Intellectual Identity and Performance. *American Psychologist* 52: 613–629.

Steele, Claude M., and Joshua Aronson. 1995. Stereotype Threat and the Intellectual Test Performance of African Americans. *Journal of Personality and Social Psychology* 69: 797–811.

Third World Organization for Women (TWOWS). 2007. Proceedings of the International Conference on Women's Impact on Science & Technology in the New Millennium. In *International Conference on Women's Impact on Science & Technology in the New Millennium*, ed. V. Krishnan. Bangalore: Institute of Science.

UNESCO Institute for Statistics. 2007. *Science, Technology and Gender: An International Report*. Montreal: UNESCO.

U.S. Bureau of Labor Statistics. 2013. *CPS Tables, Annual Averages,* http://www.bls.gov/cps/tables.htm#annual (accessed 12 December 2013).

Valian, Virginia. 1998. *Why so Slow?: The Advancement of Women*. Cambridge, MA: MIT Press.

Wenneräs, Christine, and Agnes Wold. 1997. Nepotism and Sexism in Peer-Review. *Nature* 387: 341–343.

Wilcox, Diane. 2015. A Personal Reflection on Advancing in South African Science. In *Advancing Women in Science: An International Perspective*, ed. W. Pearson Jr., L.M. Frehill, and C.L. McNeely. New York: Springer.

Williams, Christine L. 1992. The Glass Escalator: Hidden Advantages for Men in the "Female" Professions. *Social Problems* 39: 253–267.

Vignette 3.1
Focus on Brazil

Alice Abreu

The case of Brazil is worth looking at in more detail, since at first glance women appear to have made important progress in the scientific system. Figures 3.6 and 3.7 show the percentage of M.Sc. and Ph.D. graduates by sex for the period from 1996 to 2009.

Women have been the majority of M.Sc. graduates since 1998 and the majority of Ph.D. graduates since 2004, making the famous scissors diagram change direction. As discussed in Vignette 10.3, this was the result of a consistent universal policy of support for graduate training. In 2008 women accounted for 53.9 M.Sc. graduates and 51% of Ph.D. graduates.

Between 1996 and 2008 there were 87,000 Ph.D.s graduated in all scientific areas CGEE (2010). The number of Ph.D.s conferred increased 278% between 1996 and 2008, a yearly rate of 11.9%. The large majority of the Ph.D.s graduated from public universities, either from the state system of São Paulo, or the Federal Universities. In fact, five universities, including three of São Paulo, accounted for about 60% of total Ph.D.s conferred in Brazil between 1996 and 2008. Having women as the majority of Ph.D.s graduates puts Brazil among the very few countries, which includes Portugal and Italy, where women represent the majority at this level of training. Across the EU, women earn, on average, 46% of Ph.D.s European Commission (2013) and in the United States women earned 49% of Ph.D.s in 2011.

In Brazil, as in other countries, there are considerable differences in women's participation between the scientific disciplines. In 2008 women represented a very strong majority of Ph.D. graduates in Health Science (59%) and Biological Sciences (63%), which is similar to the high rates of participation in these areas in the United States and many European nations. However, unlike the United States and some

---

A. Abreu (✉)
Federal University of Rio de Janeiro, Rua Anibal de Mendonça 28 Apto 501,
22410-050 Rio de Janeiro, Brazil
e-mail: alicepabreu@gmail.com

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_3

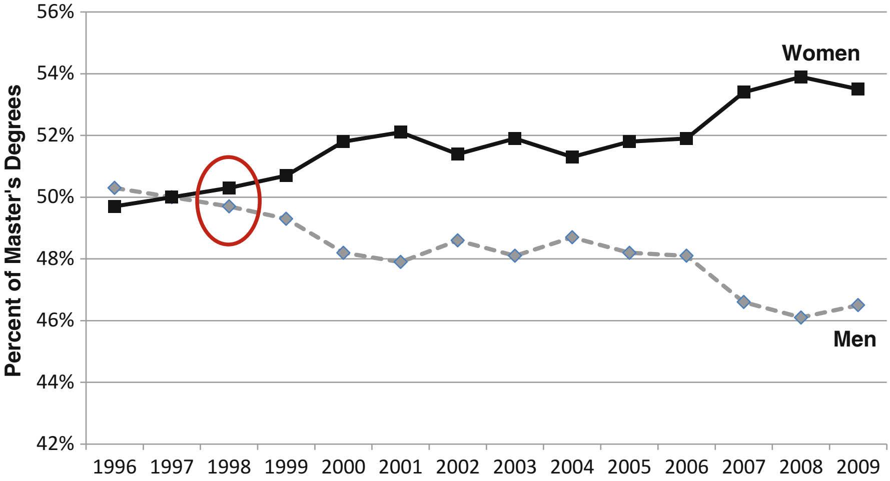


Fig. 3.6 Percent of M.Sc. degrees awarded in Brazil by sex, 1996–2009. *Source*: *Frehill*, *Lisa M. 2013. Analysis of data from CGEE 2012*

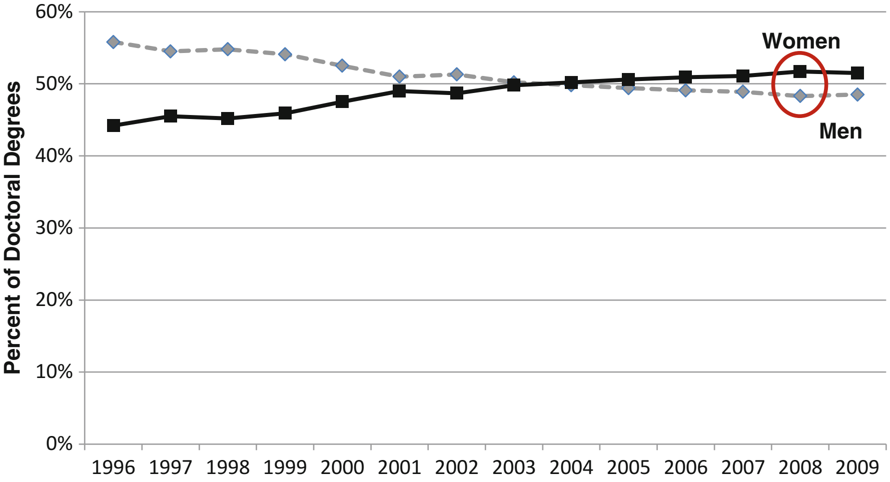


Fig. 3.7 Percent of Ph.D. degrees awarded in Brazil by sex, 1996–2009. *Source*: *Frehill*, *Lisa M. 2013. Analysis of data from CGEE 2010*

European nations, Brazilian women are more highly represented in Engineering (33%) and Exact Sciences (38%).

Looking in more detail at the three scientific areas focused by this book, mathematics, computer science, and chemical sciences, Fig. 3.8 shows that there are important differences among the Ph.D. graduates according to the subareas of those fields. In Probability and Statistics and Chemistry, women earned 50% of the Ph.D.s in 2008, with even greater representation but in Biochemistry, within the

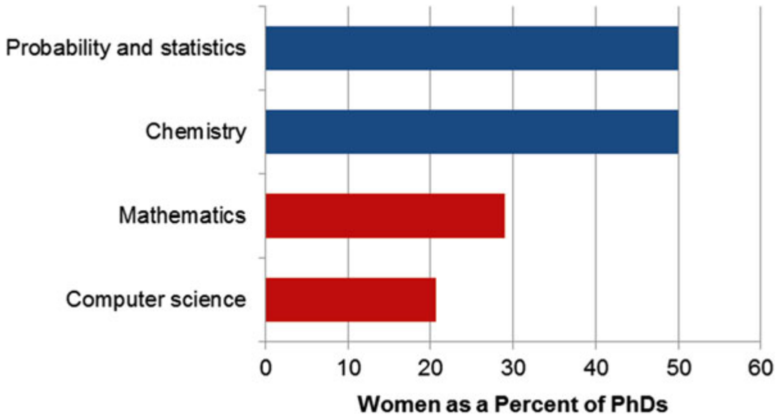


Fig. 3.8 Women as a percent of Ph.D.s in specific fields of science in Brazil, 2008. *Source*: *Frehill, Lisa M. 2013. Analysis of data from CGEE 2012*

Life Sciences, in which women accounted for 65% of Ph.D. graduates (this subfield is not shown in the chart). In Mathematics and Computer Science, however, the situation is very different; women earned only 20% of Ph.D.s graduates in 2008 in Computer Science, and just under 30% in Mathematics.

This enormous effort to qualify Brazilian scientists has had some important consequences for the S&T system in general; the overall participation of women researchers in active research groups increased from 39% in 1997 to 50% in 2010 (CNPq, Census of Research Groups 2013).

The increased number of women in the lower levels of the scientific and technological system, or even at the Ph.D. level as in Brazil, however, has not translated into increased numbers in the positions of higher prestige. For example, while women account for 50% of researchers overall, they represent just 44% of research group leaders. In engineering, even with women representing a third of new graduates a year, just 22% of research group leaders in Engineering are women (CNPq 2013).

Unlike the emphasis on tenure within US academia, tenure is not relevant to the scientific career of a Brazilian scientist. The access to the state and federal system is via public competition, which grants stability from the beginning of the work contract as a lecturer. The scientist then has to progress by merit to the different levels of the career ladder. At the highest level of the Full Professorship, another public competition is held.

Data to evaluate the position of women in the Brazilian University system as a whole are difficult to obtain, but there are some specific case studies that can shed light on this. A recent study of one of the large State universities of São Paulo, UNICAMP, shows that in 2006 women represented 34% of the total number of lecturers. They represented 42% of lecturers holding a Ph.D., but only 23.2% of Full Professors. This is however a substantial increase from the situation in 1994, when only 10.3% of Full Professors were women (Vasconcelos *e* Brisolla 2009).

Another indicator showing women's difficulty in reaching the higher positions in the system is related to the prestigious Senior Research Scholarships, a program of scholarships that supports the best researchers in the country. A very competitive process, researchers propose a 5 year project, is evaluated and reviewed at each renewal, with important expectations for resultant high level publications from the project. With five levels of excellence, women have represented only 22–23% of grantees in the highest level, with no upward trend in the last decade. So one of the big challenges for the Brazilian S&T system is to make sure that these highly trained women scientists participate fully and are involved in the highest decision-making positions of the system.

References

CGEE. 2010. *Doutores 2010: estudos da demografia da base técnico-científica brasileira (Ph.D.s 2010: Study of the Demography of the Brazilian Techno-Scientific Base)*. Brasilia: Centro de Gestão e Estudos Estratégicos.

_____. 2012. *Mestres 2012: estudos da demografia da base técnico-científica brasileira (M.Sc.s 2012: Studies of the Demography of the Brazilian Techno-Scientific Base)*. Brasilia: Centro de Gestão e Estudos Estratégicos.

CNPq. 2013. *Diretório dos grupos de pesquisa no Brasil*. Censos a partir de 2000 e base corrente (Directory of Research Groups of Brazil. Census from year 2000 and current base).

European Commission. 2013. *She Figures 2012. Gender in Research and Innovation. Statistics and Indicators*. Brussels: Office for Official Publications of the European Communities.

Vasconcelos, E.C.C. and S.N. Brisolla. 2009. Presença feminina no estudo e no trabalho da ciência na UNICAMP (The feminine presence in scientific study and work at the University of Campinas). *Cadernos PAGU* 32.

Vignette 3.2
Greetings from Italy: What Is Changing for Women and Science and Research Careers

Sveva Avveduto

According to OECD data, the Italian female employment rate is 48% OECD (2013), one of the lowest of the OECD area as well as of all Western countries. If we consider that so few women work in Italy, much is left to the imagination about the situation of women working in scientific and academic research, areas dominated by men. When in the 1990s, I started working with data and interpretation on women's condition in scientific careers in Italy, I had to face a complete underrepresentation of women in science, the relevance of gender stereotypes in any step of female scientists and researchers careers, a lack of gendered career paths and of role models. The entire academic and research systems seemed to be based on a masculine oriented model of work: heavy workload (as much as 60 h per week), exclusive dedication to research and study, selection made out of scientific affiliations preferring, in any case, men over women. Apart from the state of research and science workplace, female scientists and researchers had to face impressive family burden, due to a remarkable lack of social services for working women. In this sense, women in research and development (R&D) had to face an authentic martyr role in university classes and research labs, instead of being just a part of a scientific community building up knowledge and development.

My research and analyses focused on: (1) (unequal) access to scientific and research careers; (2) (unequal) career paths and access to career development opportunities; and (3) gender differences in the management of work/life balance. Nor did the situation prove to be better when I moved my analyses from a qualitative point of view to a quantitative one: in the European Commission 2003 *She Figures* reports the percentage of female researchers over the total workforce in R&D in Italy was 26.8%, compared to a percentage of 50.8% female graduates. The loss of human

---

S. Avveduto (✉)
National Research Council-IRPPS (Institute for Research on Population
and Social Policies), CNR-IRPPS, Via Palestro 32, 00185 Rome, Italy
e-mail: sveva.avveduto@cnr.it

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_3

capital and human potential is clear if we consider that half of the female population graduating did not consider (or did not have access to) a scientific or research career. Resilient prejudice (and sometimes self imposed prejudice) about women's abilities in science and research, barriers in hiring and promoting female scientists from the "the old boys networks", difficulties experienced in managing family and workloads within an inadequate social welfare policy system played their part in the unfair and limited representation of women in R&D.

What can we say about the current situation of women in science and research in Italy? According to the data European Commission (2013) and to the analysis, although the general framework has not changed a lot, nevertheless, the situation for women in science and research has improved. From a quantitative point of view, we can notice from the most recent *She Figures* (2012), that female scientists and researchers in Italy reached the rate of 34% of the scientific workforce in universities and labs, with an increase of 7.2% in 10 years. This fact is interesting if we compare it with the 52% representation of female Ph.D.s (all fields) in 2010 and the 50.7% of female Ph.D.s in STEM. What happened to justify this quantitative improvement in the female presence in scientific careers? Do these data reflect also a qualitative improvement in career paths and management of work/life balance? Did Italian welfare system policies for working women improved significantly in this decade?

I find that, even if in the background context only minor changes occurred, two significant trends are emerging in the R&D system. First, the Europeanization of the research system brings with it rules and procedures regarding gender equal representation. Second, there are new relationship-building tools for encouraging exchanges between experienced and young female scholars.

Regarding the first trend: the introduction of *The European Charter of Researchers and the Code of Conduct for Recruitment* European Commission (2005) represents a turning point for better gender representation. According to the principle of nondiscrimination and the principle of gender balance, quality of research and competence of researchers were matched with an equal opportunity policy for recruiting and for further career paths. The salience of the European document is such that norms for foreseeing gender quotas European Commission (2011) in the hiring and evaluation commissions were first inserted in the procedures of Italian Public Research Institutions and then extended to all hiring commissions in the Public Administration.

The Europeanization of the Research Area with the ERA acted also as a catalyst for young female scholars, who had the chance to open their research and science horizons to a wider European scenario, comparing with different research and scientific systems where female underrepresentation has provided for different policy and cultural solutions (e.g., Scandinavia, with adequate welfare policy solutions for working women and even in countries from the former USSR block, where gender equal opportunity was tied to the concept of socialist equality). The Europeanization of the Italian research and science sector is a long-term process and it is still in a complex implementation phase, but I have to recognize that it was truly significant to give impetus to gender equal opportunities in scientific careers within the national R&D system.

But what I find really interesting, as a sociologist is the path to commonly shared social practices in female mentoring. Our scientific community finally managed to ensure (albeit still few) scientists key positions in public research institutes, universities, and laboratories, and these experienced researchers showed an uncommon ability to advice and counsel early stage female scholars starting or advancing in their careers. The widely studied practice Green and Bauer (1995; Ibarra et al. 2010) of mentoring obtained special results in gender empowerment, career counseling, and excellent research achievement when female mentors meet female mentee. The sharing of a common research path is often the occasion for mentor and mentee to meet and to start a social and professional relationship that is fruitful for both sides as well as the general affirmation of gender equality. Our social responsibility as women starts here, passing of the baton to a new generation of young women scientists that will live and work in a world more open to equal opportunities for women in science, where the quality of research will be the only evaluation parameter. We hope and we work for it.

References

European Union. 2003. *She Figures 2003*: *Women and Science Statistics and Indicators*, http://ec.europa.eu/research/science-society/pdf/she_figures_2003.pdf (accessed 1 March 2014).

_____. 2005. *The European Charter for Researchers: The Code of Conduct for the Recruitment of Researchers,* http://ec.europa.eu/euraxess/index.cfm/rights/europeanCharter (accessed 1 March 2014).

_____. 2011. *The Quote-Instrument: Different Approaches Across Europe* (Working Paper), http://ec.europa.eu/justice/gender-equality/files/quota-working_paper_en.pdf (accessed 1 March 2014).

_____. 2013. *She Figures 2012*: *Gender in Research and Innovation*, *Statistics and Indicators,* http://ec.europa.eu/research/science-society/document_library/pdf_06/she-figures-2012_en.pdf (accessed 1 March 2014).

Green, S.G. and Bauer, T.N. 1995. Supervisory Mentoring by Advisers: Relationships with Doctoral Student Potential, Productivity, and Commitment. *Personnel Psychology* 48: 537–562. doi:10.1111/j.1744-6570.1995.tb01769.x

Ibarra, H., Carter, N.M. and Silva, C. 2010. *Why Men Still Get More Promotions than Women. Harvard Business Review* (September 2010), http://hbr.org/2010/09/why-men-still-get-more-promotions-than-women/ (accessed 1 March 2014).

Organisation for Economic Cooperation and Development (OECD). 2013. *Employment Rate of Women*. Employment and Labour Markets: Key Tables from OECD, No. 5. doi:10.1787/emp-fe-table-2013-1-en

Vignette 3.3

A Reflection on Advancing in the Mathematical Sciences in South Africa

Diane Wilcox

Uncertainty about one's ability to execute one's research plan can be one of the most challenging aspects of graduate student life. As a result, institutional and circumstantial hurdles can seem menacing, particularly when it takes significant discipline and perseverance to redefine one's own and society's boundaries of knowledge through some process of scientific discovery which one is still discovering.

When I graduated with a B.Sc. in 1994, women were a small minority among the candidates majoring in mathematics and in computer science. Fortunately demographics were improving. By the time I submitted my Ph.D. for examination in 2001, gender seemed less of an impediment to my progress as a mathematician than to general social interaction: it can be difficult to interact confidently with family or friends when a proof you're working on becomes more and more convoluted or when you're grappling with concepts and cannot see how pieces fit together.

I was fortunate to have been spared much overt chauvinism and did not encounter sexual harassment as a university student. Therefore, my own social challenges often seemed more idiosyncratic than symptomatic of fundamental prejudices in society (cf. Hanisch 1970). Having attained success at something less ordinary, the challenge of reintegrating to the mainstream, while continuing research, would turn out to be as difficult. Over the years, it has become easier to appreciate that barriers are an aspect of social cohesion and it takes significant emotional intelligence and mentoring to nonconform acceptably. Mathematical scientists are not best known for their EQ's and the system is not always sympathetic.

Thus, I am most thankful for friends and mentors who have offered encouragement, feedback and critical review and for generous funding to conduct and disseminate research.

D. Wilcox (✉)
School of Computational and Applied Mathematics, University of the Witwatersrand,
Private Bag 3, Wits, 2050 Johannesburg, South Africa
e-mail: Diane.wilcox@wits.ac.za

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_3

Big career highlights have included extending the theory of semi-Fredholm relations, developing the theory of Atkinson operators in a generality that had not been detailed before my first publications, the ICM2002 and graduation in December that year, and a decade more of continued discovery and new insights in financial markets, mathematical modeling and multivalued operators. The honor of being enabled to prove theorems, dissecting the applicability of theories, developing new perspectives, and meeting leading thinkers has been its own amazing reward.

As a mid-career researcher I have found pressures due to gender inequity became more acute: referral networks for women's promotion on merit are still limited and childbearing makes us less mobile to pursue promising opportunities. Coping with incongruities and hypocrisy can be perplexing and implied skepticism of one's credentials, which can be as stringent from the female camp, can cause negative feedbacks. Even the best policies do not always benefit pioneers who create precedents, while academics with comparable capacity, but more celebrated or focused contributions, may move through the ranks more quickly.

Discouraging experiences are less likely to occur once there is sufficient critical mass and South Africa's National Research Foundation has launched several initiatives to increase research output, including focus programs for women (Mouton et al. 2009). The strategy has shown success and mathematical scientists are writing more papers. There are always counter-examples. I, myself, experienced diminished output of published papers, despite a promising start. Several factors contributed to this decline including: student project supervision; evolution in research focus and associated further skills development; parenting; relocation; and time-allocation to promoting women-in-science. Thus, over-exuberant encouragement to publish has sometimes been more frustrating than motivating.

I acknowledge that I have taken on more than I could cope with at times. This sort of career error has the downside of eroding one's professional integrity by making one seem unnecessarily weak or even incompetent. Professional education now commonly includes learning how to say "no" and administrators should be vigilant of unreasonable workloads that lead to burn-out.

In a competitive environment, we all want to be distinguished. As I morphed from being a young researcher to a more established academic, I, too, have found myself "sizing up" competition from younger researchers. This highlighted how building the women-in-science network has some natural enemies within and corroborated that biases paradoxically push up the bar by which women get measured as capable or outstanding scientists (Raymond 2013).

Gender issues in STEM are complex, not least because they are subsumed by their context in greater society (Hill et al. 2010; Hyde and Mertz 2009). At a women-in-science meeting an established academic once offered some advice to younger women. Highlighting the professionalism required to be an academic, she concluded with: "you don't want to be one of those women." I was intrigued. While I'm aware people judge one another and have heard scathing gossip, I have not met a scientist who I could bin as "one of those women." Since we all have different life stories, there's little logic in expecting all women in STEM to conform to a standardized mold. Nevertheless, females are sometimes forced to curtail their personalities in professional environments, while males are less censured (Pronin et al. 2004; Rudman 1998; Bowles et al. 2007).

Unsurprisingly, I have found that developing a comprehensive and competitive research program as a leading investigator comes with fresh challenges. Good science is not a clear-cut process (Dyson 2014; Levy2010) and it takes skill and confidence to cope with the complexity of project management and work on multifaceted problems (Gladwell 2013). Discovery entails experimentation and risk. Fortunately, women have also emerged as great risk managers (Widmer 2013), giving further evidence for fairer sex demographics for the future.

Prejudice will continue to be a reality for members of marginalized minorities, particularly when obstacles are scaled or expectations are exceeded in historically elite areas, as long as we are blinkered by our biases. We've certainly made progress, but our journey is not over for a global community in which women are not just regarded as clever, but as being able and necessary to advance in science and play leading roles without being stereotyped.

Acknowledgements I thank Lisa M. Frehill, Connie L. McNeely, Willie Pearson, Jr., Cheryl de la Rey, and participants of the CPST meeting in 2009 as well as J. Castle, R. Maharaj, M.-F. Ouerdraogo, M.-F. Roy for discussions on gender matters in STEM and for the encouragement to reflect. I thank my coauthors, members of the AWMA, SAMS and SAMSA, SAWISE, and the greater women in STEM network as well as the computational finance and market risk research communities for sharing insights and discussions on academia and on the nature of research and development. As always, I am thankful to my parents for their courage to view the world rationally and am grateful for a generous support network of family and friends.

This contribution relates to my research career, which has been supported in part by the National Research Foundation of South Africa (Grant numbers 87830, 74223, and 70643) as well as other development agencies. The conclusions herein are due to the author and the NRF accepts no liability in this regard.

References

Bowles, H.R., L. Babcock, and L. Lai. 2007. Social Incentives for Gender Differences in the Propensity to Initiate Negotiations: Sometimes it Does Hurt to Ask. *Organizational Behavior and Human Decision Processes* 103: 84–103.

Dyson, F. 2014. The Case for Blunders. *The New York Review of Books* (March 6 Issue).

Gladwell, M. 2013. Complexity and the Ten-Thousand-Hour Rule. *The New Yorker* (August 21 Issue).

Hanisch, C. 1970. The Personal Is Political. In *Notes from the Second Year*: *Women*'*s Liberation*: *Major Writings of the Radical Feminists,* ed. Firestone, Shulamith and Anne Koedt. New York: Radical Feminism.

Hill, C., C. Corbett and A. St. Rose. 2010. *Why so Few*? Washington, DC: AAUW.

Hyde, J. and J. Mertz. 2009. Gender, Culture, and Mathematics Performance. *Proceedings of the National Academy of Sciences* 106 (*22*): 8801–8807.

Levy, J. 2010. *Scientific Feuds* London: New Holland.

Mouton, J., M. Ritter, and N. Boshoff. 2009. *Facing the Facts: Women's Participation in Science, Engineering and Technology*, Collaborative report published by the DST, NACI and SET4W of South Africa.

Pronin, E., Steele, C.M. and Ross, L. 2004. Identity Bifurcation in Response to Stereotype Threat: Women and Mathematics. *Journal of Experimental Social Psychology*, 40, 152–168.

Raymond, J. 2013. Most of Us Are Biased. *Nature* 495: 33–43.

Rudman, L.A. 1998. Self-Promotion as a Risk Factor for Women: The Costs and Benefits of Counterstereotypical Impression Management. *Journal of Personality and Social Psychology*, 74 (3): 629–645.

Widmer, L. 2013. Woman at Work: Why Women Should Lead Risk Management. *Risk Management* (May 1 Issue).

Chapter 4

Building Knowledge to Narrow the Gender Divide: Data and Indicators for Women in STEM and International Benchmarking

Wendy Hansen

The intent of this chapter on data and indicators was originally envisioned to identify and inventory key data for measurement of women in STEM subjects of chemistry (and other chemical sciences), computer science and mathematics (and statistics); suggest useful indicators; and explore options for international benchmarking. Over the course of the writing of this book, more thought was given to the contribution of this chapter. As a consequence, the direction moved from an inventory type exercise to an examination of some of the challenges associated with data access, collection and development of timely and comparable information for women in STEM.

The chapter begins with *Data and Indicators—Some Enduring Issues and Considerations* for women in STEM, some of which have been addressed with moderate success over the last decades. Suggestions for core data and indicators are given. Comparable data and indicators on women in STEM at the international level give a bird's eye view of women's participation and career outcomes in other economies, in other cultures. With timely and comparable indicators for international benchmarking, policy and program planners can take lessons from other countries' efforts to narrow the gender divide. In *Data Collection and Indicator Development at the International Level* efforts and data collection to promote sound international comparability are described. *Emerging Issues and Concerns* reminds the reader that progress does not always make social science research on STEM less problematic. Information technologies and the Internet may provide access to data 24/7 and at a global level, but there can be repercussions for data availability, comparability and financial consequences. Macro-data are available but gender-based discipline and sub-discipline data can be illusive and expensive. *Concluding Remarks and Observations* ends the chapter with observations and notions on what can be done to further data and indicator development for women in STEM.

W. Hansen (✉)
UNU-MERIT, Keizer Karelplein 19, 6211 TC Maastricht, The Netherlands
e-mail: w.hansen@maastrichtuniversity.nl

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_4

The focus of this chapter is on large-scale or "big" data from national and international statistical agencies and organizations but the discussions have consequences for the use of databases of different scale and origin. Examples are drawn from national and international data sources.

4.1 Data and Indicators: Some Enduring Issues and Considerations

The role of STEM for innovation and economic growth together with the globalization of science, technology and innovation (STI) activities makes it imperative that a nation has an adequate supply of highly skilled STEM professionals. A country cannot afford to waste STEM resources in a highly competitive international market for goods and services. Qualitative and timely statistics on women in STEM can inform policy and decision makers on trends and identify targets for policy intervention to alleviate gender disparity.

Timely trend data on the education "pipeline" is a key component to develop an understanding of the status of women's participation in STEM education and career outcomes. Enrolment and degree data can be used to observe changes in women's choices and achievements in postsecondary STEM programs. In the US, throughout the decade 2001–2010, women earned close to three in five bachelor degrees awarded annually and half of the bachelor degrees awarded in the field of science and engineering (S&E). S&E includes disciplines where women have a tradition of strong representation including the social sciences, psychology and biological sciences, as well as natural sciences and engineering. In mathematics/statistics, growth lagged that of men and despite the 7,248 bachelor degrees women earned in 2010 were almost one third higher (32%) than the number in 2001, their share shrank from 48 to 43%. In computer sciences the 7,306 bachelor degrees awarded to women in 2010 was 39% lower than the figure for 2001 and so their share fell from 28 to 18% (Fig. 4.1).

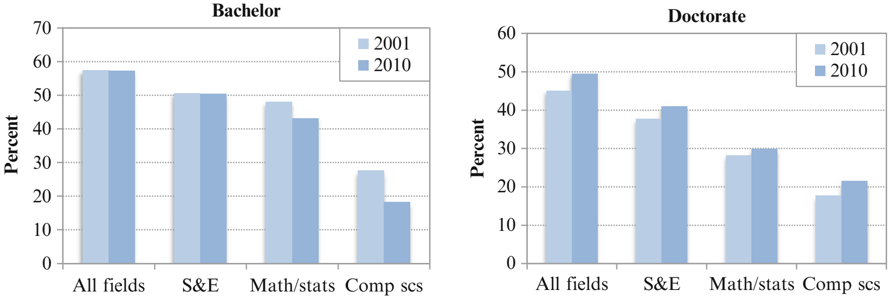


Fig. 4.1 Share of bachelor degrees and doctorate degrees awarded to women, United States, 2001–2010. *Source*: Based on data from National Science Foundation (2013)

At the doctorate level, among the fields examined, women saw their share expand over the decade. In 2010, women earned 28,397 doctorates bringing their share to half of those awarded. In the field of S&E, the 13,411 in 2010 earned by women increased their representation to 41 from 38%. In mathematics/statistics, the 476 degrees earned by women in 2010 brought their share to 30% from 28%. In 2010, women earned 336 of doctorates in computer sciences and so their share reached 22% up from 18% a decade earlier.

Data and indicators on enrolment and degrees can help identify when women are abandoning their STEM pursuits. Comparing the results for women's enrolment and graduation rates to that of men can help elucidate on the timing and reasons behind women dropping out of STEM degree programs.

International mobility patterns of STEM students can be used to observe on the quality of postsecondary institutions and their programs, and on their ability to provide a learning environment responsive to the needs of women and men equally. Host countries benefit as the reputation of their higher education system grows at the international level. They can be evaluated by their ability to attract foreign STEM students based on the quality of their universities and faculty, infrastructure, R&D support and participation of women in their STEM programs. The number of women entering Canada to study at the university level is increasing every year. The 19,325 reported in 2012 was 51% higher than in 2003 (Fig. 4.2). Despite the growth rate of men outpacing that of women in recent years, women accounted for 45% of foreign students coming to Canada to study at the university level in 2012.

Five countries (Australia, France, Germany, the UK and the US) attracted almost half of foreign tertiary level students worldwide in 2010. Seventeen percent went to the US (OECD 2010a). China and India supply the largest number of foreign students. In the US, China, India and South Korea account for almost half of the noncitizens receiving a Ph.D. (Stephan et al. 2013a). Gender disparity may accompany foreign students. For example, data for internationally mobile students from India

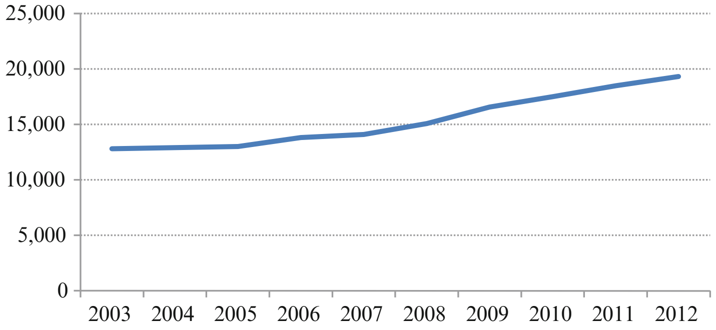


Fig. 4.2 Number of women entering Canada to study at the university level, 2003–2012. *Source*: Based on data from Canada immigration files access January 2013, http://www.cic.gc.ca/english/resources/statistics/facts2012/temporary/17.asp

suggest that around one quarter are women. Conditions in a host country and gender disparity in disciplines such as engineering (which accounts for a large share of Indian students going abroad to study) are factors to consider against these results (Mukherjee and Chanda 2012). At the doctorate level of study, although men are still in the majority of internationally mobile students, women are gaining ground (OECD 2010b).

Foreign students contribute to host countries' body of scientific knowledge and host countries can reap the economic and social benefits. If host country conditions are favourable, the student may decide to remain there for further education, research and even permanent employment. The home country gains when the student returns (if she returns) with knowledge and competences (OECD 2010c). Sending and host countries can realize additional benefits from the networks students develop while abroad. Studying abroad also provides students opportunities to gain international experience of language, entrepreneurial skills and culture, all of which are assets for doing business in a global marketplace.

Information on women's inclination to study abroad can be used to shape policies and programs to encourage women to pursue STEM studies in home and host countries. For instance, are women opting to study abroad based on a lack of high quality university programs in their desired field in their home country (push factor) or lack of research funding (push factor), or is the decision based on the reputation of the foreign university (pull factor) and an environment with narrower gender divides (pull factor)? Access to high quality facilities, funding support, culture and quality of life may factor differently for women compared with men.

Data on the transition from formal learning to workplace are used to develop indicators of women's experience relative to that of their male colleagues in STEM. Graduate surveys, first destination surveys and leaver surveys are typical sources. Longitudinal surveys that revisit the graduates over time are ideal to examine career outcomes for women in STEM but they are infrequent and gender-based discipline and sub-discipline data acquisition can be costly.

Skilled STEM professionals are mobile (geographic location, occupation, sector of employment). This raises interesting questions when it comes to the different career experiences of women and men in STEM. How does the correlation of qualification to occupation for women in STEM compare with their male counterparts? There is a role for policy to ensure women have the same career opportunities as men. The career choices of women and men have a direct impact on a nation's pool of highly qualified STEM. Supply pipeline and replacement needs will vary in magnitude for women and men but supply/demand models may not consider gender inconsistencies. When it comes to choice of occupation for example, if women are more inclined to work in a broader range of occupations compared with men, this needs to be considered in policy and program planning. Moreover, with potential for wastage of STEM higher among women than men, this has implications for supply/demand-driven policy planning.

Examination of academic rank shows the extent to which gender disparity continues. In Europe, "Since the 1990s, the majority of university graduates have been women, but an analysis of senior university staff reveals a serious dichotomy in

Fig. 4.3 Representation of women in top academic rank, selected European countries, 2004 and 2007. *Source*: Based on data from Deloitte (2012)

career outcomes for men and women, where men are three times more likely than women to reach the most senior levels." (European Commission 2008a) Countries like Romania, Latvia and Turkey show a higher probability of women reaching the top academic rank positions where research is normally carried out (based on 2007 data) (Fig. 4.3). When it comes to assessing progress, countries of Slovakia, Bulgaria, Germany and Slovenia showed the greatest increase in the percentage of women at the senior academic rank over the years between 2004 and 2007 (Deloitte 2012).

In the UK in 2009/2010, whether in mathematics or chemistry, 12% of women in permanent academic positions were at the professorial level; for men the figures were 35% and 34%, respectively (McWhinnie 2012). In Latin America, women in academia are more often found in short-term positions and lower ranks of lecturers and researchers (OECD 2006a). If women are not given the same opportunities as men, valuable STEM resources are being wasted.

The numbers are revealing but the factors prove evasive. For example, it is important to determine that the supply of qualified women in the STEM field(s) is sufficient in number to enable comparison with hiring practices for male colleagues. Is the low representation of women at the senior level in faculty due to the small pool of doctoral-qualified women available to hire from rather than inequitable hiring practices? Is the hiring of foreign faculty displacing women or are there not enough women with the necessary credentials available? In order to answer these types of questions, timely trend data at the discipline and sub-discipline level for university academic staff by rank and gender and links to other sources like degree trends, representation of foreign-sourced faculty and research funding are desirable. Lack of presence of women in STEM in university and research can have unexpected consequences. For instance, "Universities and research institutions with very low percentages of female professors could lose out in international competition for partnerships with other countries that have a greater participation of women researchers, and thus a larger pool of talent, and have thereby benefited from quality increase brought about by greater diversity". (European Commission 2008a)

Data on women's progress in the university sector, and in federal and state government departments and agencies, is important to inform public and private policy planners and decision makers so they can tackle barriers that inhibit women's participation including level of responsibility, representation in senior management and earning potential. How do the work experiences of women in academia compare with their colleagues in government and the private sector when it comes to career track, earning potential and the opportunity to have positions of responsibility? Additionally, how does the employment situation for women in STEM in government or the private sector compare with their male counterparts? How does the experience of a woman working as a computer scientist in scientific R&D services in manufacturing compare with that of men? How does it compare with their colleagues in other industries? These are the kinds of questions that need to be answered in order to develop a broader understanding of the experiences and career development of women in STEM.

Data at the industry level is important in light of women's low representation in STEM in the private sector but inherently difficult to obtain. Of particular urgency is information on women's representation in emerging areas of science and technology (S&T) that attract university/industry collaborations and venture capital funding. Are women making inroads when it comes to positions of decision-making that influence R&D funding and support?

Reasons for gender disparity in STEM are complex. Gender disparity in R&D across countries may be due to traditional hurdles in "hard science" or other socio-economic factors. For instance, it may be the relative size of a country's business enterprise sector that is a main determinant of the representation of women researchers. "… in countries where research is focused on the private sector, there are also relatively fewer women researchers than in countries where research is focused on the public sector". (European Commission 2008b) Analysis of women's representation in R&D needs to consider the relative size of the public and private sectors. The public sector is often the leader in addressing discriminatory hiring practices. The promotion of gender equality can be more readily undertaken in the public sector than the private sector. Care ought be exercised when interpreting the picture revealed by even the most complete and timely set of indicators for employment of women in STEM—socio-economic context matters.

A lack of women in management positions in research funding means men dominate decision-making at the organization or agency level. "From the perspective of political decision makers and citizens, the gender challenge concerns the accountability of the use of public funding allocated for research". (European Commission 2009) This in turn may introduce gender bias on the advice given to politicians who take counsel from their Ministry and/or departmental senior management to set and direct research funding and national research priorities. It has also been suggested that gender bias in research and management of research can affect the quality of research (The Research Council of Norway 2009). It is important to have data on the participation of women in funding of research such as applications for grants, how often women apply for research funding, their success rate and funding amounts. In addition, data on women serving on peer review committees and in positions of direct influence on funding and program decisions should be collected.

Foreign countries are important sources for nations' STEM workforce needs and international mobility of highly skilled STEM professionals has consequences for the sending and recipient countries. Identifying, gaining access and collecting information on international mobility of women in STEM can be a challenge. Information collected by administrations of postsecondary institutions and immigration files are reliable sources but gender breakdown availability is limited. In Nordic countries of Denmark, Sweden and Norway, systematic register data is a valuable source but micro-data may not be available in the public domain. Often if discipline and subdiscipline data are collected on a timely basis, they are behind closed doors due to high cost of data acquisition while in other cases, databases for gender-based STEM analyses aren't maintained.

A big motivation for improving data collection and information for women in the STEM work force is the role and contribution highly skilled STEM persons represent to a nation's competitiveness in a global market. Scientists and engineers represent valuable investments and key resources to a nation's ability to innovate and realize the socio-economic benefits. An adequate supply of STEM professionals is imperative. In the US, computer and mathematical occupations are projected to grow by 18% by 2022 and mathematical science occupations by 26%. Postsecondary teacher occupations are projected to grow by 17% (Table 4.1).

Gender-biased constraints on women's ability to participate fully in the STEM labour force limit their potential to contribute to productivity and growth. This can have particular relevance for already limited resources of developing countries. Information on labour market outcomes and career development is important to

Table 4.1 Employment of 2012 and projections to 2022, selected occupations, United States

Occupation	Projected change, 2012–2022 (%)
Computer and mathematical occupations	+18.0
Computer occupations	+17.7
Computer and information research scientists	+15.3
Computer systems analysts	+24.7
Software developers and programmers	+18.6
Mathematical science occupations	+26.1
Mathematicians	+22.7
Statisticians	+26.7
Engineers	+8.6
Chemical engineers	+4.5
Computer hardware engineers	+7.4
Life, physical and social science occupations	+10.1
Biological scientists	+7.3
Biochemists and biophysicists	18.6
Chemists and material scientists	+5.6
Chemists	+5.6
Material scientists	+5.2
Postsecondary teachers	+16.6
Mathematics and computer teachers, postsecondary	+12.0
Life sciences teachers, postsecondary	+17.2
Physical sciences teachers, postsecondary	+13.2

Source: Employment matrix Table 1.2, http://www.bls.gov/emp/ep_table_102.htm

ensure resources are not wasted because of structural barriers and biases. STEM occupation data can be used for demand indicators such as number of women employed in STEM occupations. They can be used to develop profiles of the skills mix including level of postsecondary qualification and field of specialization (discipline, sub-discipline) of persons in STEM occupations. Occupation data can be used to compare and contrast rewards for women and men in STEM as measured by salary level, academic ranking and representation in management. Table 4.2 suggests a list of data variables to develop information for women in STEM and helpful for international benchmarking indicators.

Main data sources for the data suggested in Table 4.2 include enrolment and degree surveys (administrative data), faculty surveys, labour force surveys, census, community surveys, patents and citations. There are special surveys targeting subpopulations such as graduate surveys, e.g. Careers of Doctorate Holders (CDH) and national graduate surveys of school to workforce transition. Large-scale surveys are typically carried out by or with the cooperation of national statistical agencies that develop and conduct surveys adhering to international definitions and standards. Rich databases typically reside with government departments and agencies at the national level.

Table 4.2 Variables for data collection and indicator development for women in STEM

Demographic	Age
	Country of birth
	Country of citizenship
	Country of residence
	Marital status
Education	Undergraduate degree
	Subject
	Country of degree (e.g. inform on mobility)
	Graduate degree
	Subject
	Country of degree
	Financing of studies
Labour force	Employment status
	Employed/unemployed/not looking for work
	Permanent/temporary/contract/self-employed
Occupation	Sector or employment
	Public
	Government
	Academia
	Private
	Industry of employment, e.g. manufacturing, R&D services
	Salary
	Activities, e.g. responsibilities
Employment conditions	Job benefits, e.g. health plan
	Alternative working arrangements
R&D funding engagement	Research funding application experience
	• Applications
	• Success/failures
	• Funding received (by source)
	Member of evaluation panel
	Member of peer review panel
	Member of decision-making (panel)
Other	Papers authored/co-authored
	Articles published in refereed journals
	Books published (or accepted)
	Patent applications/patents granted

Ministries and government departments and agencies provide funding and guidance to national statistical agencies as well as funding for ad hoc surveys so they can carry out their mandates. For example, in the US the Bureau of the Census, Bureau of Labour Statistics and the National Center for Education Statistics are key sources and federally funded, as is the National Science Foundation (NSF), a central actor for

STEM data and indicators for the US with a prominent role at the international level. STEM data and indicators can be found in-house across Ministries and federal departments and agencies including those with mandates for immigration and citizenship, education, labour, industry, economic development and S&T. Granting and funding councils maintain in-house databases that may contain data on grants and funding, e.g. postgraduate scholarship career outcomes, program information including undergraduate, postgraduate awards, grants by gender. Professional societies and associations survey members and can be good sources of timely data. There are other key players including research institutes within countries or across countries that make use of national sources for data and are able to enrich their information banks through funded targeted research. For example, the Institute of International Education collects and analyzes data on student mobility. One of its current projects is the development of an atlas on student mobility and includes partners from around the world from developed and developing countries[1]. Public and private funded not-for-profit research organizations can be valuable sources for data as well as networking opportunities. There is no one source of information of comparable data on women in STEM and there is no map for a systematic approach to locate existing data, indicators and studies on women in STEM. One can only wonder at the share of time and resources that are expended locating data compared with more fruitful time on the analyses and interpretation of the data.

4.2 Data Collection and Indicator Development and International Benchmarking

International benchmarking informs policy and decision makers on their progress by providing them with measures of how they are doing compared with others. And policy and decision makers rely upon international organizations like the Organisation for Economic Cooperation and Development (OECD). The OECD has been working on data collection and analyses of STI for some 50 years. Today it has 34 member countries from North America, South America, Europe, Oceania and Asia and partner countries including Brazil, China, India, Indonesia, Russia and South Africa. Together with organizations like Eurostat, the statistical bureau of the European Union, the OECD develops series of evolving manuals to collect and interpret data relating to STI. This includes guidelines for data collection, indicator development, measurement and interpretation on R&D, globalization, patents, the information society, human resources in S&T and biotechnology at the international level (OECD 2013a).

The 1995 release of *The Manual on the Measurement of Human Resources Devoted to Science and Technology*, the *Canberra* (draft) was significant for a number of reasons, not the least that it was the first OECD manual dedicated to the measurement of human resources in S&T. It provides classifications and indicator development

---

[1] http://www.iie.org/en/Research-and-Publications/Project-Atlas

guidance to encourage and improve international comparability for supply-side (e.g. education pipeline, immigration) and demand (e.g. occupation, employment/unemployment, sector of employment, mobility, financial rewards). It guides analyses of STEM data across countries with different economic and social landscapes.

The Canberra manual is noteworthy for another reason—it came about through multidisciplinary and multinational efforts of the OECD, DGXII and Eurostat of the European Commission, United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Labour Office (ILO). They recognized the need for developing ways and means to measure human actors in S&T at the international level for developed and developing countries and provided resources accordingly. The manual development brought together statisticians, subject matter experts from statistical bureaus and policy ministries, and policy analysts from around the world, all with a common goal in mind.

> The Canberra manual helped focus on the disparity of data and information on human actors in STEM as compared with, for example, R&D funding and performance and investment and brought together data experts and policy planners from developed and developing countries from around the world. "The Manual represents several years of solid international teamwork. We believe these guidelines represent an important step forward in the harmonisation of the data and in the use of HRST indicators. The guidelines will be tested in practice and then revised in light of this experience". (OECD 1995)

Yet data collection and measures for human actors in S&T continue to have lower priority than other STI elements to measure national innovation efforts. In spite of the recognition of the role of human resources in S&T in economic and social growth, almost two decades later the Canberra 'draft' manual is yet to be revisited. In contrast, the *Frascati Manual for the Measurement of Scientific and Technological Activities* receives regular updates to reflect changes in S&T such as the emergence of new fields like ICT, biotechnology and nanotechnology (sixth revision underway for 2015 release) and the OECD's Oslo Manual guidelines for innovation data has a third edition (OECD 2005). Although preliminary views on the Canberra manual's revision have been tabled (OECD 1999, 2002), in the end the Canberra Manual has not succeeded in becoming a "full member" of the OECD's guidelines that serve national policy interests and provide for international data comparability. It is available in its original form as a reference document on websites of the OECD, Eurostat, UNESCO and national statistical agency websites.

Organizations like the OECD, Eurostat and UNESCO cannot be held responsible for the inertia on international data collection and indicator development for human resources in S&T. National experts and delegates work to progress data and measures as STI evolves; they plan for and respond to the needs of their policy planners and decision makers. Priorities on data collection, indicator development and information building are guided by political pressure(s). This is how task priorities are set and budgets are allotted in organizations like the OECD and Eurostat, as well as in contributing national statistical agencies. In the end it is policy demand and political pressure for information on women and men in STEM that will ensure STEM human resources data collection and information development is entrenched in the work programs of national statistical agencies and international organizations such as the OECD, Eurostat and UNESCO.

In many countries, responsibility for postsecondary education data collection is typically at the national level and is carried out with the cooperation or support of state, provincial or regional administrations as well as the universities that remit administrative data to the national agencies. In Europe, education responsibility may lie at the province or region level as in Germany. In Italy, the universities remit university enrolment and degree data to the Ministry for Higher Education and Research, which in turn passes it to the Italian Institute of Statistics (ISTAT) for remit at the European Union level (Eurostat). Data comparability may be inconsistent across countries (regions, provinces) and takes time and resources to bring them to international classification remit requirements. Challenges of international comparisons are compounded by the need to interpret and classify data from different statistical organizations and agencies. International definitions are used for remit to international organizations like the OECD, Eurostat and UNESCO.

Resources available for STEM data collection and development are linked to national priorities and this can introduce disparities in availability in terms of scope, coverage, timeliness and access. Data availability and gaps are inherent in data sets that rely upon policy priority setting and accompanying public funding for continuity and duration. Surveys come and go based on political will and associated funding. A remarkable example is the decision of the Canadian government to cancel Statistics Canada's quinquennial "long form" Census (20% sample population). Since the introduction of discipline and sub-discipline variables in 1986 to a host of existing variables for indicator development (e.g. level of education, subject of education, age, employment/unemployment, occupation, sector of employment, earnings, citizenship, country of origin and mobility), it was a rich source of data for a range of socio-economic issues for women in STEM both for Canada and other countries. Statistics Canada discontinued its survey of university and college academic staff (fall 2012) that had discipline and sub-discipline level data for women in STEM faculties including age, previous employment, education, country of citizenship, country of earned degree, academic rank, subject taught and year of appointment for women and men in faculties across Canada. Both surveys could be tapped to explore brain gain/brain drain and a host of socio-economic benchmark indicators for women in STEM for Canada as well as other countries.

Access limitations tend to multiply when seeking data for women in STEM. Sometimes gender information is simply not available. Often it is too costly. Policies of remit organizations can limit access to aggregate level data in disciplines and sub-disciplines and availability of gender information is restricted. Limitations of confidentiality block access to micro-data. For example, it may be possible to have information on doctorate-qualified chemists working in the pharmaceutical industry and data may be available for men because of sufficient numbers whereas confidentiality restrictions block access to data on women. Complicating this, cell size restrictions vary among domestic collection agencies and across countries. Access to information on women in STEM can be a particular challenge among countries with smaller STEM population and in developing countries where information on women falls below data confidentiality thresholds.

Demand for micro-based data on women and men in STEM will continue to grow. “Against a background of growing demand for S&T workers, combined with concerns about declining interest in science among youth and an ageing workforce, policy makers are increasingly keen on tapping the other half of the human talent pool”. (OECD 2006b) 2011 macro-data reveals that women earned almost half of the OECD average of doctoral degrees (47%) (Fig. 4.4).

In some countries, indicators are that the share of women in research is growing. Table 4.3 shows that in countries of Italy, Austria, Japan and Korea, women’s

Fig. 4.4 Percentage of doctorates earned by women, selected countries, 2011. *Source*: OECD (2013b)

Table 4.3 Women researchers as a percentage of total researchers (headcount), selected countries, 2004–2010

	2004	2005	2006	2007	2008	2009	2010
Australia	..	..	..	..	..	..	..
Austria	23.6	..	25.3	26.4	..	28.4	..
Belgium	28.8	29.6	30.7	31.1	32.2	32.7	..
Canada	..	..	..	..	..	..	..
Chile	..	..	..	27.8	27.5	32.3	32.4
Czech Republic	28.5	26.8	28.5	28.3	28.5	28.9	28.1
Denmark	..	29.7	..	30.2	..	31.7	..
Estonia	..	4.8	42.4	44.3	41.7	42.5	43.4
Finland	29.0	30.2	31.6	31.5	30.7	31.4	31.9
France	27.8	28.0	27.4	27.8	27.4	26.9	25.6
Germany	..	21.3	..	23.2	..	24.9	..
Greece	..	36.4	..	..	..	..	..
Hungary	34.5	34.2	33.5	33.5	33.0	32.1	32.0
Iceland	..	39.3	38.6	37.8	37.8	41.0	..
Ireland	30.0	30.3	31.2	32.0	32.3	33.2	33.0
Israel	..	..	..	..	..	..	..
Italy	29.9	32.3	33.3	33.2	..	33.8	34.5
Japan	11.9	11.9	12.4	13.0	13.0	13.6	13.8
Korea	12.0	12.9	13.1	14.9	15.6	15.8	16.7
Luxembourg	..	18.2	..	24.1[e]	..	21.2	..
Mexico	..	..	..	..	..	..	..
The Netherlands	..	21.0	..	23.0	..	25.9	..
New Zealand	..	..	..	..	..	..	..
Norway	..	31.6	..	33.5	34.1	35.2	35.7
Poland	38.9	39.3	39.5	39.9	39.5	39.5	39.0
Portugal	4.3	44.4	43.8[e]	43.4	43.0	45.8	45.5
Slovak Republic	41.2	41.5	41.8	42.3	42.3	42.5	42.4
Slovenia	32.5	34.8	35.3	34.9	35.1	35.7	36.3
Spain	36.1	36.7	36.7	37.0	37.5	38.1	38.4
Sweden	..	35.8	..	35.1	..	35.7	..
Switzerland	26.7	..	..	..	..	30.2	..
Turkey	36.4	36.1	36.3	36.7	36.5	36.3	35.8
United Kingdom	..	35.7[e]	..	36.8[e]	..	..	37.9[e]
United States	..	..	..	..	..	..	..

Source: Based on data from Science and Technology: Key tables from OECD (2013d), 10.1787/2075843x-table3; ISSN 2075-843X

.. = Not available

e = estimate

researcher representation is on the rise. In France and Hungary, however, the representation of women in research is shrinking.

Women in research tend to be concentrated in public sector research (higher education, government) although this varies by country, by the

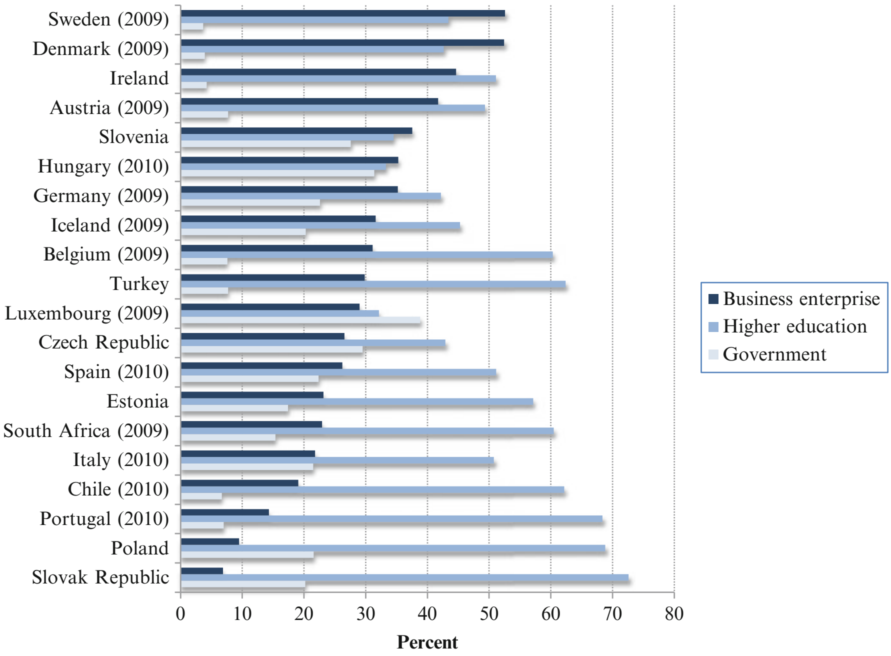


Fig. 4.5 Women researchers in higher education and business enterprise sectors as a percentage of total women researchers, selected countries, 2011. *Note*: Women researchers data are full-time equivalent (not headcount); figures do not add to 100%; private-not-for-profit figures not given in figure above. *Source*: OECD (2013d)

socio-economic-political environment. In northern European countries like Sweden and Denmark, more than half of women researchers are in the business enterprise sector whereas in Poland and the Slovak Republic, fewer than one in ten women researchers are in the business enterprise sector. Indicators for South Africa show about the same share of women researchers are in the business enterprise sector as in Italy and Estonia (Fig. 4.5).

On its own, this indicator can be used to inform on how representation of women in the business enterprise sector is growing. But context is important, and in order to develop an understanding of why this is taking place a broader socio-economic setting needs to be considered such as the supply of highly skilled women researchers, research funding and characteristics of the business enterprise sector. Women tend to be concentrated in certain disciplines and the extent to which this links to their representation in the business sector should not be overlooked.

Even with adequate political will and accompanying financial support, the time lag from survey collection to public access can be lengthy and discouraging and even more so at the international level. Responding to domestic pressures, statistical agencies may be delinquent in timeliness and completeness of remit to organizations like the OECD. “Most current available” varies across agencies and countries. In Table 4.3, empty cells were left in to show the information gaps. In some cases, the data is not available and in others the periodicity varies. Organizations like the OECD, Eurostat and UNESCO face considerable challenges when it comes to availability, completeness and timeliness of key data for women in STEM. They rely upon the cooperation, contributions and goodwill of member countries.

The value placed on Ph.D.-qualified STEM persons as drivers for innovation and concerns about brain drain/brain gain gives priority to data collection on doctorates although here too support and funding rises and ebbs over time. The OECD works with Eurostat and UNESCO on STEM doctorate degree holders' career and mobility patterns of women and men with its *Careers of Doctorate Holders* (CDH) survey. After a 2005 pilot study, large-scale surveys with 25 participating countries were conducted in 2007 and 2010. Results show although women are earning, on average, half of the new doctorate degrees across the OECD they are systematically less likely to be engaged in research (OECD 2013e). The OECD will continue to collect and disseminate statistics on the doctorate holders but the completeness of country coverage and years available is up to the contributing countries. Different countries are at different stages with the survey. Some countries will conduct the survey for the first time while others will re-conduct the survey. Other countries simply do not have the resources to participate.

Macro-data are available online as are analytic papers for labour market and mobility indicators, among others. The trouble is that micro-data remain by and large inaccessible to interested researchers (Auriol et al. 2012). Auriol et al. suggest that if these inaccessible large pools of data were made available to researchers more insights might be secured. If countries were willing to explore and share linking of databases, e.g. bibliometrics with CDH and, e.g. industry activity codes with other CDH information, measurement can move beyond benchmark indicator development. National interests need to be convinced information sharing will reap greater benefits than maintaining STEM information silos. Domestic investment in data collection can realize greater returns if cooperation can be enhanced across agencies and national boundaries.

Ad hoc studies although limited to smaller populations can be valuable sources of key and timely data on women in STEM and should be considered viable sources to explore in the quest for data. For short- and medium-term needs, fresh possibilities are offered by funded research (e.g. research organizations funded to carry out research on STEM; research funded through program financial support such as the NSF, the US National Bureau of Economic Research and the European Commission framework programs). In 2011, some 17,000 researchers in four fields (biology, chemistry, earth and environmental sciences and materials) in 16 countries were surveyed to find out what leads perspective Ph.D. students to choose one country over the other and what factors lead newly minted Ph.D.s to take a postdoctoral position in one country rather than another (Stephan et al. 2013b). Results show "that women are less likely to leave for Ph.D. training than are men … that although women are less likely to leave their home country for study abroad, conditional upon leaving, women are more likely to come to the US for Ph.D. study than go elsewhere". The challenge is to find qualitative reports, gain access to the micro-data and ensure appropriate use of the results.

4.3 Emerging Issues and Concerns

There is no doubt that the Internet brings greater than ever before ready access to data and products of statistical agencies and government departments, and research from a variety of platforms from around the world. Initially the wealth of information available via the Internet was staggering. In what seemed a relatively short time, there was online gratis and instant 24/7 access to domestic and international reports, research papers and databases provided through a range of macro- and micro-level portals including:

- Federal departments and agencies dedicated to broad data collection and analyses (e.g. national statistical agencies).
- Other federal government departments and agencies (e.g. labour, immigration, commerce, S&T).
- Funding agencies and institutions (e.g. research funders like the NSF in the US, granting councils).
- International organizations with prevailing mandates and influence such as the Directorates within the European Commission, Eurostat, UNESCO, ILO and the OECD. A supranational organization like the World Bank collects and generates socio-economic information for policy advice[2].
- State and regional public sector organizations and agencies also maintain in-house data collection and research for policy and programs.
- Research organizations like National Opinion Research Centre (NORC) (University of Chicago) are important sources of data and expertise for researchers of women in STEM. NORC conducts and generates socio-economic research in support of evidence-based policy[3]. It posts information on its research projects and provides access to data and findings on its website. Its *Center for Advancing Research and Communication* in STEM research interests include encouraging women to pursue education and careers in STEM (NORC 2013).
- University research institutes like Georgetown University's *Center on Education and the Workforce*, can house valuable data sets, generate analytic reports and provide expertise of issues, e.g. women in STEM.
- Corporate planning reports and documents can contain timely information on women in STEM, e.g. representation of women on Boards and senior management.

There are networks like the Social Science Research Network (SSRN) composed of specialized research networks in the social sciences that provide for worldwide dissemination of social science research (SSRN 2013). Along with providing access to research reports organizations like the SSRN encourage communication and networking among social science researchers.

E-documents and online databases represent tremendous potential rich sources for social science research on the socio-economic aspects of women in STEM

---

[2] http://databank.worldbank.org/data/home.aspx

[3] http://www.norc.org/

education, workplace and careers. The problem is that more often the case, although easy to access and manipulate with a range of online offerings and at no cost, often only aggregate level data is available. And this trend seems to be growing. The Nordic Council provides an online databank that contains comparable statistics for the Nordic countries including enrolment, graduates, financial support and studies abroad.[4] Free access, however, is limited to field level data, e.g. natural science, mathematics and computing science subtotal. In the UK, the Higher Education Statistics Agency (HESA 2013) provides a wealth of gratis data and indicators online, but for gender-based discipline and sub-discipline, data availability is on a cost-recovery basis. Discipline and sub-discipline level data requests for women in STEM often means direct contact with the individual agencies for special tabulations availability, timing and cost estimates.

Another model for data access is through "membership" or limited access. In Canada for example, Statistics Canada together with the Social Sciences and Humanities Research Council (SSHRC), the Canadian Institutes for Health Research, the Canada Foundation for Innovation and university consortia has set up research data centres (RDC) on university campuses across Canada. The RDC program was established to address obstacles to research in the social and health sciences including the lack of access to micro-data, and to strengthen links among social scientists and users like policy and decision makers in the public and private sector (Statistics Canada 2013). Qualified researchers have access to Statistics Canada micro-data from surveys useful for STEM gender-based research such as the National Graduate surveys with trend data on education, employment, labour and outcomes of education and intentions to stay or relocate in the US. Access is based on having a committee-approved project and the work is carried out under the auspices of Statistics Canada and SSHRC (University of British Columbia 2013) and the researcher agrees to produce a publicly available report that falls within Statistics Canada's mandate. But this raises a question. Given the Statistics Canada's mandate is itself guided by political agendas, what restrictions might this put on blue-sky thinking and social science research? The "members only" model may provide no cost micro-data access for university researchers to a wide range of data but this may result in costs beyond financial implications.

Although evidence is anecdotal, there seems to be an emerging trend toward a reduction in number and frequency of value-added analytic reports generated by national statistical agencies. Perhaps this is linked to shrinking budgets and statistical agencies are simply turning their focus to their core activities of data collection and development, but it is a worrying trend. Statistical agencies are ultimately the data experts. Their divesting of responsibilities to produce accompanying analytic reports puts the onus on users to maintain understanding and knowledge of classifications, methodologies and interpretation of the data. In turn, this can bring additional resource burden to the social science researcher community on women in STEM. A decrease in the availability of high quality analytic reports does not bode well for data collection needs outside of national statistical agencies. Professional associations dealing with

---

[4] http://91.208.143.50/pxweb/pxwebnordic/dialog/statfile1.asp

their own limited resources are being left to "go it alone" for information on their profession with waning federal government engagement and financial support. Smaller professional societies and organizations may not have the expertise and funds to conduct surveys and build in-house intelligence on their members' careers, salary, level of responsibility in the workplace, age and other career outcome indicators for policy planning and decision makers. That said, as mentioned in the previous section, research organizations and professional societies represent valuable potential sources of data for women in STEM. Smaller scale data collection can bring agility when it comes to scope, content and turnaround times. Working with the representatives can also bring intrinsic value-add. This may also come with challenges. Collection of data on smaller scales outside of federally mandated data collection activities might bring lower response and completion rates along with increased confidentiality limitations, and international comparability may be more problematic.

4.4 Concluding Remarks and Observations

The need for data and analyses on women and men who create knowledge, diffuse knowledge and apply knowledge will continue to grow. Lack of timely and comparable data and information on women in STEM compounds the challenge to develop interventions to improve hiring practices and employment conditions for women in the STEM workplace. In the absence of evidence and an understanding of the difference among the STEM public and private employment environments and without comparable information on men's experience for benchmarks, remedial actions to encourage women in STEM employment may not realize their full potential and supporting public funds may be wasted.

One aim of this chapter was to describe the importance and associated challenges of data collection, indicator development and analyses for evidence-based policy and decision-making for women in STEM. It should also serve to provoke action to respond to the need to work with comparable data and indicators for benchmarking a domestic landscape in a global community. International benchmarking of women in STEM can inform domestic policy-making and raise potential outcomes of programs designed to address gender disparity by learning from best practice policies.

Data comparability for women in STEM can be impaired by lack of common definitions, size of universe surveyed and response rate. It would be constructive to have up-to-date guidelines for measuring HRST and women in STEM at the international level to make better use of existing data and enhance comparability. Whether the data comes from national statistical agencies or researchers in the field, a set of common definitions needs to be followed. Efforts like the Canberra manual need to be supported. It would be useful to investigate the status of the Canberra manual and options for Canberra-type manual development. Perhaps there are opportunities to explore to introduce new actors to share the workload of revision and explore alternative funding sources. An updated manual could serve as a valuable teaching tool for data collection and research on STEM in developing countries.

There can be serious and long-lasting implications from policies put in place without the benefit of timely data and sound intelligence to suggest the most beneficial path. Data gaps and lack of access to data on women in STEM means that policy and planning are done by ideology and not evidence. Without reliable and timely data and information, policy planners and decision makers are in danger of being ill equipped to assess success of policies and programs targeting gender disparity. Public funds are put at risk without qualitative timely information on the outcomes.

The needs of policy planners and decision makers direct statistical agencies and political agendas prioritize their actions through provision of support and funding. As the public purse shrinks, prioritization of data collection will impact on data and indicator development for women in STEM. It is important to continue to educate and remind policy planners and decision makers on the value of data collection and indicator development for women in STEM. If you cannot track behaviour, you cannot change it. Ultimately it is political pressure that will force statistical agencies to focus their attention and resources on data collection and measurement for women and men in STEM.

Data and indicator development on women in STEM ought to be about filling additional information gaps and avoiding duplicative efforts of launching new surveys and adding to respondent burden and financial costs. A state-of-the-art assessment of data collection and indicator development is a valuable tool in funding negotiations. This could include a review of access to data and analyses on government department and agency websites at an international level and assess cost implications for aggregate, discipline and sub-discipline data requests. This could incorporate descriptions of the cost-recovery policies and other issues related to use of the data including copyright limitations.

An important auxiliary undertaking is an assessment of national and international support policies and programs for women in STEM (government, academic and private sectors). This can include information on the development and implementation of programs to address gender gaps in faculty, private sector, management of R&D and other decision-making positions. Evaluation reports of policies and programs can be useful resources for gleaning information on progress and can provide insights for measures of progress on addressing gender disparity.

Doubtless, there are data sets that are underutilized, perhaps data sets not even considered for development of indicators on women in STEM. It is easy to fault lack of new and timely data but perhaps social scientists need to be more innovative with existing data. A Blue Sky Conference (Hansen et al. 2006) presentation explored linking human resources in S&T to technology and innovation. The high correlations between persons in STEM (as measured by Ph.D.s) and technological performance (as measured by patents) suggested how existing data can be used to develop new indicators for human capital and S&T performance. This has implications for research on women in STEM. Social science researchers should be encouraged to explore the potential of links between existing databases where useful gender data may lie “buried” yet to be mined for its full potential, such as citations and patents. The extent to which existing databases can be better exploited for gender-based analyses needs to be researched. Statistical agencies should be encouraged to link databases that might result in realizing more and added value from existing data sets.

Building on work already done is an economical way of taking advantage of previous investments of time and money and expertise and a preventative measure against reinventing the wheel. The updating of substantial efforts can provide a starting point for gauging progress and also suggest paths to enhance the value of such studies as it applies to today's policy and program needs for women in STEM, e.g. the work of the Helsinki Group on Women and Science and subsequent follow-up reports. Survey methodology can be repeated for measures of progress and change; survey methodology can be exploited as a foundation for a revised survey instrument; and contributing agencies and contacts are documented. Ph.D.-qualified persons in STEM represent a critical but small segment of STEM education and workforce. Methodologies developed and lessons learned through international projects like the CDH can be used to expand coverage from a focus on doctorate-qualified STEM professionals to those with other qualifications (technicians/technologists, Bachelor's, Master's).

The challenge remains that despite the importance of STEM human resources, researchers and policy analysts need to consult a variety of data sources and are often left to cobble together intelligence from a range of surveys of differing universes, sample size, periodicity, timing and hope that international definitions and standards are adhered to so sense can be made of the harvested data and analytic reports. "… no one database collects consistent information across countries on mobile researchers and on factors affecting their decision to emigrate for training". (Stephan et al. 2013c)

Budgets are shrinking and the need for information on women is growing. A research consortium can bring together a multidisciplinary depth of skill and knowledge to the task(s). A consortium will have a "purchasing power" advantage, both in terms of attracting funding and purchasing data. Obtaining data on women in STEM at the discipline and sub-discipline level is becoming more challenging because of the costs associated with obtaining micro-data. Gender-based sub-discipline data can quickly run up costs. A consortium model may become even more attractive if "money walls" continue to appear and make access to gender-based discipline and sub-discipline level data and special tabulations cost prohibitive.

4.5 Notes

1. The data source for UK faculty (S. McWhinnie) is the Higher Education Statistics Agency (HESA); higher education institutions remit data to HESA based on subject "cost" centres for mapping for the Higher Education Funding Council.
2. Table 4.2 builds on work of S. Avveduto and W. Hansen, *Careers of Doctorate Holders—Building Comparability at the International Level*, prepared for the Expert Group on the CDH for the OECD, Montreal April 2005, http://www.

irpps.cnr.it/en/pubblications/conference-proceedings/building-comparability-at-the-international-level.

3. OECD efforts on the Canberra draft manual were led by experts on the Working Party of National Experts on Science and Technology Indicators (NESTI) of the Directorate for Science, Technology and Industry (DSTI) in consultation with other Directorates, e.g. education, labour.
4. The 2006 OECD Blue Sky conference invited experts to present on new ways and means for, e.g. measurement for STI. Work of W. Hansen, H. Hollanders, R. Tijssen and B. van Looy, *Linking Human Resources in Science and Technology and Innovative Performance, Developing Concordance Schemes and Indicators to Enable the Analysis of Education-Science-Technology-Industry Relationships*, was presented. It explored how use of existing data sets could be used to explore for indicators for STI. This type of work could also be explored for women in STEM.

Chapter References

Auriol, L., M. Misu, and R.A. Freeman. 2012. *Careers of Doctorate Holders: Analysis of Labour Market and Mobility Indicators*, OECD Science, Technology and Industry Working Papers, 2013/04, 1. Paris: OECD, http://dx.doi.org/10.1787.5k43nxgs289w-en

Deloitte. 2012 “DG Research and Innovation” in *Monitor Human Resources Policies and Practices in Research, The Researchers Report 2012 Scorecards,* 9, http://ec.europa.eu/euraxess/pdf/research_policies/121003_The_Researchers_Report_2012_FINAL_REPORT.pdf (accessed December 2013).

European Commission. 2008a. *Mapping the Maze: Getting More Women to the Top in Research*, 25. Luxembourg: Office for Official Publications of the European Communities. ISBN 978-92-79-07618-3.

_____. 2008b. *Benchmarking Policy Measures for Gender Equality in Science*, Luxembourg: Office for Official Publications of the European Communities, 14. ISBN 92-79-07619-0.

_____. 2009. *The Gender Challenge in Research Funding, Assessing the European National Scenes*, 69. Luxembourg: Office for Official Publications of the European Communities. ISBN 978-92-79-10599-9.

Hansen, W., H. Hollanders, B. Van Looy, and R. Tijssen. OECD Blue Sky Workshop 2006, http://www.oecd.org/sti/inno/37759954.pdf

HESA, http://91.208.143.50/pxweb/pxwebnordic/documents/about.htm (accessed August 2013).

McWhinnie, S. 2012. *Academic Physics Staff in UK Higher Education Institutions*. London: IOP Institute of Physics; Tables 9 and 7.

Mukherjee, S., and R. Chanda. *Indian Student Mobility to Selected European Countries—An Overview*, 15. Working Paper 365, Indian Institute of Management Bangalore India, May 2012.

National Science Foundation, National Center for Science and Engineering Statistics. 2013. *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2013.* Special Report NSF 13-304, NCF, Arlington, http://www.nsf.gov/statistics/wmpd/

Organisation for Economic Cooperation and Development. 1995. *The Measurement of Scientific and Technological Activities, Manual on the Measurement of Human Resources Devoted to S&T “Canberra Manual,”* 2. OECD/GD(95)77. Paris: OECD.

_____. 1999. *The Canberra Manual, Some Preliminary Thoughts on the Revision of the Manual on the Measurement of Human Resources Devoted to Science and Technology.* DSTI/EAS/STP/NESTI/RD(99)7 (unclassified). Paris: OECD.

_____. 2002. S*ummary Record, Item 7.* OECD DSTI/EAS/STP/NESTI/M(2002)2 (unclassified). Paris: OECD.

_____. 2005. *Oslo Manual, Guidelines for Collecting and Interpreting Innovation Data,* 4. 3rd ed. Paris: OECD.

_____. 2006a. *Women in Scientific Careers, Unleashing the Potential*, 194. Paris: OECD. ISBN 92-64-02537-5.

_____. 2006b. *Women in Scientific Careers, Unleashing the Potential,* 25, Paris: OECD. ISBN 92-64-025237-5.

_____. 2010a. *Education at a Glance 2012 OECD Indicators*, 363. Paris: OECD. ISBN 978-92-64-17715-5.

_____. 2010b. *International Mobility of Doctoral Students, Measuring Globalisation: OECD Economic Globalisation Indicators*, 138. Paris: OECD.

_____. 2010c. *Measuring Globalisation: OECD Economic Globalisation Indicators 2010*, 138. Paris: OECD.

_____. 2013a. http://www.oecd.org/sti/inno/frascati-manual-revision.htm (accessed August 2013).

_____. 2013b. *OECD Science, Technology and Industry Scoreboard 2013*, 94. Paris: OECD. ISBN 978-92-64-20500-0.

_____. 2013c. Science and Technology: Key Tables from OECD 2013. Paris: OECD. doi:10.1787/2075843x-table3; ISSN 2075-843X.

_____. 2013d. *OECD Science, Technology and Industry Scoreboard 2013*. Paris: OECD. ISBN 978-92-64-20500-0, http://dx.doi.org/10.1787/888932890884.

_____. 2013e. *Key Findings of the OECD-KNOWINNO Project on the Careers of Doctorate Holders*, 2, http://www.oecd.org/sti/inno/CDH%20FINAL%20REPORT-.pdf, http://www.oecd.org/sti/inno/CDH%20final%20conference%20report.pdf) (accessed August 2013).

SSRN (2013), http://www.ssrn.com/en (accessed October 2013).

Statistics Canada, http://www.statcan.gc.ca/rdc-cdr/ (accessed July 2013).

Stephan, P., C. Franzoni, and G. Scellato. 2013a. *Choice of Country by the Foreign Born for PhD and Postdoctoral Study: A Sixteen Country Perspective*, 97, NBER Working Paper 18809

_____. 2013b, *Choice of Country by the Foreign Born for PhD and Postdoctoral Study: A Sixteen Country Perspective*, 26. NBER Working Paper 18809

_____. 2013c, *Choice of Country by the Foreign Born for PhD and Postdoctoral Study: A Sixteen Country Perspective*, 4. NBER Working Paper 18809.

The Research Council of Norway. 2009. *Policy for Gender Equality and Gender Perspectives in Research*, 1. Oslo: RCN. ISBN 978-82-12-02668-1.

U.S. Bureau of Labor Statistics, Employment projections matrix, http://www.bls.gov/emp/ep_table_102.htm (accessed August 2013), Table 1.2.

University of British Columbia, http://data.library.ubc.ca/rdc/QnA.html (accessed August 2013).

Vignette 4.1

The Perception of Equality Between Males and Females in STEM Higher Education Opportunities Among Vietnamese Academics

Margaret Petrochenkov and Phuong Thi Thanh Nguyen

The Vietnam Education Foundation (VEF) administered an electronic survey to 745 Vietnamese students, instructors and administrators (236 females or 32% and 509 males or 68%) in selected STEM fields during May and June of 2013, followed by qualitative interviews in July 2013. The research was intended as a follow-up to reports sponsored by VEF and published in 2006 and 2007 (Van Alfen et al. 2007; Director et al. 2006). The new set of surveys and interviews sought to duplicate the questions and themes in the previous reports in order to document improvements in the situation in current higher education in Vietnam and to suggest ideas for further development. Most of the survey questions were parallel to the content of the first survey but VEF added questions dealing with the parity of opportunity for males and females in higher education.

At the request of the Ministry of Education and Training of Vietnam (MOET), VEF also added civil engineering, environmental sciences, and transport and communications to the fields already targeted in the first two reports (agriculture, computer science, physics and electrical engineering). Our respondents are not a random sample, since we surveyed and interviewed students and academics from the same Vietnamese institutions that participated in the first project and we included additional universities with an excellent reputation in Vietnam (no official ranking exists). We did not acquire the names or emails of all students, instructors or administrators in order to initiate a random sampling; the universities distributed the survey links to the departments under review, and we do not know to whom the links were sent in those departments. Nevertheless, face-to-face interviews allowed the site visitors to dig more deeply into important issues, including the situation of Vietnamese women in STEM fields.

M. Petrochenkov (✉)
Vietnam Education Foundation, Arlington, VA 22201, USA
e-mail: margaretpetrochenkov@vef.gov

P.T.T. Nguyen
Vietnam Education Foundation, Hanoi, Vietnam
e-mail: phuongnguyen@vef.gov

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_4

In 2011–2012, there were more than 23.3 million students in Vietnam; 2,204,303 or 9% of these were in higher education, and of those, 1,092,433, or 50%, were female (MOET 2012). Faculty members in higher education numbered 84,109, and of those women made up 49% of the total. However, MOET's statistics do not provide a further breakdown by field (MOET 2012). Although the government has had incentive policies in place, there are few faces of women at scientific conferences (Khanh 2012).

In VEF's Fellowship Program for Vietnamese students to pursue graduate studies in the United States, women have earned 32% of the awards. Women were overrepresented in biological and biomedical sciences (69%), agriculture (59%) and environmental sciences (57%). Only 16% of the computer scientists, 17% of the physicists, 22% of the engineers and 23% of the mathematicians were female (VEF OMS 2013). In 2012, women in the United States earned less than 30% of the doctorates in physical sciences and engineering, so, in comparative terms, the VEF percentages are not as low as one might fear (NCSES 2012, p. 4).

In the pool of respondents from VEF's online surveys, only 31% of the students, 41% of the instructors and 15% of the administrators were female. Although not a verifiable measure of Vietnamese women's participation in academe in STEM fields, other available statistics confirm that there is a glass ceiling (Khanh 2012). From 2007 to 2012 only 26% of the Associate Professorships and only 11% of the Professorships were awarded to women (VWU 2012). This total includes all fields, so it is likely that, in STEM-based fields, the percentages are significantly smaller. In 2012 the number of female Principal Investigators in research projects in Vietnam stood at 20%. Even in STEM fields, women's participation is on a par with that of men in fields of agriculture, forestry and aquaculture (51%), but remains at 33% in other fields of science and technology (GSD 2012, p. 25).

Ultimately, the Vietnamese STEM academics that we surveyed and interviewed overwhelmingly reported that males and females have equal opportunities at all levels—entering graduate school, getting financial support, becoming instructors, getting promotions to the Associate or Full Professor level and becoming administrators, at rates above 87% overall. Nevertheless, 11% of the female administrators did not think they have the same opportunity to receive scholarships or other funding to attend the university or to be promoted. Interestingly, 13% of the female instructors and 5% male instructors did not think that women have the same opportunity to be promoted to administrative positions, a significant difference in perception.

Despite this mostly homogenous sense of equal opportunity in higher education, there is a representational disparity, especially in STEM fields. However, in our interviews a few female undergraduate degree recipients in agriculture said that they found it harder to get a job (the men were employed immediately) because women are recruited for desk jobs and for positions that purportedly pay less. The women themselves stated that females are physically weaker and cannot travel to remote areas alone, nor can they work in the field, despite the large number of women seen in rice fields in Vietnam. Construction engineers insisted that women are too physically weak to work in construction, and particularly to work in the hot sun. One interviewee reported that job announcements in construction often restrict employment to men. Regionalism also impedes women's ability to travel far from home due to the perception that they must tend to their important responsibilities at home. One female instructor complained that her work load was very heavy since she had to teach, work in the lab and complete all household responsibilities.[5]

More than 20 years ago, Nelly Stromquist noted that "women are guided and eventually choose themselves to move into fields that are sanctioned by society as being 'proper' for their gender" (Stromquist 1991, p. xi). Still now, the under-representation of women in fields of S&T appears to be perceived not as a problem in Vietnam, but rather as an accepted outcome of the culturally accepted "fact" that these fields are not really suitable for women (Nguyen, nd).

References

Director, Stephen W., Philip Doughty, Peter J. Gray, John E. Hopcroft, and Isaac F. Silvera. 2006. *Observations on Undergraduate Education in Computer Science, Electrical Engineering, and Physics at Select Universities in Vietnam*. Washington, DC: Vietnam Education Foundation.

General Statistics Department (GSD). *Report on Vietnam's Census of Workforce and Employment 2011* [*Bao cao Dieu tra Lao dong va Viec lam Viet Nam Nam 2011*]. 2012. Hanoi: Ministry of Planning and Investment.

Ministry of Education and Training (MOET). 2012. *MOET Statistics 2012*, http://www.moet.gov.vn/?page=11.10&view=4446 (accessed August 26, 2013).

National Center for Science and Engineering Statistics (NCSES). Doctorate Recipients from U.S. Universities: 2011. December 2012. NSF 13-301.

Nguyen, Mai Huynh. "Women and Science" in *Dan Tri Online Newspaper*, http://dantri.com.vn/khoa-hoc/phu-nu-va-khoa-hoc-657322.htm (accessed August 31, 2013).

Stromquist, Nelly P. 1991. *Daring to be Different: The Choice of Nonconventional Fields of Study by International Women Students*. IIE Research Report. New York: IIE.

Van Alfen, N., J. Scott Neal, H. Ray Angle, Andrew G. Gamble, Jaw-Kai Wang Hashimoto, Lynne McNamara, and Phuong Nguyen. 2007. *Observations on the Current Status of Education in the Agricultural Sciences in Vietnam.* Washington, DC: Vietnam Education Foundation.

Vietnam Education Foundation Online Management System (VEF OMS). Data on program as of August 28, 2013.

Vietnam Women's Union (VWU) [Hoi Lien hiep Phu nu Viet Nam] cited by Dien Khanh "More Support for Female Scientists," *Nhan dan Cuoi tuan's Newspaper,* October 21, 2012, http://www.nhandan.com.vn/cuoituan/khoa-hoc-giao-duc/item/928902-.html (accessed August 30, 2013).

---

[5] Observations on the Current Status of Higher Education in Agricultural Sciences, Civil Engineering, Computer Science, Electrical Engineering, Environmental Sciences, Physics, and Transport and Communications at Select Universities in Vietnam" was published by VEF in July 2014.

Vignette 4.2
Women in Science: The Case of Singapore

Yu Meng

Singapore was founded as a trading port under British colonial rule in the early 19th century. In 1965, it gained independence after a short merger with the Malaysian Federation. Regardless of being an island state with no natural resources, Singapore has gained remarkable economic growth. In less than a half century, it was classified as a high-income country by the World Bank. Singapore's success is mainly attributed to the government's strategies of building and enhancing national technological and industrial capabilities (Huff 1995; Wong 2001). While human resources are the only resources the state has to carry out its strategies for the developmental goal, rare research has assessed the status of females in its science and technology (S&T) area, let alone their contributions[6]. To partially address this gap, this essay provides a snapshot about women's participation and status in S&T, which is framed in the more general cultural and societal conditions in Singapore.

Despite its highly sophisticated industrial economy and highly rated education system, Singapore is a traditionally patriarchal society where women are expected to fulfil their roles as homemakers and caregivers, especially after the national fertility rate fell below the reproduction level in the 1980s (Chua 2011; Tan 2003). While this suggests strong gendered stereotypes exist against women's pursuit for independence and professional advancement, the Singapore government has taken a number of steps[7] to promote women's participation in education and workforce

---

[6] The only exception is Yeoh and colleagues' (2004) article, but their focus is only on the geography field and thus the article does not provide a big picture of the focal issue.

[7] At the fundamental level, the Women's Charter was passed in 1961 to abolish child marriage, legalize monogamy (except for Muslims) and accord women equal rights to acquire and hold property and vote. Regarding access to education, the Compulsory Education Act passed in 2003 mandates the first 6 years of primary education as compulsory. Additionally, the bilingualism, a

Y. Meng (✉)
The Public Policy & Global Affairs Program, School of Humanities
and Social Sciences, Nanyang Technological University,
HSS-05-16, 14 Nanyang Drive, Singapore 637332, Singapore
e-mail: Mengyu2211@hotmail.com

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_4

to resolve the pressure from tightened labour force (Chua 2011), which may undermine the influence of those stereotypes. How these two forces interactively affect women's participation in the education and workforce in general, and the S&T area in particular? The following paragraphs draw on statistical data to provide some response.

In general, women perform quite well in education in Singapore. By 2011, the literacy rate for females and males was 94.4% and 98.6%, respectively; indicating much progress from that in 1965 (42.6% among women and 76.4% among men)[8]. The average length of schooling for women is 9.9 years, lagging behind men (10.9 years) by only 1 year. With respect to performance in science, an international benchmarking study, Trends in International Mathematics and Science Study (TIMSS), reveals that Singaporean students at the primary and secondary levels stand out in the science and mathematics tests[9]. Unfortunately, the results are not disaggregated by gender and thus no inference can be made on female students' participation and achievements in science and mathematics at these levels.

At the tertiary level, according to the most recent data on full-time intake in polytechnics[10], female students account for around 48%, rising from 9.5% in 1970. In universities, overall female students have outnumbered their male peers in terms of enrolment since 1980 and graduation since 1990. However, they are still underrepresented in computer science and engineering. Surprisingly, the data show there are more female than male university students and graduates in the natural, physical, chemical and mathematical sciences (Ministry of Education 2012). While more detailed information on gender contrasts in specific fields is unavailable at this point, I postulate that this is a consequence of Singapore's prioritizing biotechnology and biomedical sciences (Wong 2007) and women's preference for the bio-related fields (Ding et al. 2006; Sonnert and Holton 1995; Whittington and Smith-Doerr 2005). Nevertheless, the postulation needs verification with more specified data.

In contrast to that in education, women's progress has been slow in the general labour market and the S&T profession. According to the Ministry of Manpower

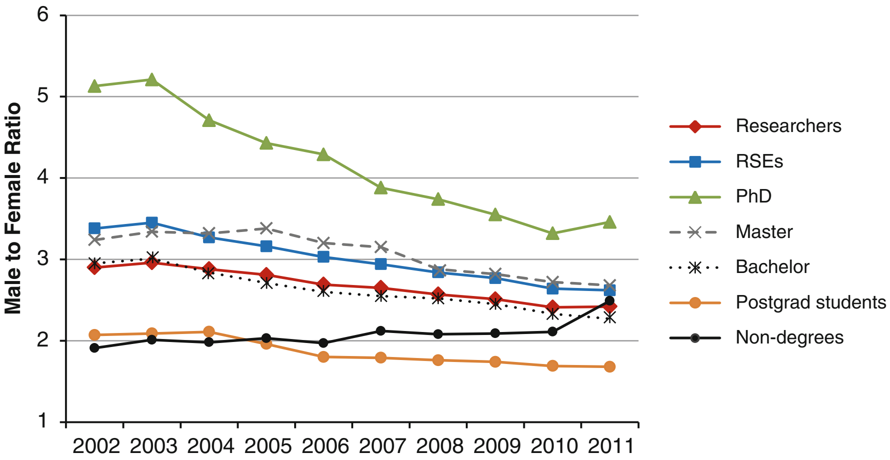
---

policy requiring the instruction in school has to be conducted in English while all students have to learn an official Mother Tongue Language (Chinese, Malay or Tamil), should equip students with the language competencies to access the advanced knowledge in science and technology. These measures are not specifically targeting females, but they tend to work under the principle of meritocracy to create more equal opportunities for both genders for at least basic training. In terms of work force participation, the Employment Act and the Child Development Co-Savings Act grant working women certain protection and benefits, such as forbidding dismissal pregnant women and providing 16-week paid maternity leave.

[8] http://www.singstat.gov.sg/statistics/latest_data.html, retrieved on July 21, 2013.

[9] http://www.timss.org, retrieved on July 21, 2013.

[10] The higher education in Singapore comprises five polytechnics (Nanyang Polytechnic, Ngee Ann Polytechnic, Republic Polytechnic, Singapore Polytechnic and Temasek Polytechnic), four universities (the National University of Singapore, the Nanyang Technological University, the Singapore Management University and the Singapore University of Technology and Design) and international private universities with campuses in this state. While polytechnics target the provision of practice-oriented and middle-level professionals, universities provide more diverse and interdisciplinary programs and courses to train students to be highly knowledgeable and creative talents.



(2012), among Singaporeans, female labour force participation (LFP) rate was 57.7% in 2011, substantially below that for men (76%). The situation is even worse considering that about 14% of the employed women (versus only 6.5% among employed men) are part-time employees, and their concentration in the lower level occupations (e.g. about 22.5% of them hired in the clerical support positions). As regards S&T profession, the absolute number of female researchers[11] doubled in the last decade from 5,517 in 2002 to 11,103 in 2011 and the share of Ph.D. earners increased steady from 10.8 to 15.7%. However, the male researchers also expanded very fast in the same period, which keeps the male to female ratio quite stable (2.9 in 2002 and 2.42 in 2011). When researchers are disaggregated by subgroups according to the educational qualification, the gender gap is biggest among those who hold doctoral degrees and smallest among the postgraduate students as Fig. 4.1 shows. A noticeable change in the figure is the narrowing gap among researchers with doctoral degrees. Again, gender-disaggregated occupational information is not available, preventing the analysis of gender disparities in various occupational positions. But the revealed gaps on educational qualification implies that female researchers are most likely to be present in lower level occupational positions and encounter more difficulties in promotion.

Women are not receiving as much remuneration as men, which is indicated in the official salary report (Ministry of Manpower 2011). As of June 2011, the median gross monthly income is S$3,099 for full-time employed women and S$750 for part-time employed women, compared to S$3,441 and S$830 respectively for men. Similarly, the salary gap between genders exists among S&T profession. For instance, on the selected S&T occupations shown in Table 4.4, women earned about 70–98% of their male counterparts in terms of median monthly gross wage in mid-2011.

---

[11] Researchers refer to all research scientists and engineers (RSEs) with doctoral degrees, master degrees and bachelor degrees, as well as postgraduate students and non-degree individuals.

Table 4.4 Median monthly gross wages of selected R&D professional occupations, June 2011

	Female	**Male**	**Female/Male**
Professionals	*4450*	*4740*	*93.9%*
Chemical engineer	6626	7875	84.1%
Chemist	3590	3752	95.7%
Civil engineer	3750	4500	83.3%
Electrical engineer	4098	4496	91.1%
Electronics engineer	4000	4673	85.6%
Industrial and production engineer	3831	5500	69.7%
Mechanical engineer	3782	4212	89.8%
Medical scientist	4570	5238	87.2%
Telecommunications engineer	5317	5414	98.2%
University lecturer	8633	11812	73.1%

Source: Report on Wages in Singapore (Ministry of Manpower, 2011), Table 1, Table 1.1, & Table 1.2

In brief, women's status in S&T education and work force is less than desirable. Yet insufficient attention has been devoted to this inequality issue. The lack of systematical gender-sensitive data at different educational levels and the workforce regarding women's participation and performance in S&T fields prohibits comprehensive analysis and monitoring of this issue. While the deficiency seems conflicting with the state's developmental goal, it reflects the cultural expectations for women in Singapore.

References

Chua, M.Y. *Women, Work and Choice Making in Singapore.* Master, Singapore: National University of Singapore, 2011.

Ding, W.W., F. Murray, and T.E. Stuart. 2006. Gender Differences in Patenting in the Academic Life Science. *Science* 313: 665–667.

Huff, W.G. 1995. The Developmental State, Government, and Singapore's Economic Development since 1960. *World Development* 23(8): 1421–1438.

Ministry of Education. 2012. *Education Statistics Digest*. Singapore.

Ministry of Manpower. (2011). *Reports on Wages in Singapore*. Singapore.

_____. 2012. *Report on Labour Force in Singapore*. Singapore.

Sonnert, G., and G. Holton. 1995. *Who Succeeds in Science? The Gender Dimension*. New Brunswick: New Rutgers University Press.

Tan, K.P. 2003. Sexing up Singapore. *International Journal of Cultural Studies* 6(4): 403–423.

Whittington, K.B., and L. Smith-Doerr. 2005. Gender and Commercial Science: Women's Patenting in the Life Sciences. *Journal of Technology Transfer* 30: 355–370.

Wong, P.K. 2001. The Role of the State in Singapore's Economic Development. In *Industrial Policy, Innovation and Economic Growth: The Experience of Japan and the East Asian NIEs*, ed. P.K. Wong and C.Y. Ng. Singapore: Singapore University Press.

_____. 2007. Commercializing Biomedical Science in a Rapidly Changing "Triple-Helix" Nexus: The Experience of the National University of Singapore. *Journal of Technology Transfer* 32: 367–395.

Vignette 4.3

Pakistani Women Scientists: Promises and Constraints

Jamil Afaqi

> *"Would you tell me, please, which way I ought to go from here?"*
> *"That depends a good deal on where you want to get to." said the Cat.*
> *"I don't much care where –" said Alice.*
> *"Then it doesn't matter which way you go," said the Cat.*
>
> —*from Alice in Wonderland*

Lahore, Pakistan's second most populous metropolitan area and famous for its historical buildings set in the traditions of Mughal and Gothic architectural styles, has recently added to its architecture an elegant multi-levelled structure whose stylish dark grey exterior attracts the attention of onlookers, particularly tourists. The building houses Arfa Software Technology Park (ASTP), named after Arfa Karim, the computer prodigy who had the distinction of being the youngest Microsoft Certified Professional in 2004, at the age of nine. She later died of cardiac arrest and the resultant brain damage in 2011 at the age of 16 (PITB 2013). This was almost the same period when another very young Pakistani girl, Malala Yousefzai, living up north in the war-torn region of Swat, was writing and speaking in favour of women's right to education, an "offense" for which she would soon get a bullet in her head from those she dared to challenge (CNN 2013).

Together, Arfa Karim and Malala Yousefzai stand as emphatic reminders of the resilience of that segment of Pakistani society called *woman*—constituting 48.5% of its total population, out of which 22% over the age of ten now work outside the home (PCST 2013). Flocks of young women can be seen entering the corridors of professional colleges and universities every morning, some wearing head covers,

---

J. Afaqi (✉)
259-A, Govt. Officers Residences—V (GOR-V), Faisal Town, Lahore, Pakistan
e-mail: j.afaqi@gmail.com

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_4

others clad in traditional *chaaders* and *burqas* covering their entire bodies, and still others wearing jeans and T-shirts. According to Mariam Sultana, the first Pakistani women to get a Ph.D. in Astrophysics, “in the University of Karachi, almost 70% of enrolled students are female and [only] 30% are male. In this kind of a situation, being a female always brings a positive edge”.

However, statistics depicting the larger picture of Pakistani society present a more sombre image. According to the *Science and Technology Data Book* developed by Pakistan Council for Science and Technology in 2009, women lag behind men in almost all fields of science by a wide margin. In the premier national research and development laboratories managed by the Pakistan Council of Scientific and Industrial Research (PCSIR), only 30% of the researchers are female (PCSIR 2013). Indicators related to the impact of research also do not paint a very encouraging picture. The cumulative *Impact Factor* for female researchers for the period 2004–2010 is 11.14 and the *Citation Index* for female researchers for the same period is just 10.03 (PCST 2013).

Casting a wider glance on women’s presence on the landscape of Pakistani science and technology, they are found particularly marginalized in the fields of engineering (13%) and in agriculture sciences where they constitute a meagre 9% of the total research force. The proportional presence of women is comparatively healthier in the fields of natural sciences (33%) and in medical sciences (36%). Among the total Ph.D.s in the fields of science and technology, just 16% are women, while those holding the post of professor in the institutions of higher education are a bare 15%. Another interesting trend, however, holds our attention when we examine the proportion of women among lecturers, which is 40% (PCST 2009). This big climb in the numbers of young female lecturers assumes greater significance when we take into account the fact that most of the institutions of higher learning in the fields of science and technology in Pakistan are co-educational with a majority of male enrolment.

The patterns of female presence in the field of science in Pakistan cannot be analysed without taking into account the overall structure of Pakistani society and the place of women in it. Despite a pronounced trend toward urbanization, Pakistan is still predominantly a traditional culture with a social structure based on strong patriarchal values. The ultimate goal of every young woman in such a society is often to get married and have a family. Her educational priorities, in such a case, are guided by the twin aims of gaining knowledge (in order to be a good partner and an able mother), as well as for acquiring a qualification which may enable her to adopt a career that is less demanding in terms of time and can be pursued side-by-side with household work. Hence teaching, medicine, and laboratory research are preferable to more arduous on-the-ground pursuits of an engineer or an agricultural scientist. The motive to get a job is not so much to be economically independent as it is to contribute toward the better future of one’s children. As one study points out, women “spend 97% of their income and savings on their families, more than twice as much as men who spend 40% on their families” (PCST 2013)

Caught between the aspirations for personal development through education on the one hand, and ultimate realization of that development in the ideal of a happy and economically prosperous family life on the other, the Pakistani woman scientist has assumed a double responsibility with a disproportionate burden of work on her shoulders. In the long run, how the Pakistani society corrects this imbalance and creates more incentives for women to invest their talent in conducting science will determine, in large part, the future of science in Pakistan, the sixth most populous country of the world.

References

CNN, http://www.cnn.com/2013/07/17/world/asia/pakistan-taliban-malala (accessed August 18, 2013).

Notes of Life, *Economic Survey of Pakistan—2012–13*, http://www.aamirilyas.com/economic-survey-of-pakistan-2012-13-pdf/ (accessed July 25, 2013).

Pakistan Council of Scientific and Industrial Research, http://www.pcsir.gov.pk/ (accessed August 20, 2013).

Pakistan Council for Science and Technology. 2009. *Science and Technology Data Book 2009*, http://www.pcst.org.pk/wst/wst_wsci.php (accessed August 10, 2013).

Punjab Information Technology Board, http://www.pitb.gov.pk/ (accessed August 20, 2013).

Qadeer, M. 2006. *Pakistan: Social and Cultural Transformations in a Muslim Nation*. New York: Routledge.

Science Blogs. 2012. *The First Pakistani Woman PhD in Astrophysics: Exclusive Interview with Maryam Sultana*, http://scienceblogs.com/startswithabang/2012/10/04/the-first-pakistani-woman-phd-in-astrophysics-exclusive-interview-with-mariam-sultana/ (accessed August 12, 2013).

Part II
Exemplar Disciplines

Chapter 5
International Status of Women in the Chemical Sciences

Lisa J. Borello, Robert Lichter, Willie Pearson, Jr., and Janet L. Bryant

Globally, the participation and advancement of women chemical scientists as they progress through higher education and their careers continue to lag behind those of their male colleagues (National Science Foundation (NSF), National Center for Science and Engineering Statistics (NCSES) 2013a, 2013b, 2013c; NSF NCSES 2012; National Research Council (NRC) 2007, 2010b; Marzabadi et al. 2006; NRC 2006a; Royal Society of Chemistry 2008). Gender disparities also persist in pay, promotion rates, access to certain areas of specialization in research funding and engagement, and key leadership positions. The issue has become one of increasing concern among many nations that frame the underrepresentation of women in chemistry and other science, technology, engineering, and mathematics (STEM) fields as a threat to their country's global economic competitiveness (National Science Board 2012; NSF, Committee on Equal Opportunities in Science and Engineering (CEOSE) 2011; Osborn et al. 2000; Organisation for Economic Co-operation and Development (OECD) 2007; Goulden et al. 2009; Pearson and Fechter 1994). In the United States, despite maintaining global leadership in chemistry for some time, increased competition from Germany, the United Kingdom, Spain, Italy, and some Asian countries—all of which are all making more-strategic investments in chemistry research and in training—pose a growing concern for policy-makers and employers (NRC 2006b).

L.J. Borello (✉)
Kansas State University, Manhattan, KS 66506, USA
e-mail: lborello@ksu.edu

R. Lichter
Merrimack Consultants, LLC, Great Barrington, MA 01230-0963, USA

W. Pearson, Jr.
Georgia Institute of Technology, Atlanta, GA, USA

J.L. Bryant
Pacific Northwest National Laboratory, Richland, WA 99352, USA

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_5

While increasing the participation of and leadership by women in STEM fields is vital for all the reasons discussed in this volume, it is especially critical in the chemical sciences for two important reasons. First, the fundamentals of the chemical sciences underpin advances in many other scientific and technical arenas: biology, materials, electronics, environmental sciences, and more. Second, chemical scientists work in a variety of settings, not just in those specific to their disciplines. Thus, in addition to recruitment, *retention* of talented women in the chemical sciences is of equal importance. While women have made numeric gains in earning undergraduate degrees in chemistry as in most other science fields, they are lost at each rung along the career ladder, with many highly trained women opting out of careers in chemistry altogether (Marzabadi et al. 2006; UK Resource Centre for Women in SET and RSC 2008; National Science Board 2010). However, owing largely to data limitations across the globe, much has remained unknown about the status of women chemical scientists on a global level, in both educational attainment and career outcomes.

5.1 Background and Purpose

Originally, this chapter intended to provide an overview of the status of women chemical scientists in an array of nations and regions. However, as work proceeded, it became apparent that substantial challenges exist in uncovering systematic and uniform data on the status of women chemical scientists on an international level that can be analyzed in a meaningful way. The main origins of these challenges are twofold. The first, which is not unique to the chemical sciences, lies in the disparate nature, degree of completeness, disciplinary disaggregation, assignment of responsibility, and methodological inconsistency of data collection across regions. No sole entity seems to be responsible for systematically gathering and analyzing global data on education and labor market trends not only in the chemical sciences but also for most STEM fields. For this reason, data from populous countries such as China and India, which produce and employ significant numbers of chemists, could not be included. Second, no agreed-upon operational definition of a chemist exists. For many, “chemical sciences” generally includes chemistry and closely related sciences that are grounded in fundamental chemical principles. These may include, for example, biochemistry, materials sciences, biophysical chemistry, chemical biology, and some areas of nanosciences. In some cases, these fields are considered separately; in others, they may be subsumed in chemistry, biology, physics, or even some engineering fields. These differences make cross-national comparisons challenging. Furthermore, because people who call themselves chemists may work in a variety of settings, they can often be overlooked in data-collection activities.

Nonetheless, within these limitations, this chapter provides an exploratory cross-national discussion of the status of women in the chemical sciences. In particular, the chapter explores existing and possibly unique structural and cultural factors that both hinder and facilitate women’s international participation and advancement to positions of leadership in the chemical sciences. Specifically, the chapter addresses the topics of undergraduate and graduate education in the chemical sciences, the chemical workforce, and professional recognition. Because data for women of minority status, as defined in the context of the region, were not broadly available, corresponding discussion was limited to the United States. The large gaps in available data, however, mean that important topics specific to women chemical scientists must remain unaddressed in an informed way, with attendant political, legal, social, and indeed scientific consequences. As acknowledged in the *She Figures* Report (European Commission 2009), without reliable statistics, there can be no accompanying policy. Thus, the results presented in the heart of this chapter have to be viewed as preliminary steps along the pathway to collect essential data in a way that allows comprehensive cross-national and cross-cultural comparisons, so that meaningful conclusions leading to actionable outcomes can emerge.

5.2 The United States

Because of the availability of more-systematic data, we begin with a more-detailed study of the United States to provide a statistical portrait of women studying chemistry at the undergraduate and graduate levels, and their participation in academia and in postdoctoral appointments.

5.2.1 Minority Women

The definition of "minority" depends on global location and historical context. Outside of the United States, it is difficult to locate published data regarding minorities (by any definition) in chemistry or even in science in general, although limited data for the United Kingdom exist (see later in this chapter). For example, a search of the OCLC WorldCat identifies only US-based publications. This section uses the NSF definition of racial/ethnic minorities: African Americans, Hispanics, Native Americans, Asian/Pacific Islanders, and Alaskan Natives.[1]

5.2.1.1 Undergraduate Degrees

Table 5.1 presents summaries of the bachelor's (undergraduate) degrees awarded to women US citizens and permanent residents in chemistry and chemical engineering in the snapshot years 2001, 2005, and 2011. The table also disaggregates the numbers and percentages of degree holders by race and ethnicity. The comparison among the three snapshot years is arbitrary and does not always reflect variations in

---

[1] Note that racial/ethnic minorities *underrepresented* in the chemical sciences do not include Asians, whose numbers dominate the data for Asian/Pacific Islanders. For a historical and biographical study of African American women chemists who have been historically underrepresented in the field, see Jeanette Brown's (2011) *African American Women Chemists.*

Table 5.1 Chemistry and chemical engineering bachelor's degrees awarded to women US citizens and permanent residents by field and race/ethnicity: 2001, 2005, and 2011

	Chemistry			Chemical engineering		
	Year					
Race/ethnicity	2001	2005	2011	2001	2005	2011
All	4,594	4,930	6,023	1,941	1,643	2,082
White	2,983 (64.9%)	3,168 (64.3%)	3,617 (60.1%)	1,229 (63.3%)	1,064 (64.8%)	1,322 (63.5%)
Asian/Pacific Islander	590 (12.8%)	614 (12.5%)	932 (15.5%)	298 (15.4%)	224 (13.6%)	335 (16.1%)
Black	513 (11.2%)	508 (10.3%)	581 (9.6%)	194 (10.0%)	152 (9.3%)	114 (5.5%)
Hispanic	357(7.8%)	417 (8.5%)	499 (8.3%)	157 (8.1%)	147 (8.9%)	197 (9.5%)
American Indian/ Alaska Native	23 (0.5%)	32 (0.6%)	28 (0.5%)	9 (0.5%)	14 (0.9%)	12 (0.6%)
Other/unknown	128 (2.8%)	191 (3.9%)	366 (6.1%)	54 (2.8%)	42 (2.6%)	102 (4.9%)

Sources: NSF NCSES (2013a, Table 5-4); NSF NCSES (2013b); Department of Education/ National Center for Education Statistics: Integrated Postsecondary Education Data System (IPEDS) Completions Survey by Race; special tabulation from NSF's WebCASPAR (https://webcaspar.nsf.gov/), July 2013

the numbers during the intervening years. The original data should be consulted for a more-comprehensive examination.

Overall, the numbers of undergraduate chemistry degrees earned by women increased by 31.1% between 2001 and 2011. While the 21.7% increase in American Indians/Alaskan Natives over that time span is an artifact of the small absolute numbers, increases for Asian/Pacific Islander (58.0%), Hispanic (39.8%), White (21.3%), and Black (13.3%) women are meaningful and, in fact, represent a monotonic increase over the 11-year period. Noteworthy is that while White women continue to earn the majority of all undergraduate chemistry degrees awarded to women, the categorical percentages decreased or remained relatively flat from 2001 to 2011. Data on undergraduate degrees in biochemistry are not included in the NSF dataset.

In contrast to the increase in chemistry bachelor's degrees awarded to women, Table 5.1 shows that the numbers of chemical engineering degrees awarded to women in the same period remained relatively flat. Hispanic and Asian/Pacific Islander women display 25.4% and 12.4% increases, respectively, while White women show a 7.6% increase and Black women a striking 41.2% decrease.

5.2.1.2 Graduate Enrollment and Degree Trends

Master's Degrees

Compared to the numbers of bachelor's and doctoral degrees, the overall numbers of master's degrees awarded in the chemical sciences, shown in Table 5.2, continue to be small, primarily because historically it has not been widely pursued. Data for

Table 5.2 Master's degrees awarded to women, US citizens/permanent residents 2001, 2005, and 2011 by field and race/ethnicity

	Chemistry			Chemical engineering		
	Year					
Race/ethnicity	2001	2005	2011	2001	2005	2011
All	559	639	723	208	226	233
White	375 (67.1%)	432 (67.6%)	428 (59.2%)	113 (54.3%)	124 (54.9%)	130 (55.8%)
Asian/Pacific Islander	77 (13.8%)	77 (12.1%)	108 (14.9%)	46 (22.1%)	31 (13.7%)	47 (20.2%)
Black	42 (7.5%)	38 (5.9%)	61 (8.4%)	19 (9.1%)	24 (10.6%)	15 (6.4%)
Hispanic	30 (5.4%)	39 (6.1%)	51 (7.1%)	15 (7.2%)	19 (8.4%)	19 (8.2%)
American Indian/ Alaska Native	4 (0.7%)	3 (0.5%)	1 (0.1%)	1 (0.5%)	2 (0.9%)	1 (0.4%)
Other/unknown	31 (5.5%)	50 (7.8%)	74 (10.2%)	14 (6.7%)	26 (11.5%)	21 (9.0%)

Sources: NSF NCSES (2013a, Table 6-4); NSF NCSES (2013b); Department of Education/ National Center for Education Statistics: Integrated Postsecondary Education Data System (IPEDS) Completions Survey by Race; special tabulation from NSF's WebCASPAR (https://webcaspar.nsf.gov/), July 2013

the first 5 years of the covered period show a steady increase in the numbers of White women receiving master's degrees, which remains relatively level during the second 5-year period. The reverse pattern is displayed for Black, Asian/Pacific Islander, and Hispanic women. Percentage changes in the numbers of chemistry master's degrees awarded from 2001 to 2011 range from a 14.1% increase for White women to a 75% decrease for American Indians/Alaskan Natives, although the latter, like those for bachelor's degrees, is an artifact of the small absolute numbers. The remaining percentage changes include Asian/Pacific Islanders (40.3), Blacks (45.2), Hispanics (70.0), and Other/Unknown (138.7), with a 29.3% increase for all women. NSF does not report data on the race, ethnicity or nation of origin of non-US citizens earning science and engineering (S&E) degrees. NSF also does not provide data on those who earned master's degrees in biochemistry, only enrollment figures.

In chemical engineering, women in total exhibited an increase of 12.0% in the number of degrees awarded during the reported period, and indeed the total variation from the 2001 number over that period was only ±8.8%. The relatively small numbers for the other populations make the percentage changes between 2001 and 2011 statistically less meaningful. As in the chemistry data, the absolute numbers of American Indian/Alaskan Natives are vanishingly small, ranging from zero to two over the 11-year period.

Table 5.3 Chemistry and chemical engineering doctoral degrees awarded to women and men: 2001, 2005, and 2011 (number and percentage)

	Chemistry			Chemical engineering		
	Year					
Gender	2001	2005	2011	2001	2005	2011
Both	2,134	2,226	2,685	680	872	951
Women	719 (33.7%)	770 (34.6%)	1,047 (39.0%)	162 (23.8%)	205 (23.5%)	280 (29.4%)
Men	1,415 (66.3%)	1,456 (65.4%)	1,638 (61.0%)	518 (76.2%)	667 (76.5%)	671 (70.6%)

Sources: NSF NCSES (2013a, Table 7-1, 7-2, 7-3); NSF NCSES (2013b); Department of Education/National Center for Education Statistics: Integrated Postsecondary Education Data System (IPEDS) Completions Survey by Race; special tabulation from NSF's WebCASPAR (https://webcaspar.nsf.gov/), July 2013

Doctoral Degrees

Table 5.3 shows the number and percent of women and men earning doctoral degrees in chemistry and chemical engineering in 2001, 2005, and 2011. The increase in the numbers of women in both disciplines who received doctoral degrees in 2001 and 2011 (45.6% and 72.8%, respectively, in chemistry and chemical engineering) is substantially greater than the increase in the total number of degrees awarded (25.8% and 39.9%, respectively) and the number of degrees awarded to men (15.8% and 29.5%, respectively). All disciplines display a steady increase in the numbers over the 10-year period, except for men in chemical engineering, whose numbers remained more or less flat during the second 5-year period.

It should be noted that these figures are not disaggregated for citizenship status. Additionally, NSF does not does not disaggregate publicly available data by race/ethnicity within each of the specific disciplines; rather, it provides racial-ethnic data on "physical sciences" (which includes chemistry, physics, astronomy, and "other") and "engineering" (all engineering disciplines).

5.2.1.3 Postdoctoral and Academic Appointments

An NRC report (NRC 2006c) claims that while postdoctoral appointments in the United States have grown over time, women's representation, relative to their degree production, has not increased accordingly. The report attributes this to insufficient advising or mentoring during graduate school, individual preferences of career goals, and bias against female applicants.

Table 5.4 compares the total numbers of women and men postdoctorates in biochemistry, chemistry, and chemical engineering for 2001, 2010, and 2011, for both foreign postdocs and those who were US citizens and permanent residents. The percentage of women US citizens and permanent residents in 2001 and 2011,

Table 5.4 Biochemistry, chemistry, and chemical engineering postdoctoral feslows, by sex and citizenship: 2001, 2010, and 2011[a]

	Biochemistry			Chemistry			Chemical engineering		
Sex	2001	2010	2011	2001	2010	2011	2001	2010	2011
All citizenship categories	2,552	2,533	2,312	3,864	4,241	4,018	574	1,092	1,137
Women	907 (35.5)	997 (39.4)	884 (38.2)	810 (21.0)	986 (23.2)	886 (22.1)	111 (19.3)	234 (21.4)	264 (23.2)
Men	1,645 (64.5)	1,536 (60.6)	1,428 (61.8)	3,054 (79.0)	3,255 (76.8)	3,132 (77.9)	463 (80.7)	858 (78.6)	873 (76.8)
US citizens and permanent residents	1,057	1,164	1,006	1,241	1,682	1,541	132	454	462
Women	407 (38.5)	508 (43.6)	422 (41.9)	317 (25.5)	426 (25.3)	377 (24.5)	37 (28.0)	96 (21.1)	96 (20.8)
Men	650 (61.5)	656 (56.4)	584 (58.1)	924 (74.5)	1,256 (74.7)	1,164 (75.5)	95 (72.0)	358 (78.9)	366 (79.2)
Temporary visa holders	1,495	1,369	1,306	2,623	2,559	2,477	442	638	675
Women	500 (33.4)	489 (35.7)	462 (35.4)	493 (18.8)	560 (21.9)	509 (20.5)	74 (16.7)	138 (21.6)	168 (24.9)
Men	995 (66.6)	880 (64.3)	844 (64.6)	2,130 (81.2)	1,999 (78.1)	1,968 (79.5)	368 (83.3)	500 (78.4)	507 (75.1)

Sources: NSF NCSES (2009, Table G-2); NSF NCSES (2013a, Table 8-1); NSF NCSES (2013b); NSF NCES (2013c)

[a] Numbers in parentheses are percent of totals for each citizenship category

respectively, increased by 3.4% points for biochemistry, remained relatively constant for chemistry, and decreased by 7.2% points for chemical engineering. By contrast, the number of men decreased or was relatively constant in all citizenship categories except for US citizens and permanent residents in chemical engineering.

The data in Table 5.4 do not display easily discernible trends. The slight decrease in numbers of women and men postdoctoral fellows in biochemistry and chemistry between 2010 and 2011 contrasts with the numbers for chemical engineering, which shows a slight uptick. In all cases, however, the percentages remain relatively flat. The data in Table 5.4 also reinforce the observation that postdoctoral positions in all three disciplines for both genders continue to be dominated by non-US citizens.

For comparison, Table 5.5 displays the postgraduation status of those 2010 doctoral recipients in chemistry and chemical engineering who had definite employment plans in academia and industry (NSF NCSES 2011). The data do not give the types of academic or industrial positions. While the percentages of employed women and men chemistry degree recipients do not differ markedly (18.3% vs. 16.4%, respectively), the divergence is greater for employed women and men chemical engineering degree recipients (33.2% vs. 26.3%, respectively). Still, a smaller

Table 5.5 Postgraduate employment outcomes of doctoral recipients in chemistry and chemical engineering, 2010, 2011

	Chemistry						Chemical engineering					
	Year											
	2010			2011			2010			2011		
	Total	Women	Men	Total	Women	Men	Total	Women	Men	Total	Women	Men
No. degrees	2,306	863	1,443	2,439	922	1,515	821	247	574	826	258	567
No. employed	395	158	237	453	174	279	233	82	151	262	68	194
Academic	118	74	57	116	50	66	23	7	16	20	ND	ND
Industrial	222	61	148	287	103	184	189	66	123	225	61	164

Sources: NSF NCSES (2011, Table 59 and 63); NSF NCSES (2013b)
ND Data suppressed to avoid disclosure of confidential information

percentage of both women chemical scientists and chemical engineering doctoral degree recipients (6.9% and 10.0%, respectively) took employment than did men (10.3% and 18.4%, respectively). Of the total number employed, women comprise 40% of the chemists and 35.2% of the chemical engineers.

A significantly greater percentage of employed women chemical scientists accepted academic positions than did men (46.8% vs. 24.1%), in sharp contrast to those who moved into industrial position (38.6% vs. 62.4%). By contrast, the gap between women and men chemical engineering degree recipients choosing academic and industrial positions is much narrower (8.5% and 10.6%, respectively for academia, and 80.5% and 81.5%, respectively, for industry). These percentages are close to the total for academia and industry (9.9% and 81.1%, respectively). Ceci and Williams (2011) attribute women's underrepresentation in the applicant pool for tenure-track positions as partially linked to women's own preferences in terms of opting for greater work-life balance in their careers over demands of the tenure clock, which are largely inconsistent with plans to have a family.

Faculty Representation

The discussion in this section is based on data on academic departments that NSF characterizes as the "top 50" in research expenditures. Many factors, including how departments are designated, influence those numbers, which can fluctuate annually and hence result in minor changes in the composition of the list. Hence, it is necessary to exercise caution in drawing general conclusions from this limited sample.

A recent *C&E News* survey (Rovner 2011) found that only 13 of the 50 chemistry departments have achieved 20% or more women faculty members in all ranks combined in 2010–2011, compared with 12 in the previous academic year. Although a number of departments are reported to be taking this challenge seriously (including some not covered in the survey), attrition and tenure remain persistent problems (Rovner 2011). In 2010–2011, women comprised 27%, 22%, and 13% of assistant, associate, and full professors, respectively (17% overall) in these departments. In chemical engineering, women held 12.9% of faculty posts at the same universities, but comprised only 8.3% of those in the full professor level. For comparison purposes, in 2007, White males held 74.8% of all positions in those chemistry and comprised 69.6% of those on chemical engineering faculties (Nelson and Brammer 2007, 2010; Nelson 2007). Minority women continue to be dramatically underrepresented on the faculties of the chemistry departments surveyed (Nelson 2007); representation of Black females change from one to three between 2002 and 2007, and Hispanic females grew from five to nine in that same period. No Native American women were faculty members in the departments in 2007. Overall, the study shows very few US-born minority women made gains in achieving full professorship.

The disparities in women faculty by rank are most glaring at the full professor level and in high-level leadership positions, such as department chairs, deans, and endowed chairs (NRC 2010b). Even when controlling for scientific discipline, the quality of the institutions from which they earned their doctorate, and the number of years since their doctorates were earned, gender differences persist in tenure and rank. In addition, NSF data show that, among those with Ph.D.s in S&E working in academia, women represented a larger fraction of those employed in temporary positions (adjunct and postdoctoral positions) than leadership posts (deans and college presidents) in 2006 (Burrelli 2008).

5.3 Poland

In Poland, women constitute a higher percentage of students, including in the physical sciences/chemistry, than ever before (Central Statistical Office 2009, 2010). As shown in Table 5.6, women comprised 58% of the nearly two million students in higher education in 2009, with over 60% of physical science students. Additionally, half of all doctoral degrees are awarded to women.

As shown in Table 5.7, women earned 65% of the 208 doctoral degrees awarded in chemistry in 2009. However, data suggest that women tend to gravitate toward less costly studies and institutions (Goh 2008).

While women have made considerable gains in higher education, their election to the Polish Academy of Sciences has been considerably slower (Nowak 2011; Central Statistical Office 2009, 2010).

Table 5.6 Students of higher education institutions by group and subgroup of fields of education, 2009

	Total	Of which are women	% of women
Students	1,900,014	1,105,442	58
Group—Science	159,810	58,635	37
Subgroup—life science	35,637	24,226	68
Subgroup—physical science	27,913	17,046	61
Subgroup—mathematics and statistics	15,178	9,249	61
Subgroup—computing	81,082	8,114	10
Group—Technology, industry, construction	265,433	77,484	29
Subgroup—engineering and engineering trades	129,304	24,767	19
Subgroup—manufacturing and processing	62,619	26,251	42

Source: Higher Education Institutions and Their Finances in 2008 and 2009); Central Statistical Office 2009, 2010)

Table 5.7 Doctorate degrees awarded to women, 2009

Students	Total	Of which are women	% of women
Total	5,068	2,663	53
Life science	264	180	68
Chemistry science	208	135	65
Economics science	451	241	53
Pharmaceutical science	115	80	70
Physics science	179	60	34
Humanities science	1031	588	57
Forestry science	24	7	29
Mathematics science	103	39	38
Medical science	871	548	63
Earth science	93	45	48
Technical science	862	237	27
Veterinary science	48	28	58

Source: Higher Education Institutions and Their Finances in 2008 and 2009. Central Statistical Office 2009, 2010)

5.4 The United Kingdom

The Royal Society of Chemistry (RSC) occupies the leadership position in advancing women in chemistry in the United Kingdom. In 2008 the RSC, in collaboration with the UK Resource Center for Women in Science, Engineering, and Technology (UKRC), published two reports addressing the retention of women in chemistry. The first was a survey of recent chemistry Ph.D. recipients about their career plans (RSC 2008). The 650 responses revealed that, while a significant number of women initially planned a science-related career, the proportion of women Ph.D. students planning such a career fell from 85% in the first year to 79% in the third year, while the proportion of men increased from 73 to 86% in the same period. More strikingly, the proportion of women who planned a career as a research chemist fell from 72% in the first year to 37% in the third, while the proportion of men remained about the same (61–59%). Of the women who were planning a research career, 51% intended during their first year of graduate study to stay in academia, but this proportion fell to 33% in the third year. The drop in men's interest was smaller: 44 to 36% from the first to the third year. Overall, only about 12% of women planned to remain in academia compared to 21% of men.

These results should be viewed in the context of available data on the number of women in chemistry in the United Kingdom (UK Resource Centre for Women in SET and RSC 2008). Women represent almost 50% of the undergraduate chemistry degree recipients, 40% of the doctorate recipients, and 30% of chemistry researchers, but comprise only 12% of junior faculty (senior lecturers) and 6% of professors. More systematic and quantitative data about gender are difficult to obtain. Available

Table 5.8 UK chemistry and chemical engineering enrollments, 2011–2012 academic year

	Chemistry		Chemical engineering	
	Undergraduate	Graduate	Undergraduate	Graduate
Women	6,680 (42.7%)	1,825 (39.8%)	1,830 (25.9%)	745 (28.8%)
Men	8,980 (57.3%)	2,760 (60.2%)	5,230 (74.1%)	1,840 (71.2%)
Total	15,660	4,585	7,060	2,585

Source: HESA (2013, Tables 4a and 4b)

annual data tables from the Higher Education Statistical Agency (HESA) provide largely aggregated data for the physical sciences, although a few provide some data in chemistry. Relevant chemistry and chemical engineering enrollment data for the 2011–2012 academic year are given in Table 5.8 (HESA 2013).

A 2011 joint report from the RSC and Institute of Physics (IOP) presents data from a survey of chemistry and physics postdoctoral researchers (McWhinnie 2011). Based largely on a survey of perceptions rather than on quantitative data collection, the report identifies both similarities and differences between women and men in each discipline and between the two disciplines. One of the more striking findings is that, while the percentages of women and men chemists who felt that one postdoctoral experience strengthened their interest in a research career are comparable (47% and 43%, respectively), those percentages dropped disproportionately after a second postdoctoral appointment. The proportion of males stayed the same, but the proportion of females reporting that they were more intent on a research career halved to 21% and the proportion that now had doubts about this doubled from 30 to 61%. Similar observations arose among physicists, but with less-dramatic differences.

Furthermore, a second postdoctoral experience dissuaded more women than men chemists from pursuing an academic career as well, falling from 65 to 44%, while their interest in an industrial career went from 21 to 40%. By contrast, women physics postdoctoral researchers exhibited no loss of interest in an academic career after a second postdoctoral appointment. Possibly related to this outcome is the observation that more physicists than chemists (76% vs. 57%, respectively) reported taking part in activities that were considered to support academic careers (teaching, conference attendance, external presentations) and in having the opportunity to teach (82% of physicists vs. 63% of chemists). In addition, 23% of women chemical scientists and 15% of men chemists felt they were viewed more as students than as professionals, contrasting with 11% of women physicists and 10% of men physicists. Fewer women chemical scientists felt respected by their departments than did women physicists (29% vs. 45%).

Effective practices to recruit women chemical scientists into academia in the UK include targeting female candidates and ensuring a woman is included among those interviewed (RSC 2008). Like others, the 2002 report also suggested that, in order to ensure equity in selection and hiring, women needed to be included on the interviewing panel, including a woman from outside the department; this effort could help create a more welcoming climate in the interview process, although such an outcome is not necessarily a foregone conclusion.

5.5 Germany

The German Chemical Society (GDCh) conducts annual surveys of the numbers and graduation rates of chemistry, biochemistry, food chemistry, and industrial chemistry students at undergraduate and graduate levels, categorized by citizenship status, gender, and institution (Schmitz 2012a). The GDCh also collects data biennially on the numbers of junior faculty members categorized in the same way (Schmitz 2013; Statistisches Bundesamt 2012b). Selected data for the most recent reports on students (2011) are provided in Table 5.9. Faculty data for 2012 are shown in Table 5.10.

Table 5.9 German enrollment and graduation numbers in chemistry and biochemistry, 2011[a,b]

	Men	Women	Total	Percent women
Chemistry				
Enrollment				
Diplom	2,784	1,482	4,266	34.7
Bachelor's[b]	10,323	5,874	16,197	36.3
Master's	2,625	1,663	4,288	38.8
Total predoc	15,732	9,019	24,751	36.4
Doctorate	4,493	2,885	7,378	39.1
Degrees awarded				
Diplom	803	514	1,317	39.0
Bachelor's	1,167	774	1,941	39.9
Master's	436	349	785	44.5
Total predoc	2,406	1,637	4,043	40.5
Doctorate	1,021	640	1,661	38.5
Biochemistry[c]				
Enrollment				
Diplom	284	364	648	56.2
Bachelor's	1,565	1,989	3,554	56.0
Master's	532	833	1,365	61.0
Total predoc	2,381	3,186	5,567	57.2
Doctoral	293	343	636	53.9
Degrees awarded				
Diplom	89	128	217	59.0
Bachelor's	227	323	550	58.7
Master's	134	190	324	58.6
Total predoc	450	641	1,091	58.8
Doctoral	78	82	160	51.3

Source: Schmitz (2013)

[a] Does not include the smaller numbers in food chemistry and industrial chemistry

[b] Universities only; does not include technical institutes that yield engineers

[c] Includes smaller numbers for "Life Sciences"

Table 5.10 Total employment in the chemical and polymer sectors by gender, 2002–2011, in thousands

Year	Men	Women	Total[a]	Percent women
2002	182	47	229	20.5
2003	179	48	227	21.1
2004	172	47	220	21.4
2005	188	47	235	20.0
2006	174	44	218	20.2
2007	178	43	221	19.5
2008	188	42	230	18.3
2009	173	40	214	18.7
2010	172	37	210	17.6
2011	175	38	214	17.8

Source: Statistisches Bundesamt (2012a)

[a] Totals are subject to rounding errors in the numbers of men and women

5.5.1 Student Enrollment and Degree Outcomes

Recent years have witnessed an increase in enrollment and graduation at all levels in the chemical sciences. Interestingly, while the numbers of both German and foreign students have grown, enrollment and graduation of German students has increased faster than that of foreign students. Comparison of year-to-year student data is difficult because the conversion of the German postsecondary education system from the traditional Vordiplom-Diplom-Promotion (doctorate) sequence into a bachelor's–master's–doctorate sequence, initiated in 2001, is still in progress, although it is nearly complete. Nonetheless, almost all who completed chemistry and biochemistry undergraduate degrees in 2011 enrolled in master's programs, and about 90% of the combined Vordiplom and master's students enroll in doctoral programs. Only about 6–8% of bachelor's/Vordiplom or master's degree recipients went directly into the workforce. These percentages are fairly evenly divided between men and women. However, while the proportion of women in chemistry doctoral programs has risen from 24% in 1999 to 39% in 2011, the proportion of women enrolled at the bachelor's/Vordiplom level has dropped from 46 to 36% in that same period.

The data in Table 5.9 also illustrate that the percentage of women at the several levels of enrollment and degree completion in chemistry varies only over a very narrow range between 37 and 42%. By contrast, the percentage of women in biochemistry at the several levels is greater than that of men, ranging from 53 to more than 60%. And unlike the trend in chemistry, the percentage of women enrolled in biochemistry at the bachelor's level (no Vordiplom degrees have been awarded) has increased between 1999 and 2011.

5.5.1.1 Employment Data

The German Federal Statistics Office publishes detailed employment data classified by multiple categories, including employment sector, salary, education, region, and others (Statistisches Bundesamt 2012a). Data are disaggregated by gender and age as well. Summary data for employment classified as the chemical and polymer sectors are given in Table 5.10 for the period 2002–2011. These data, of course, combine chemists in all positions and at all levels of education, and do not capture chemists who work in other sectors. The percentage of women has not varied substantially during that period, ranging from 17.6 to 21.4%.

The same office reports (Statistisches Bundesamt 2012b) academic employment data, included in Table 5.11, by institutional type and position.

Of note is the substantially lower percentage of women in professorial ranks compared with their percentages in all professional positions. These outcomes are consistent with those reported by Schmitz (2013). Table 5.11 also displays 2012 data (Schmitz 2013; Statistisches Bundesamt 2012b) for younger faculty members, including Habilitanden, who are roughly equivalent to Instructors in the United States. Habilitanden carry out independent research and write what is effectively a second dissertation, called a Habilitation. Approval of the Habilitation by their respective institutions allows advancement to professorial ranks. In recent years, some institutions have eliminated this requirement, which likely accounts for the decrease in the numbers of completed Habilitations in the past decade (Statistisches Bundesamt 2012b). Noteworthy is that even the small differences within corresponding data in reports by the GDCh (Schmitz 2013) and the German Federal Statistics Office (Statistisches Bundesamt 2010, 2012b) for a given year, where available, result in large differences in the percentage of women, a consequence of the small actual numbers of women. Tables 5.10 and 5.11 show that, while the percentage of women at the predoctoral level continues to grow, the percentages diminish strik-

Table 5.11 Full-time professional academic employment in the chemical sciences in Germany by gender and academic setting, 2011, 2012

Setting	Men	Women	Total	Percent women
All academic institutions	9,243	6,234	15,477	40.3
Universities	7,144	3,373	10,517	32.1
Technical institutes	310	107	417	25.7
Universities and technical institutes	7,454	3,480	10,934	31.8
Professorial ranks	951	124	1,075	11.5
Habilitations in progress (Habilitanden)[a]	198	71	269	26.4
Habilitations completed[b]	29/31	6/3	35/34	17.1/8.8
Junior professors[a]	42	15	57	26.3
Professors, all upper ranks[c]	990	119	1,124	11.9

Sources: Schmitz (2013); Statistisches Bundesamt (2012a, 2012b)

[a] Statistisches Bundesamt (2012b), data from 2012

[b] The first figures are from Statistisches Bundesamt (2012b), the second are from Statistisches Bundesamt (2012a), data from 2011

[c] The total of all women professors amounts to 134 in both surveys (Statistisches Bundesamt 2012a). However, Statistisches Bundesamt (2012b) does not report 2012 data for men professors

ingly along the academic pathway from completion of the doctorate to the professoriate.

More limited, gender-related data appear to be available for the nonacademic pathways followed by doctorate recipients in 2011 (Schmitz 2012a, 2012b). While comparable percentages of men and women began positions as postdoctoral researchers or in research institutes, 3% (12) of women compared with 5% of men (37) moved into full-time faculty positions. The remainder is distributed evenly over a range of enterprises, except for 42% of women vs. 34% of men (37% total) who entered the chemical or pharmaceutical industry. A slightly higher percentage of women than men (8% vs. 6%) were still seeking positions, although uncertainties in the data may make this difference vanish.[2]

5.5.1.2 Women in Industry

No data are available for the types of positions that women hold in German industry, although allusions exist (LCI 2000; Goos and Veronika Keller-Lauscher 1999) to women in the late 1990s holding 4.1–15.5% of leadership positions in the chemical industry. Nonetheless, enabling women to advance into positions of leadership is a stated objective of employers and the trade unions. Beginning in 1989, the National Chemistry Employers Federation (BAVC) and the Mining, Chemical and Energy Workers Union (IG BCE) have created a series of partnership activities to ensure equal opportunity in hiring and promotion (which is embedded in German law), to promote the advancement of women, and to establish family-friendly employment practices. A conference to review outcomes in the first 10 years was held in 1999. The published proceedings (LCI 2000) reveal that many of the justifications and suggested measures appear to mirror those that are familiar elsewhere. However, no data appear to be available on actual outcomes at that time or as of this writing. Overwhelmingly, the discussion in that symposium and elsewhere addresses issues pertaining to married women with children; single women or couples without children seem not to be a priority. Like many other chemical societies, the GDCh has a "Working Group on Equal Opportunity in Chemistry," (AKCC), which is effectively a women chemical scientists committee. While the AKCC offers a number of symposia and publications especially for younger women, no publicly available information on outcomes is available.

5.6 Denmark

Although women accounted for less than 50% (47.9%) of those earning undergraduate degrees in chemistry in Denmark in 2002, they accounted for the majority of degree recipients each year from 2003 to 2011, earning 62.7% of bachelor's

---

[2] For example, those who had accepted but not yet begun full-time positions by the end of 2011 would be counted as still seeking positions.

Table 5.12 Numbers and percent of Danish women earning undergraduate degrees in chemistry and chemical engineering, 2002, 2006, and 2012

	Chemistry			Chemical engineering		
	Year					
Gender	2002	2006	2012	2002	2006	2012
Both	117	158	171	0	1	77
Women	56 (47.9%)	99 (62.7%)	85 (49.7%)	0	1 (100%)	35 (45.5%)
Men	61 (52.1%)	59 (37.3%)	86 (50.3%)	0	0	42 (54.5%)

Source: Statistics Denmark (2013)

degrees in 2006 (see Table 5.12). In 2012, they earned only 49.7% of chemistry degrees, dropping nearly 7% points from the preceding year. In that same year, 271 women enrolled in an undergraduate chemistry degree program, but only 85 (32%) completed their degree in the field. Although no data are available from 2002 to 2005, women consistently earned less than half of the degrees in chemical engineering, with the exception of 2006. Graduate-level data is often aggregated by broad fields, thus gender-specific trends on women's attainment of doctoral degrees in chemistry and chemical engineering is not available.

5.7 Canada

No data on bachelor's or higher degree outcomes specifically in chemistry appear to be publicly available from Statistics Canada, the government statistics agency, the National Science and Engineering Research Council (NSERC), or the Canadian Institute of Chemistry and its constituent organizations. Most of the data are aggregated under physical sciences, often combined with mathematics. Statistics Canada produces a "Survey of Earned Doctorates," the latest of which appears to be for 2007–2008, but the data are not freely available. However, Engineers Canada, the professional engineering accrediting organization, publishes gender and degree data in chemical engineering (Table 5.13) (Engineers Canada 2012).

Table 5.13 shows that over the 5-year period, enrollment of women at all degree levels has generally increased, but the percentage of women enrolled at the bachelor's and master's level exhibits a slight decrease, while the percentage of women doctoral students enrolled, after a slight bump in 2008, has remained relatively constant. Trends among the degrees awarded are less systematic: the numbers of bachelor's degrees awarded remain relatively constant, while the numbers of master's degrees show a slight upward trend, and the numbers of doctorates fluctuate. The corresponding percentages, however, increase only for the master's degrees, with bachelor's and—allowing for an apparent 2007 anomaly—doctoral degrees exhibiting a slight decrease. However, in all cases, the changes are small: the percentages of women enrolled and receiving degrees at all levels hover near one-third of the corresponding totals, a result also exhibited by chemical engineering data in the United States (see Table 5.3).

Table 5.13 Canadian chemical engineering enrollment and degrees awarded, 2007–2011

Enrollment

	Bachelor's			Master's			Doctorate		
Year	Women	Total	Percent	Women	Total	Percent	Women	Total	Percent
2007	1,533	4,228	36.3	256	795	32.2	198	689	28.7
2008	1,555	4,379	35.5	242	708	34.2	207	679	30.5
2009	1,619	4,618	35.1	277	835	33.2	233	748	31.1
2010	1,740	5,189	33.5	304	924	32.9	255	805	30.0
2011	1,715	5,080	33.8	323	1,059	30.5	267	850	31.4

Degrees awarded

	Bachelor's			Master's			Doctorate		
Year	Women	Total	Percent	Women	Total	Percent	Women	Total	Percent
2007	388	917	42.3	91	289	31.5	16	95	16.8
2008	392	1,030	38.1	87	305	28.5	36	110	32.7
2009	375	987	38.0	88	286	30.8	40	119	33.6
2010	396	1,145	34.6	111	321	34.6	41	132	31.1
2011	396	1,158	34.2	119	331	36.0	34	118	28.8

Source: Engineers Canada (2012)

Gender data for chemical engineering faculty are not disaggregated by discipline. However, the Engineers Canada (2012) data show that in 2011 there were 135, 171, and 134 women assistant, associate, and full professors of engineering, respectively, comprising 20.1%, 14.1%, and 7.8% of the respective totals. The decrease in the percentages with increasing rank echoes observations elsewhere.

5.8 Brazil

According to the database of the National Research Council in Brazil (CNPq), the number of chemists and those working in the exact sciences roughly doubled in the time period 2000–2010, from 1,616 in the year 2000 to 3,302 in 2010, while the overall numbers of researchers in the country grew from 7,271 to 21,024 in the same time period (Bolzani and CNPq 2011). However, this dramatic increase in the numbers of scientists has not led to increased numbers of women at the forefront of leading research teams, as shown in Fig. 5.1. Despite an increase in women researchers from 38 to 49% from 1995 to 2008, the percentage of women leading research has actually fallen from 29 to 27%.

Founded in 1977, the Brazilian Chemical Society (SBQ) is one of the largest scientific bodies in Brazil dedicated to education and research in chemistry and related scientific fields. The number of active women members of the SBQ has grown from 2,210 of 4,480 in 2005 to 3,568 of 6,306 in 2010. Of the 23 Regional SBQ Secretaries distributed throughout all regions of Brazil, 6 or 26.1% of them are

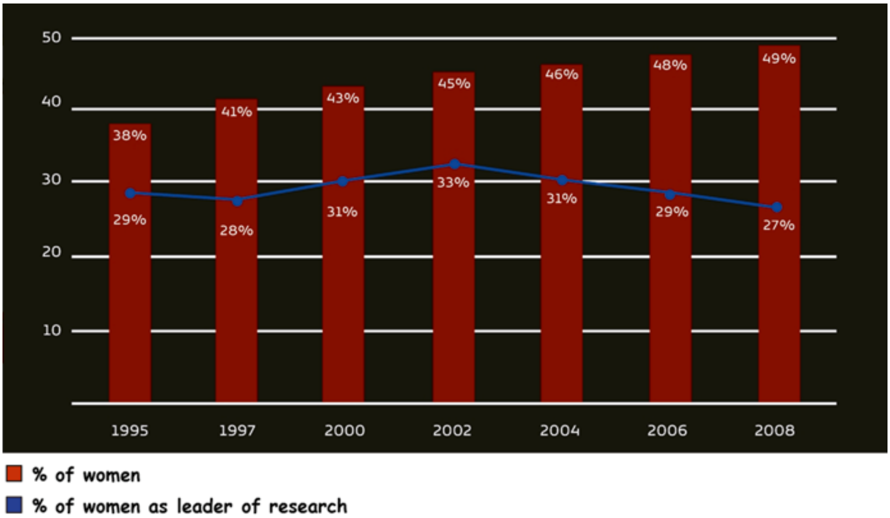


Fig. 5.1 Unbalanced growth for women in Brazil as leaders of research—1995–2008 (*Source*: Bolzani and CNPq 2011)

led by women chemists. Similarly, of the 13 Scientific Divisions, 3 or 22% are led by women. Unfortunately, there has been a lag in women chemists gaining key leadership positions in the Academia Brasileira de Ciencias, amounting to 14 of the 85 chemistry academics (16.5% women). This reality is also true for the positions of president, director, or dean at Brazilian Universities as women continued to be grossly outnumbered in leadership positions (Montes and Bryant 2011).

5.9 Barriers in the Workplace

For those who persist in the educational system and begin their careers in the sciences, an additional set of obstacles exists that prevent women from achieving equity with their male peers in the workplace. Some barriers exist regardless of workplace setting, although some differences emerge between careers in academia and in industry. Studies of women in Brazil (Plonski and Saidel 2001) and France (de Cheveigné 2009), for example, point to instances of gender bias and exclusion from male networks, which results in a “glass ceiling” in career attainment for women working in both academia and industry. A hostile workplace climate in which explicit or implicit sexual harassment exists can occur in a variety of settings, forcing some women to leave. For example, in a highly publicized case at a university in the United States, two women chemical scientists sued their former employer for tolerating a hostile work environment in which they were subject to gender discrimination and harassment at the hands of the male department chair and a male faculty member (Schulz 2009). The university settled the case in 2009 for more than $1 million but did not admit wrongdoing; the male department chair and faculty member charged with harassment remain at the university (Schulz 2010). Because women are often numerically a minority in their workplace, they may experience a sense of isolation and loneliness that can hamper women's retention in the workplace or their professional advancement. Lack of female leadership in management also exacerbates this sense of isolation; lack of women in key decision-making roles may reinforce an unwelcoming climate (Bayer Corporation 2011). About 40% of women and underrepresented minority chemists and chemical engineers state they were actively discouraged from pursuing a career in the sciences at some point in their lives (Coons 2010). The Bayer Facts of Science Education XIV survey (2011) revealed that nearly two-thirds (62%) of those polled say underrepresentation exists in their company's/organization's/institution's workforce; the leading workplace barriers for the female and minority chemists and chemical engineers include managerial bias, company/organizational/institutional bias, a lack of professional development, no/little access to networking opportunities, and a lack of promotional/advancement opportunities. In the same survey, respondents gave their companies/organizations/institutions a "C" for having women and underrepresented minorities in senior positions to serve as role models and mentors for the younger employees.

5.9.1 Industry

According to the American Chemical Society's 2012 annual *C&E News* employment survey (Tullo 2012), only one woman serves as Chief Executive Officer of large, publicly traded chemical firms (Dupont), the same as in 2011 (Sunoco, which has a woman CEO, is no longer included among chemical companies). The number of women senior executives (vice presidents, chief financial officers, general counsels, for example) held relatively steady, decreasing from 9.9% of the total in these positions in 2011 to 9.8% in 2012. And the percentage of women on boards of directors of these companies increased slightly from 12.1% in 2011 to 13.4% in 2012. In general, however, women have made only limited progress in management and most firms, on average, have only one female in a position of authority. A number of studies focused on chemists and chemical engineers in the United States (Bayer Corporation 2011) and Canada (Engineers Canada 2009, 2012) bring attention to the ways in which—despite the growing entry of women (and minorities) in chemistry and other STEM fields—many industry workplaces do not appear to value diversity. Beginning at management and trickling on down, the "culture" of many workplaces needs to be supportive of its changing workforce and place more emphasis on the need to have a diverse workplace (Rübsamen-Waigmann et al. 2003). As one woman executive has put it, "The women don't need to be fixed…The women are just fine. The issue is always what the corporate culture is. Does it allow them the opportunity to advance, improve, and excel on a playing field that is level for both men and women?" (Tullo 2011).

A 2012 survey (Morrisey 2013) of salaries of ACS members revealed that, of recent bachelor's and doctoral degree recipients, median starting salaries for women were 85 and 91% of those for men, while median starting salaries for women with recent master's degrees were 106% of those for men with master's degrees. The lower starting salaries for women with bachelor's degrees were across all work functions. A more-general survey (Rovner 2012) disclosed that the salary disparity between women and men with bachelor's degrees in all work settings grew with level of experience: women's median salaries decreased from 91% of men's salaries after 5–9 years of experience to 81% after 25–34 years of experience. These disparities tended to be less in industrial settings over time and, indeed, women's salaries after ca. 20 years of experience at all degree levels equaled or, at the doctoral level, exceeded those of men.

Several chemical and pharmaceutical companies have been singled out for their leadership, including but assuredly not limited to Dow Chemical nationally (Dow n.d.) and internationally (Dow 2011), Procter & Gamble (Hogan 2011), Bayer Corporation (Catalyst n.d.a), and DuPont (Catalyst n.d.b). Indeed, four chemical and seven pharmaceutical companies were among the 60 that the National Association of Female Executives identified in 2011 "that are paving the way in women's advancement." In 2012 and 2013, seven and nine companies, respectively, in those categories out of 50 total were so identified (Working Mother 2012, 2013; Spence 2011). Several pharmaceutical companies have also been named to DiversityInc's Top 50 Companies for Diversity in 2013, including Novartis Pharmaceuticals Corporation, Procter & Gamble, Merck & Co, Pfizer, and BASF (Diversity Inc. 2013).

5.9.2 Academia

A number of barriers have been proposed to account for the lag in representation of women on the faculty in chemistry departments across the globe. As the US data earlier in this chapter demonstrated, women are underrepresented relative to the numbers of those holding doctorates in chemistry and chemical engineering. Some sources (Marzabadi et al. 2006; Bayer Corporation 2011) attribute women's lower participation and higher turnover rates in academia mainly to dissatisfaction with departmental culture, advancement opportunities, faculty leadership, and research support. Other cases point to more systemic incidences of gender discrimination; at the Massachusetts Institute of Technology (MIT), women faculty members addressed such discrimination and gender bias in the College of Sciences, charging the academic environment made it more difficult for them to succeed, caused them to be accorded less recognition when they did achieve success, and contributed to a poor quality of life that, in turn, caused women faculty members to become negative role models for younger female students and faculty (Hopkins 2000). Tangible operational barriers also exist that keep some women from being successful in chemistry; for example, not having the travel funds to participate in academic conferences and network with colleagues, and not having adequate lab space and graduate student support. Reports between 1999 and 2006 from several highly regarded US universities (MIT 1999; Princeton 2003; Johns Hopkins 2006) have revealed persistent patterns of subtle gender biases, including lower research-initiation support for women, lower access to graduate teaching/research assistants, smaller travel budgets, and lower salaries. Indeed, in academic settings women consistently earned less than men except for those at undergraduate institutions (Rovner 2012). A study (Greene et al. 2010) of women chemistry faculty members confirms these results. The study demonstrated that women believe significant differences to exist in the resources and privileges awarded to men and women faculty—including salaries—that affect their potential for career advancement, recognition for their research, lab and office space, and workload, including teaching load and committee appointments. These studies support previous research attesting to a continued marginalization of women in academia.

5.9.3 Family-Related Issues

In 2009, Stanford University's Chemistry Department was the first such US department to introduce paid maternity leave for women graduate students, a policy that was expanded to family leave in 2010. A few additional US chemistry departments have since followed suit. And, in Canada, graduate students and postdoctoral fellows supported on grants from the NSERC and the Canadian Institutes of Health Research are eligible for paid parental leave of 4–6 months, depending on circumstances (Natural Sciences and Engineering Research Council of Canada. n.d.a). In addition, for those in the academic and industry workplace, lactation rooms and on-/off-campus daycare centers should be available for all universities and for all major conferences. Dependent-care expenses may be allowed to be charged to grants for conferences and meetings (Natural Sciences and Engineering Research Council of Canada. n.d.b).

However, women chemical scientists' low representation in leadership positions in both industry and academic positions cannot be fully explained by the division of household labor. Instead, even women without children have not made progress on par with their male counterparts (Marzabadi et al. 2006). Thus, an over-reliance on family-friendly measures as the means to ensure equity among men and women should be cautioned. Further, some authors (Ceci et al. 2009; Teitelbaum 2001) argue that family-friendly policies are not adopted universally by all disciplines; those in STEM fields are least likely to take advantage of them. Some disciplines, particularly lab-based sciences, do not permit "time off" because it may mean lack of access to current scientific knowledge, which can be stifling for one's career trajectory. Isolation from the scientific community, such as not attending conferences or not being engaged with department colleagues, can damage an individual's career (Ceci et al. 2009).

5.10 Conclusions

Despite the need to increase the representation of women in the sciences, we caution against relying solely on sheer numbers to ensure equality for women in academia and industry. Instead, critical mass is somewhat of a “paradox” that only partially resolves the dilemmas of women chemists. In their seminal study of 30 academic science departments, Etzkowitz et al. (1994) found that “overtly male behavior toward women improved (for example, invidious public sexual joking and stereotyping declined)” simply in the presence of senior women faculty. However, these same senior women faculty members were more likely to replicate the work styles of their older male colleagues, doing little to support junior women or female graduate students—a finding contrary to what is expected of “critical mass” proponents. The authors further argue that most women scientists were reluctant even to address the possibility of gender-related obstacles and are resistant to “special privileges” in hiring and promotion which they believed “devalued” their own achievements. Thus, recruitment efforts aimed at adding numbers should coincide with other changes, not just at the departmental and institutional levels, but should also address the broader social and cultural context which serves as barriers to women’s success in chemistry and other STEM fields.

Indeed, the evidence—even after 20 years since the Etzkowitz publication—continues to point to discouragingly large numbers of instances where women still lag behind the status of men in chemistry (Etzkowitz et al. 2000; Laursen and Weston 2014; National Academies, Committee on Women in Science, Engineering and Medicine, Office of News and Public Information 2009; NRC 2010a, 2010b; Wang and Raber 2009). As the data in this chapter reveal, despite some gains made by women in degree attainment in many countries across the globe, their representation in positions of leadership in the academic and industrial research sectors remains poor. Nonetheless, numerous examples exist of women achieving great things in the field of chemistry. In 2013, the presidents of five major national chemical societies—the American Chemical Society, the Hungarian Chemical Society, the Canadian Society for Chemistry, the German Chemical Society, and the Royal Society of Chemistry, are women. Lesley Yellowlees, the first woman president of the RSC in its 171-year history, has been an outspoken advocate for gender equality in the sciences and has publically condemned the UK government for slashing funding to programs that support diversity initiatives (RSC 2012). Past President Jocelyn Hicks was the first and only woman elected president of the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) in its 60-year history (Haymond et al. 2012). In the 7-year period 2007–2013, 17 of the 35 recipients of the international L’Oreal-UNESCO Women in Science Award were in the chemical sciences (UNESCO 2013).

In the short term, a few tangible steps might be taken that can make a difference in improving the status of women chemical scientists on a global level. These include shortening the time to completion of the doctoral degree and the raising of salaries for postdoctorates, which can contribute to altering the perception that scientific careers are less attractive or lucrative than other career options. Relying less on research assistantships and more on fellowships for graduate student support has been suggested (American Chemical Society 2013) to accelerate completion of the degree, although such a step is not without uncertainty. More academic institutions can follow the lead of Stanford University and several European institutions and introduce family-friendly practices for their students, postdoctorates, and faculty, as many industries have already done.

Collecting data on both education and career outcomes specifically on women chemical scientists and engineers is critical to attaining a clearer picture of the status of women chemical scientists on a global level, and thus to measuring the extent to which "progress" has been made internationally (Organisation for Economic Co-operation and Development (OCED) 2006). While much remains unknown about the status of women chemical scientists on a global level, this chapter is a first attempt to compile information to address that challenge. It has identified common areas of concern that cross national boundaries. It has uncovered programs in some countries that may be adaptable or at least bear examination in others. And it has shown that many educators, industry leaders, and policy-makers internationally recognize the need to achieve gender equity in a globalized world that depends on attracting the most talented into the chemical enterprise. Along with others in this volume, this chapter may serve as a launching pad for researchers to fill in the substantial remaining gaps in data, and ultimately assist educational and political leaders and policy-makers to grasp the goal of gender equity.

Chapter References

American Chemical Society. 2013. *Advancing Graduate Education in the Chemical Sciences: Summary Report of an ACS Presidential Commission*, 33. Washington, DC: American Chemical Society. http://portal.acs.org/portal/fileFetch/C/CNBP_031603/pdf/CNBP_031603.pdf. Accessed 12 June 2013.

Bayer Corporation. 2011. *Bayer Facts of Science Education XIV: Female and Minority Chemists and Chemical Engineers Speak About Diversity and Underrepresentation in STEM*. December 2011. http://bayerus.online-pressroom.com/index.cfm/events/bayer-facts-of-science-education-survey-xv/. Accessed 3 August 2013.

Bolzani, Vanderlan da Silva. 2011. *Brazilian Women Researchers: A Glance into the Role of Women in the Development of Chemistry Science*. In Invited presentation to the 241st ACS National Meeting & Exposition, Anaheim, California, USA, 27–31 March 2011. Database of the National Research Council in Brazil (CNPq).

Brown, Jeannette. 2011. *African American women chemists*. New York: Oxford University Press.

Burrelli, Joan. 2008. *Thirty-Three Years of Women in S&E Faculty Positions*. InfoBrief 08-308. Washington, DC: National Science Foundation Division of Science Resource Statistics.

Catalyst. n.d.a. *Bayer Corporation—Bayer Women: Leaders for the Global Marketplace*. http://www.catalyst.org/publication/106/bayer-corporationbayer-women-leaders-for-the-global-marketplace. Accessed 3 August 2013.

_____. n.d.b. *DuPont—DuPont Women's Network,* http://www.catalyst.org/knowledge/dupont—dupont-womens-network (accessed 3 August 2013).

Ceci, Stephen, and Wendy Williams. 2011. Understanding Current Causes of Women's Underrepresentation in Science. *Psychological and Cognitive Sciences* 108(8): 3157–3162.

Ceci, Stephen, Wendy Williams, and Susan Barnett. 2009. Women's underrepresentation in science: sociocultural and biological considerations. *Psychological Bulletin* 135(2): 218–261.

Central Statistical Office. 2009. *Higher Education Institutions and Their Finances in 2008.* Warszawa: Statistical Information and Elaborations.

Central Statistical Office. 2010. *Higher Education Institutions and Their Finances in 2009*. Warszawa: Statistical Information and Elaborations.

Coons, Rebecca. 2010. Survey: Women and Minorities Discouraged from Science Careers. *Chemical Week* 172(7): 14.

de Cheveigné, Suzanne. 2009. The Career Paths of Women (and Men) in French Research. *Social Studies of Science* 39: 113–136.

Diversity Inc. 2013. *The DiversityInc Top 50 Companies for Diversity,* http://www.diversityinc.com/the-diversityinc-top-50-companies-for-diversity-2013/ (accessed 13 June 2013).

Dow. n.d. *Valuing our Differences,* http://www.dow.com/diversity/environment/woman.htm.

Dow. 2011. *Dow Signs Women's Empowerment Principles to Promote Gender Equality in The Workplace*. March, http://www.businesswire.com/news/dow/20110308005510/en (accessed 23 July 2013).

Engineers Canada. 2009. *The Future is Now. Engineers Take the Lead! Final Report for Engineers Canada*. In September 10th, 2009 meeting. Toronto, ON: Engineers Canada, http://www.engineerscanada.ca/files/w_WIEAG_Workshop_Session.pdf (accessed 13 June 2013).

Engineers Canada. 2012. *Canadian Engineers for Tomorrow: Trends in Engineering Enrolment and Degrees Awarded 2007–2011*. Ottawa: Engineers Canada, http://www.engineerscanada.ca/files/w_report_enrolment_eng.pdf (accessed 13 June 2013).

Etzkowitz, Henry, Carol Kemelgor, and Brian Uzzi. 2000. *Athena Unbound: The Advancement of Women in Science and Technology*. New York: Cambridge University Press.

Etzkowitz, Henry, Michael Neuschatz, Brian Uzzi, and Joseph Alonzo. 1994. The Paradox of Critical Mass for Women in Science. *Science* 266(51): 51–54.

European Commission. 2009. *She Figures 2009: Statistics and Indicators on Gender Equality in Science*. Luxembourg: Publications Office of the European Union.

Goos, Wolfgang, and Veronika Keller-Lauscher. 1999. *Chancengleichheit im Betrieb: Umsetzung und Erfahrungen*, Hannover: Buchdruckwerkstätten Hannover GmbH, http://www.bavc.de/bavc/web/web.nsf/id/pa_publ_chancengleichheit.html (accessed 5 August 2013).

Goulden, Marc, Karie Frasch, and Mary Ann Mason. 2009. *Staying Competitive: Patching America's Leaky Pipeline in the Sciences*. Berkeley: Center on Health, Economic, & Family Security and The Center for American Progress, The University of California Berkeley.

Greene, Jessica, Jean Stockard, Priscilla Lewis, and Geraldine Richmond. 2010. Is the Academic Climate Chilly? The Views of Women Academic Chemists. *Journal of Chemical Education* 87: 381–385.

Haymond, Shannon, Amy K. Saenger, Helen M. Free, Jocelyn M. Hicks, Marilyn A. Huestis, Andrea Rita Horvath, and Corinne R. Fantz. 2012. Altering the Landscape for Women in Clinical Chemistry: Perspectives from Multigenerational Leaders. *Clinical Chemistry* 58(7). doi:10.1373/clinchem.2011.174284.

Higher Education Statistics Agency (HESA). 2013. *Students in Higher Education Institutions 2011/12*. Cheltenham: Higher Education Statistics Agency, http://www.hesa.ac.uk/index.php?option=com_pubs&task=show_pub_detail&pubid=1&Itemid=286 (accessed 3 August 2013).

Hogan, Marc. 2011. WCD Honors P&G, Coca-Cola, Kraft. *Agenda: A Financial Times Service*, 2 May 2011, http://www.womencorporatedirectors.com/displaycommon.cfm?an=1&subarticlenbr=99 (accessed 23 July 2013).

Hopkins, Nancy H. 2000. Experience of Women at the Massachusetts Institute of Technology. In *Women in the Chemical Workforce: A Workshop Report to the Chemical Sciences Roundtable*, ed. National Academies, 110–124. Washington, DC: National Academies.

Johns Hopkins University Committee on the Status of Women. 2006. *Vision 2020: 2006 Report of the University Committee on the Status of Women*. Baltimore, MD: Johns Hopkins University, http://web.jhu.edu/administration/provost/docs/Vision2020_2006.pdf (accessed 3 August 2013).

Landesverband Chemische Industrie (LCI). 2000. *Chancengleichheit im Betrieb: Umsetzung und Erfahrungen*, Ludwigshafen, http://www.cssa-wiesbaden.de/fileadmin/Dokumente/chancengleichheit.pdf (accessed 5 August 2013).

Laursen, Sandra L., and Timothy J. Weston. 2014. Trends in Ph.D. Productivity and Diversity in Top-50 U.S. Chemistry Departments: An Institutional Analysis. *Journal of Chemical Education* 91: 1762–1776, http://pubs.acs.org/doi/full/10.1021/ed4006997 (accessed 24 December 2014).

Massachusetts Institute of Technology. 1999. A Study on the Status of Women Faculty in Science at MIT. *The MIT Faculty Newsletter* 11(4), http://web.mit.edu/fnl/women/women.html.

Marzabadi, Cecilia H., Valerie J. Kuck, Susan A. Nolan, and Janine P. Buckner (eds.). 2006. *Are Women Achieving Equity in Chemistry? Dissolving Disparity, Catalyzing Change*, ACS Symposium Series. New York: Oxford University Press.

McWhinnie, Sean. 2011. *Mapping the Future: Survey of Chemistry and Physics Postdoctoral Researchers' Experiences and Career Intentions*. London: Royal Society of Chemistry and Institute of Physics, http://www.iop.org/publications/iop/2011/page_50579.html (accessed 27 August 2013).

Montes, Ingrid, and Janet Bryant. 2011. Are Women Still Underrepresented in Science? *Chemistry International* 33(6), http://www.iupac.org/publications/ci/2011/3306/5_montes.html (accessed 8 October 2014).

Morrisey, Susan R. 2013. New-Graduate Salaries: Unemployment Dropped Slightly in 2012—But so did Salaries for those who Found Jobs, ACS Survey Shows. *Chemical Engineering News* 19(16): 47–50, http://cen.acs.org/articles/91/i16/New-Graduate-Salaries.html (accessed 3 August 2013).

National Academies, Committee on Women in Science, Engineering and Medicine, Office of News and Public Information. 2009. Women Faring Well in Hiring and Tenure Processes for Science And Engineering Jobs at Research Universities, but still Underrepresented in Applicant Pools. *News Release* (2 June 2009), http://www8.nationalacademies.org/onpinews/newsitem.aspx?recordid=12062 (accessed 3 August 2013).

National Research Council. 2006a. *Biological, Social, and Organizational Components of Success for Women in Academic Science and Engineering: Workshop Report*. Washington, DC: National Academies Press, http://www.nap.edu/catalog/11766.html (accessed 3 August 2013).

_____. 2006b. *Future of U.S. Chemistry Research: Benchmarks and Challenges*. Washington, DC: National Academies Press, http://www.nap.edu/catalog/11866.html (accessed 3 August 2013).

_____. 2006c. *To Recruit and Advance: Women Students and Faculty in Science And Engineering*. Washington, DC: National Academies Press

_____. 2007. *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering*. Washington, DC: National Academies Press.

_____. 2010a. *Gender Differences at Critical Transitions in the Careers of Science, Engineering, and Mathematics Faculty.* Washington, DC: National Academies Press, http://www.nap.edu/catalog.php?record_id=12062 (accessed 3 August 2013).

_____. 2010b. *Women in the Chemical Workforce: A Workshop Report to the Chemical Sciences Roundtable*, 2000. Washington, DC: The National Academies Press.

National Science Board. 2010. *Science and Engineering Indicators 2010.* NSB 10-01. Arlington, VA: National Science Board.

_____. 2012. *Science and Engineering Indicators 2012*. NSB 12-01. Arlington VA: National Science Board, http://www.nsf.gov/statistics/seind12/ (accessed 3 August 2013).

National Science Foundation, Committee on Equal Opportunities in Science and Engineering. 2011. *Broadening Participation in America's STEM Workforce 2009–2010: CEOSE Biennial Report to Congress Committee on Equal Opportunities in Science and Engineering*. (CEOSE 11–01 June 2011), http://www.nsf.gov/od/iia/activities/ceose/reports/2009-2010_CEOSEBiennialReportToCongress.pdf (accessed 3 August 2013).

National Science Foundation, National Center for Science and Engineering Statistics (NCSES). 2009. *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2009.* (NSF 09-305 January 2009). Arlington, VA: NSF, http://www.nsf.gov/statistics/titlindx.cfm#W (accessed 3 August 2013).

_____. 2011. *Doctorate Recipients from U.S. Universities: 2010.* (NSF 12-305 December 2011). Arlington, VA: NSF, http://www.nsf.gov/statistics/sed/2011/related.cfm (accessed 3 August 2013).

_____. 2012. *Doctorate recipients from U.S. Universities: 2011*. (NSF 13-301 December 2012). Arlington, VA: NSF, http://www.nsf.gov/statistics/sed/2011/start.cfm (accessed 3 August 2013).

_____. 2013a. *Women, Minorities, and Persons with Disabilities in Science and Engineering*. (NSF 13–304 February 2013). Arlington, VA: NSF. http://www.nsf.gov/statistics/wmpd. Accessed 3 August 2013.

_____. 2013b. *Data from Department of Education/National Center for Education Statistics: Integrated Postsecondary Education Data System (IPEDS) Completions Survey by Race; Special Tabulation from NSF's WebCASPAR*, https://webcaspar.nsf.gov/ (accessed July 2013).

_____. 2013c. *Survey of Graduate Students and Postdoctorates in Science and Engineering, Special Tabulation,* August 2013.

Natural Sciences and Engineering Research Council of Canada. n.d.a. *Paid Maternity and Parental Leave For Students and Postdoctoral Fellows*, http://www.nserc-crsng.gc.ca/Professors-Professeurs/FinancialAdminGuide-GuideAdminFinancier/AdminMatters-QuestionAdmin_eng.asp#paid:parental (accessed 29 October 2013).

_____. n.d.b. *Tri-Agency Financial Administration Guide, Use of Grant Funds*, http://www.nserc-crsng.gc.ca/Professors-Professeurs/FinancialAdminGuide-GuideAdminFinancier/FundsUse-UtilisationSubventions_eng.asp#compensation (accessed 29 October 2013).

Nelson, Donna. 2007. *A National Analysis of Minorities in Science and Engineering Faculties at Research Universities,* http://www.engr.washington.edu/lead/PostedMaterials/WomenURM/2007DonnaNelsonReport-ExecSummary-2009.pdf (accessed 3 August 2013).

Nelson, Donna, and Christopher Brammer. 2007. *A National Analysis of Minorities in Science and Engineering Faculties at Research Universities*, 1–59. Norman, OK: Diversity in Science Association/University of Oklahoma, http://faculty-staff.ou.edu/N/Donna.J.Nelson-1/diversity/Faculty_Tables_FY07/FinalReport07.html (accessed 3 August 2013).

_____. 2010. *National Analysis of Minorities in Science and Engineering Faculties at Research Universities.* 2nd ed. Washington, DC: Diversity in Science Association, http://faculty-staff.ou.edu/N/Donna.J.Nelson-1/diversity/Faculty_Tables_FY07/07Report.pdf (accessed 23 July 2013).

Nowak, Isabella. 2011. *Gender Issues in Poland, Facing 21st Century Science*. Invited Presentation to the IUPAC World Chemistry Congress, San Juan, Puerto Rico, August 2011.

Organisation for Economic Co-operation and Development (OCED). 2007. *Women in Science, Engineering and Technology (SET): Strategies for a Global Workforce: Workshop Summary*. Ottawa: OECD.

Organisation for Economic Co-operation and Development (OCED) and Directorate for Science. 2006. *Women in Scientific Careers: Unleashing the Potential*. Paris: OECD.

Osborn, Mary, Teresa Rees, Mineke Bosch, Helga Ebeling, Claudine Hermann, Jytte Hilden, Anne McLaren, Rossella Palomba, Leena Peltonen, Carmen Vela, Dominique Weis, Agnes Wold, Joan Mason, and Christine Wennerås. 2000. *Science Policies in the European Union: Promoting Excellence Through Mainstreaming Gender Equality*. Luxembourg: European Commission, Office for Official Publications of the European Communities.

Pearson, Willie, Jr., and Alan Fechter, eds. 1994. *Who Will Do Science? Educating the Next Generation.* New Brunswick, NJ: Rutgers University Press.

Plonski, Guilherme Ary, and Rochelle G. Saidel. 2001. Gender, Science and Technology in Brazil. *Minerva: A Review of Science, Learning & Policy* 39: 217–238.

Princeton University, Task Force on the Status of Women Faculty in the Natural Sciences and Engineering. 2003. *Report of the Task Force on the Status of Women Faculty in the Natural Sciences and Engineering at Princeton*. Princeton, NJ: Princeton University.

Rovner, Sophie L. 2011. Women are 17% of Chemistry Faculty. *Chemical Engineering News* 89(44): 42–46, http://pubs.acs.org/doi/abs/10.1021/cen-v089n044.p042 (accessed 3 August 2013).

Rovner, Sophie L. 2012. Salary & Employment Survey for Chemists: Survey of American Chemical Society Members Shows Mixed Conditions for Chemists in 2012. *Chemical Engineering News* 90(39): 40–43, http://cen.acs.org/articles/90/i39/Salary-Employment-Survey-Chemists.html (accessed 25 July 2013).

Royal Society of Chemistry. 2008. *Change of Heart: Career Intentions and the Chemistry PhD.* London: Royal Society of Chemistry, http://www.rsc.org/images/ChangeofHeart_tcm18-139211.pdf (accessed 3 August 2013).

_____. 2012. *Does This Government Care About Women in Science? Asks Professor Lesley Yellowlees*, http://www.rsc.org/AboutUs/News/PressReleases/2012/women-science-early-day-motion-lesley-yellowlees.asp (accessed 3 August 2013).

Rübsamen-Waigmann, Helga, Ragnhild Sohlberg, Teresa Rees, Orna Berry, Pierre Bismuth, Rosanna D'Antona, Ellen De Brabander, Guy Haemers, Jenny Holmes, Maria Kristina Jepsen, Jacques Leclaire, Erika Mann, Jennifer Neumann, Roger Needham, Niels Christian Nielsen, Carmen Vela, and Darcy Winslow. 2003. *Women in Industrial Research: A Wake up Call for European Industry.* A Report to the European Commission from the High Level Expert Group on Women in Industrial Research for Strategic Analysis of Specific Science and Technology Policy Issues (STRATA), European Commission Directorate-General for Research, http://ec.europa.eu/research/science-society/women/wir/doc_pub_en.html (accessed 23 July 2013).

Schmitz, K. 2012a. *Chemiestudiengänge in Deutschland: Statistische Daten 2011*. Frankfurt am Main: Gesellschaft Deutscher Chemiker, http://www.gdch.de/statistik (accessed 4 August 2013).

_____. 2012b. Fakten und Trends: Chemiestudiengänge 2011. *Nachrichten aus der Chemie* 60(July/August): 813–824.

_____. 2013. Wissenschaftlicher Nachwuchs in der Chemie. *Nachrichten aus der Chemie* 61(April): 483–486.

Schulz, William. 2009. A Hostile Workplace: William Paterson University Faces Charges of Gender Harassment, Discrimination in its Chemistry Department. *Chemical Engineering News* 87(46): 33–36.

_____. 2010. University Settles Discrimination Suit. *Chemical Engineering News*, http://cen.acs.org/articles/88/web/2010/02/University-Settles-Discrimination-Suit.html (accessed 12 June 2013).

Spence, Betty. 2011. 2011 NAFE Top Companies for Executive Women: The List. *Working Mother*, http://www.workingmother.com/nafe-top-companies-female-executives/2011-nafe-top-50-companies-0 (accessed 4 August 2013).

Statistisches Bundesamt (Federal Statistical Office of Germany). 2010. Mikrozensus: Bevölkerung und Erwerbstätigkeit Beruf, Ausbildung und Arbeitsbedingungen der Erwerbstätigen Deutschland, https://www.destatis.de/DE/Publikationen/Thematisch/Arbeitsmarkt/Erwerbstaetige/BerufArbeitsbedingungErwerbstaetigen2010412097004.pdf?__blob=publicationFile (accessed 4 August 2013).

_____. 2012a. *Bevölkerung und Erwerbstätigkeit: Beruf, Ausbildung und Arbeitsbedingungen der Erwerbstätigen Deutschland 2011*. Wiesbaden: Statistisches Bundesamt, https://www.destatis.de/DE/Publikationen/Thematisch/Arbeitsmarkt/Erwerbstaetige/BerufArbeitsbedingungErwerbstaetigen2010412117004.pdf?__blob=publicationFile (accessed 4 August 2013).

_____. 2012b. *Bildung und Kultur: Personal an Hochschulen 2011*. Wiesbaden: Statistisches Bundesamt, https://www.destatis.de/DE/Publikationen/Thematisch/BildungForschungKultur/Hochschulen/PersonalHochschulen2110440117004.pdf?__blob=publicationFile (accessed 4 August 2013).

Statistics Denmark. 2013. *Students by Bachelor Education by Age, Ancestry, National Origin And Sex: Chemistry and Chemistry Engineering, 2002–2012*. StatBankDenmark. http://www.statbank.dk/statbank5a/default.asp?w=2560. Accessed 23 August 2013.

Teitelbaum, Michael. 2001. How We (Unintentionally) Make Scientific Careers Unattractive (Ch. 10). In *Scientists and Engineers for the New Millennium: Renewing The Human Resources*, ed. Daryl Chubin and Willie Pearson, Jr. Washington, DC: Commission on Professionals in Science and Technology.

Tullo, Alexander. 2011. Women in Industry: Women Show Marginal Gains in this Year's Edition of the C&EN Survey of Female Executives. *Chemical Engineering News* 89(32): 22. http://pubs.acs.org/doi/abs/10.1021/cen-v089n032.p022. Accessed 4 August 2013.

_____. 2012. Women in Industry: Chemical Company Boards Gain a Few Women, but Representation Stagnates Among Top Execs. *Chemical Engineering News* 90(34): 16–18, http://cen.acs.org/articles/90/i34/Women-Industry.html (accessed 4 August 2013).

Wang, Linda, and Linda R. Raber 2009. Exploring the 'Double Bind': Symposium Explores Contributions of Race, Ethnicity, and Gender to Science's Demographics. *Chemical & Engineering News* 87(46):37–38, http://pubs.acs.org/doi/abs/10.1021/cen-v087n046.p037 (accessed 4 August 2013).

Working Mother. 2012. 2012 NAFE Top 50 Companies for Executive Women. *Working Mother,* http://www.workingmother.com/best-company-list/122869 (accessed 23 July 2013).

_____. 2013. 2013 NAFE Top 50 Companies for Executive Women. *Working Mother*, http://www.workingmother.com/best-company-list/135080 (accessed 23 July 2013).

UK Resource Center for Women in SET and Royal Society of Chemistry. 2008. *The Chemistry PhD: The Impact on Women's Retention.* Prepared by Jessica L. Newsome. London: UK Resource Center for Women in SET and Royal Society of Chemistry, (http://www.theukrc.org/files/useruploads/files/the_chemistry_phdwomensretention_tcm18-139215.pdf) (accessed 23 July 2013).

UNESCO. 2013. *15th annual L'ORÉAL-UNESCO Awards for Women in Science—2013*. UNESCO, http://www.unesco.org/new/en/natural-sciences/priority-areas/gender-and-science/for-women-in-science-programme/2013-awards/ (accessed 23 July 2013).

Vignette 5.1
Enrollment and Degree Awards in Chemical Engineering

Sybrina Atwaters and Yu Tao

5.11 Introduction

Chemistry reflects a broad field with several branches that span into other areas of science, including engineering (see Chap. 5 in this volume). This article explores women's experiences at the intersection of gender and race/ethnicity within chemical engineering which falls between chemistry, where women have shown major progress (NSF, 2012), and engineering, where women and minorities continue to have extremely low participation (NSF, 2013; Hill et al. 2010).[3] Using American Society for Engineering Education (ASEE) and Integrated Postsecondary Education Data System (IPEDS) databases, we examine statistical trends in women's undergraduate enrollment and degree awards as well as graduate degree awards.[4]

---

[3] Engineering, Physics, and Computer Science continue to be the lowest S&E participation fields for women.

[4] Data and analysis are for US Citizens and Permanent Residents only, unless otherwise stated. ASEE database was used to create figures and tables regarding undergraduate enrollment and degree awards. IPEDS completions survey by race was used to create figures and tables for graduate degree awards.

S. Atwaters (✉)
Georgia Institute of Technology, Atlanta, GA 30032, USA
e-mail: syatwat@gatech.edu

Y. Tao
Stevens Institute of Technology, Hoboken, NJ 07030, USA
e-mail: yu.tao@stevens.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_5

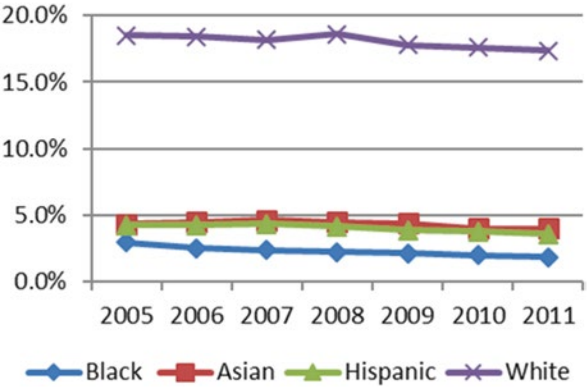


Fig. 5.2 Percentage women among all baccalaureate enrollment in chemical engineering, by race/ethnicity, 2005–2011

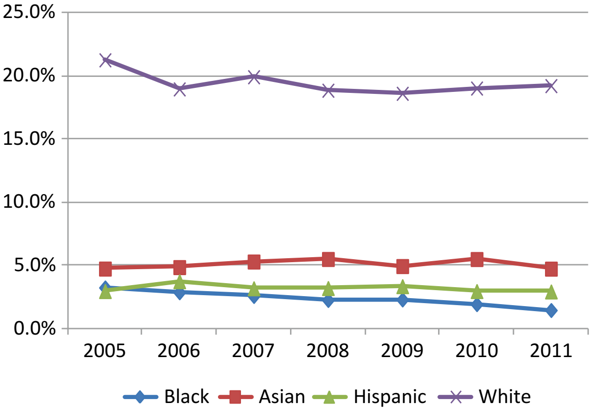


Fig. 5.3 Percentage women among all bachelor's degree recipients in chemical engineering, by race/ethnicity, 2005–2011

5.12 Findings

Between 2005 and 2011, the number of women enrolled in chemical engineering at the baccalaureate level increased from 8,035 to 12,308. Yet the percentage of women enrolled declined from 34.5 to 31.7%. The percent of Asian and Hispanic women among chemical engineering baccalaureate enrollment fluctuated by less than 1% during this time period, while the percentage of Black women declined from 3.0 to 1.8% and White women declined from 18.5 to 17.4% (Fig. 5.2).

The percentage of women awarded bachelor's degrees in chemical engineering followed a similar trend as enrollment. While Asian and Hispanic women remained around 5 and 3% of chemical engineering bachelor's degree recipients, respectively, Black women declined from 3.3 to 1.5% and White women declined from 21.3 to 19.3% (Fig. 5.3).

Fig. 5.4 Percentage of racial/ethnic groups among all women baccalaureate enrollment in chemical engineering, 2005–2011

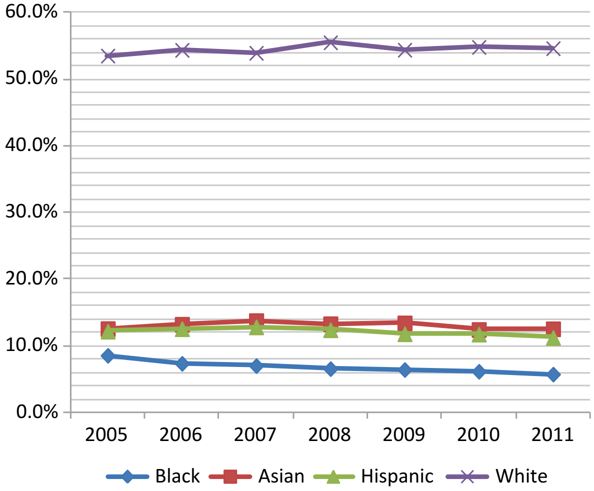
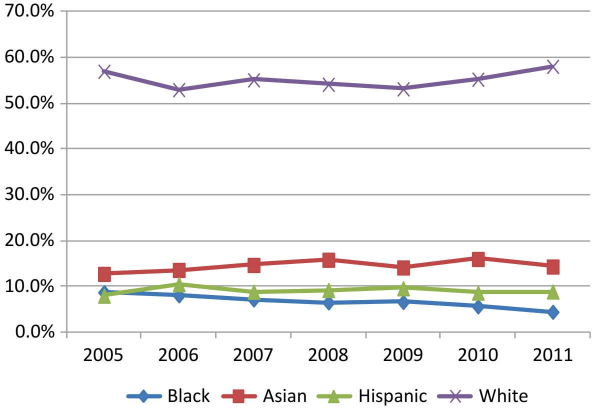


Fig. 5.5 Percentage of racial/ethnic groups among all women bachelor's degree recipients in chemical engineering, 2005–2011



Among women in chemical engineering, African American's representation decreased most significantly.[5] In 2005, African American women comprised 8.6% of all women enrolled in chemical engineering and 8.8% of all degrees awarded to women in chemical engineering at the baccalaureate level (see Figs. 5.4 and 5.5). By 2011, their enrollment among all women declined to 5.8%. Also, African American women decreased to 4.5% of all women awarded bachelor's degrees in chemical engineering.

---

[5] Temporary residents are not reflected in graphs but are included in the calculation of total enrollment and degree awards, as well as total women enrollment and degree awards at all levels. The percentage of temporary residents at the undergraduate level ranges from 5.9 to 12.8% during this period.

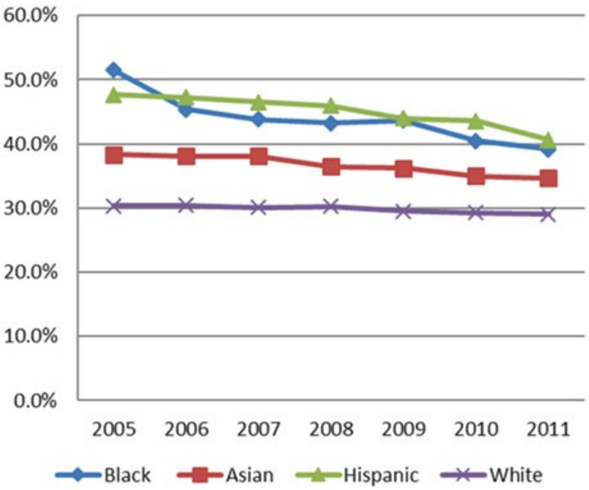


Fig. 5.6 Percentage of women baccalaureate enrollment in chemical engineering among each racial/ethnic group, 2005–2011

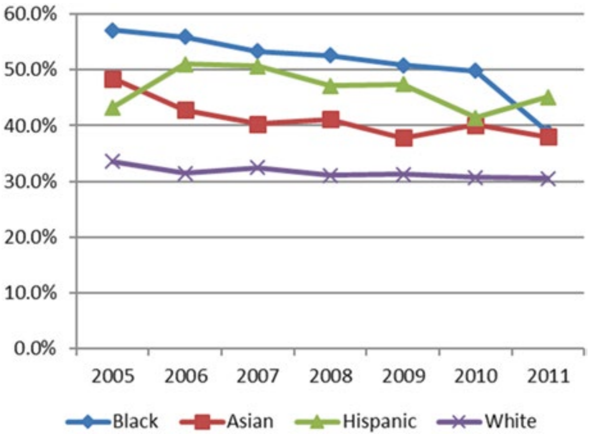


Fig. 5.7 Percentage of women bachelor's degree recipients in chemical engineering among each racial/ethnic group, 2005–2011

Interestingly, while African American and Hispanic women have lower racial/ethnic representation than their gender counterparts, they have the highest gender representation among their racial/ethnic counterparts. African American women peaked in 2005 with 51.5% (690) of total African American undergraduate chemical engineering enrollment and 57.1% (149) of African American undergraduate chemical engineering degree recipients (Figs. 5.6 and 5.7). In 2005, Hispanic women were 47.6% (981) of all Hispanic undergraduates enrolled in chemical engineering and in 2006 they were 51.0% (172) of all Hispanic undergraduate chemical engineering degree recipients.

At the graduate level, the numbers of degrees in chemical engineering awarded to women were much smaller, and the changes over time were not as straightforward as at the baccalaureate level. White women were the largest group in receiving master's degrees. Nevertheless, their share among all women master's degree recip-

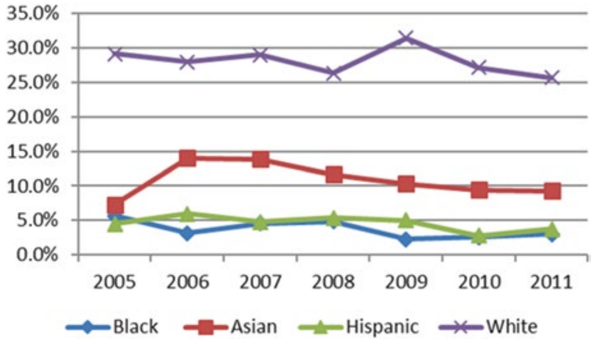


Fig. 5.8 Percentage of racial/ethnic groups among all women master's degree recipients in chemical engineering, 2005–2011

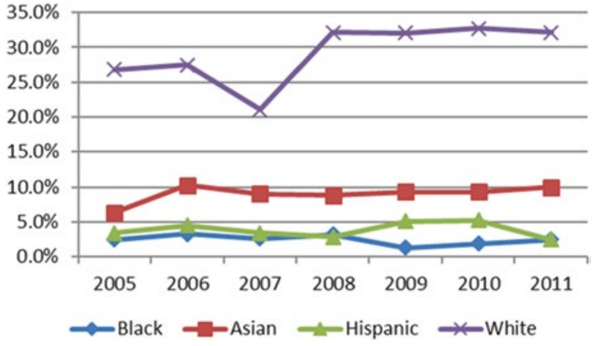


Fig. 5.9 Percentage of racial/ethnic groups among all women doctorate recipients in chemical engineering, 2005–2011

ients (including temporary residents) decreased from 29.2% (124) in 2005 to 26.3% (93) in 2008, peaked at 31.4% (125) in 2009, and then decreased 25.7% (130) in 2011. Asian women were the second largest group, receiving 7.3% (31) master's degrees in 2005 and 9.3% (47) in 2011. Black and Hispanic women had similar low shares and both declined over time. However, the drop was greater for Black women (from 5.6 to 3%) than for Hispanic women (from 4.5 to 3.8%) (Fig. 5.8).

The patterns at the doctoral level were somewhat similar. However, unlike at the master's level, White women's representation among all women doctorate recipients increased from 26.8% (55) in 2005 to 32% (90) in 2011. Asian women's representation increased from 6.3% (13) to 10% (28). Both Black and Hispanic women's representation remained low—at 2.4% (5) and 3.4% (7), respectively, in 2005 and at 2.5% (7) each in 2011 (Fig. 5.9).

In terms of the representation among their own racial/ethnic groups, the patterns for the four groups somewhat converged at the master's level. In 2011, White women earned 25.7% of all master's degrees awarded to all Whites, and Hispanic women accounted for 35.8% of those awarded to all Hispanics (Fig. 5.10). At the doctoral level, the percentages of Black and Hispanic women among their own race/ethnicity declined between 2005 and 2011, from 55.6 to 46.7% and from 35 to

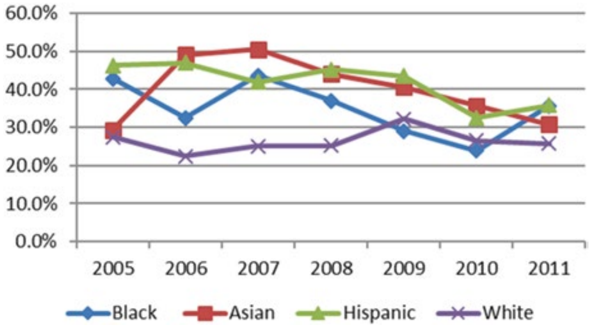


Fig. 5.10 Percentage of women master's degree recipients in chemical engineering among each racial/ethnic group, 2005–2011

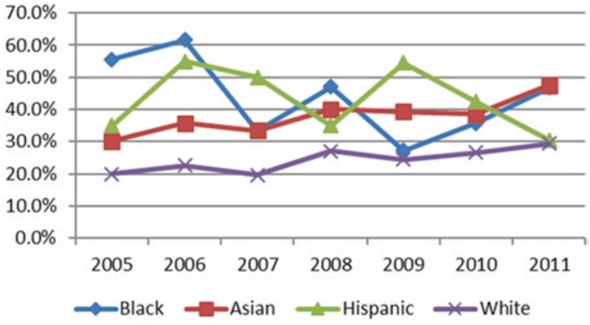


Fig. 5.11 Percentage of women doctorate recipients in chemical engineering among each racial/ethnic group, 2005–2011

30.4%, respectively. However, the percentages of Asian and White women within their own race/ethnicity increased from 30.2 to 47.5% and 20 to 29.3%, respectively (Fig. 5.11).

5.13 Discussion and Conclusion

Similarities in enrollment and degree trends at the baccalaureate level for all women in chemical engineering suggest that women persist in chemical engineering at consistent rates. However, the low representation of women, especially White, Black, and Hispanic women, supports the need for a renewed emphasis on recruitment of women in chemical engineering. Moreover, the steady decline in enrollment and degree awards trends for African American women across all three cohorts (total, women, and African Americans) suggests the need for more research regarding experiences at the intersection of being African American and female.

The large gap in the numbers of women receiving graduate degrees and those receiving bachelor's degree could be explained by the fact that the bachelor's chemical engineering degree is a professional degree (Hanson, 2011a). However, the master's degree can provide more opportunities, including an increase in salary (Hanson, 2011b). Women's representation within all races/ethnicities declined from the bachelor's to the master's level, which indicates that women were not taking advantage of the master's degree as much as their male counterparts. However, Black, Hispanic, and White women's representation relative to their male counterparts were higher at the doctoral level than at the master's level in over half of the time period. In other words, while the numbers were low, Black, Hispanic, and White women were able to maintain or even increase their representation relative to their male counterparts.

References

Hanson, David J. 2011a. To a Degree. *Chemical and Engineering News* 89(11): 52, http://cen.acs.org/articles/89/i11/Degree.html (accessed 9 April 2014).

Hanson, David J. 2011b. Starting Salaries. *Chemical and Engineering News* 89(11): 49–53, http://cen.acs.org/articles/89/i11/Starting-Salaries.html (accessed 9 April 2014).

Hill, Catherine, Corbett, Christianne, and St. Rose, Andresse. 2010. *Why so Few? Women in Science, Technology, Engineering, and Mathematics*. Washington, DC: American Association of University Women.

National Science Foundation. 2012. *Science and Engineering Indicators* (NSB 12-01). Arlington, VA: National Science Foundation.

National Science Foundation/National Center for Science and Engineering Statistics. 2013. *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2013*. Special Report NSF 13-304. Arlington, VA, http://www.nsf.gov/statistics/wmpd/ (accessed 7 April 2014).

Vignette 5.2
Science Activities in Taiwan

Chia-Li Wu

The Projects on Mainstreaming of Gender in Science and Technology, together with the Chemical Society of Taiwan and the National Science Council of Taiwan, have offered a number of activities directed to attracting youngsters—and especially young girls—into the chemical sciences. For example:

5.14 Chemistry Papago ("Chemistry Down the Road")

A van loaded with simple chemicals and posters drives around the island, particularly to rural areas, including isolated small islands. Usually, remaining for 4 h at each stop, youngsters see a chemistry magic show, carry out hands-on experiments, and take part in games that require scientific thinking.

Activities sponsored or partly sponsored by Projects on Mainstreaming of Gender in Science and Technology (2011–2013)

C.-L. Wu (✉)
Department of Chemistry, Tamkang University, New Taipei City, Taiwan
e-mail: clwuster@gmail.com

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_5

5.15 Science Camps for Junior High School Students

During summer vacations, an average of 50 students, half of whom are girls, spend 3 days and 2 nights in the dormitories of Tamkang University, in which they listen to lectures and carry out experiments that illustrate the role of science in everyday life. Two such camps are held each summer. At least half of the lecturers are female scientists in order to provide more role models for the youngsters. The campers are also shown a short film on gender respect, followed by discussions hosted by gender experts.

5.16 Science Camps for High School Students

For 1–2 days on weekends during the semester, or 2–3 days during winter/summer vacations, students largely from girls' high schools listen to lectures and carry out chemistry and physics experiments. As with the science camps for junior high school students, at least half of the lecturers are female scientists who serve as role models for the participants. Similarly, students are shown a short film on gender respect and participate in discussions hosted by a gender expert. The camps may be in their own schools or at one of the universities.

5.17 Gender and Science Summer/Winter Camps

Directed mainly to female college and graduate students from STEM fields (although a few other fields are also included), participants spend 3 days in a scenic area to take part in discussions that focus on gender aspects in science.

Chapter 6
Women in Mathematics: Change, Inertia, Stratification, Segregation

Cathy Kessel

More than a century ago, Germany was the acknowledged center of mathematical research, and aspiring mathematicians often earned doctorates or studied at the universities in Göttingen and Berlin. Two of these aspiring mathematicians were Grace Chisholm from England and Mary Winston from the United States. After petitioning, they were granted permission to enroll at the university in Göttingen. In 1895, Chisholm became the first woman to have enrolled as a student and earned a doctorate in mathematics. In 1897, Winston became the second, graduating magna cum laude (Green and LaDuke 2009, pp. 39–40, 256). In earning a doctorate at Göttingen, they were preceded by the Russian Sofia Kovalevskaya who had been granted her degree in 1874 without being officially enrolled in the university. In matriculating, Chisholm and Winston preceded German women who had to wait until 1902.

Kovalevskaya and Chisholm were internationally celebrated, albeit in different ways. In 1889, Kovalevskaya became the first woman in modern Europe to hold a chair at a research university. She was the first woman to be on the editorial board of a major scientific journal, received the prestigious Prix Bordin from the French Academy of Sciences, and was the first woman elected as a corresponding member of the Russian Imperial Academy of Sciences (Koblitz 1999, pp. 216–217). Although she did not hold a university position, Chisholm traveled in Europe to pursue her mathematical interests and learn about new ideas. She published joint work with her mathematician husband as well as solo work under her own name (Wiegand 2005, pp. 39–45).

Winston did not have a notable career as a researcher and her later academic affiliations were not impressive. She returned to the United States, taught at a high school for 1 year and for 3 years at Kansas State Agricultural College. She resigned in order to marry a mathematician in another Kansas town, but, due to university

---

C. Kessel (✉)
Consultant, Berkeley, CA 94704, USA
e-mail: cbkessel@earthlink.net

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_6

anti-nepotism policies, could not obtain an academic position there. After her husband's death, she obtained academic posts, first at Washburn College in Kansas, then Eureka College in Illinois, where she became the chair of its mathematics and science division (Green and LaDuke 2011).

As the decades passed, aspiring US mathematicians did not flock to European universities as before. US universities recruited European mathematicians who helped them become centers of mathematical activity that attracted foreign talent and nurtured home-grown talent. Due to institutional policies and professorial preferences, that nurture was not always extended to women or minorities. The first African-American man known to have been awarded a mathematics doctorate was Elbert Frank Cox, who earned his in 1925 (Walker 2009). Euphemia Lofton Haynes, his female counterpart, earned her doctorate almost two decades later, in 1943. Like Mary Winston a half-century earlier, she obtained a position at a high school. Unlike Winston, she remained in that position for three decades, becoming the chair of its mathematics department (Murray 2012).[1]

Although these stories are old and much has changed, they illustrate some longstanding themes as well as individual variations. Studying at a center of mathematical activity is still important. It may involve learning in another culture and another language. Affordances and constraints may be different for foreign students than for native students, although today these tend to involve eligibility for scholarships rather than permission to matriculate. The "two-body problem"—having a mathematician or academic partner as did Mary Winston and Grace Chisholm—still exists and still affects employment, although anti-nepotism regulations are gone—at least in the United States (Kessel 2009). And, unusual talent and achievement are not necessarily associated with prestigious careers. Despite the talent and motivation that must have accompanied Mary Winston's and Euphemia Lofton Haynes's acquisition of doctorates, their subsequent employment occurred in institutions not intended to support mathematical research. And all, from Kovalevskaya to Haynes, encountered problems of unequal access to education. With these considerations in mind, we turn to a statistical account of the current situation.

6.1 Graduate Education

To get a sense of the international situation for mathematics, we begin with an overview of doctorates for science and engineering granted by different countries. The US National Science Foundation has compiled statistics for 68 nations from the five continents and Oceania. The nations which grant the largest numbers of science and engineering doctorates are shown in (Fig. 6. 1).

---

[1] See also http://www.math.buffalo.edu/mad/PEEPS/haynes.euphemia.lofton.html.

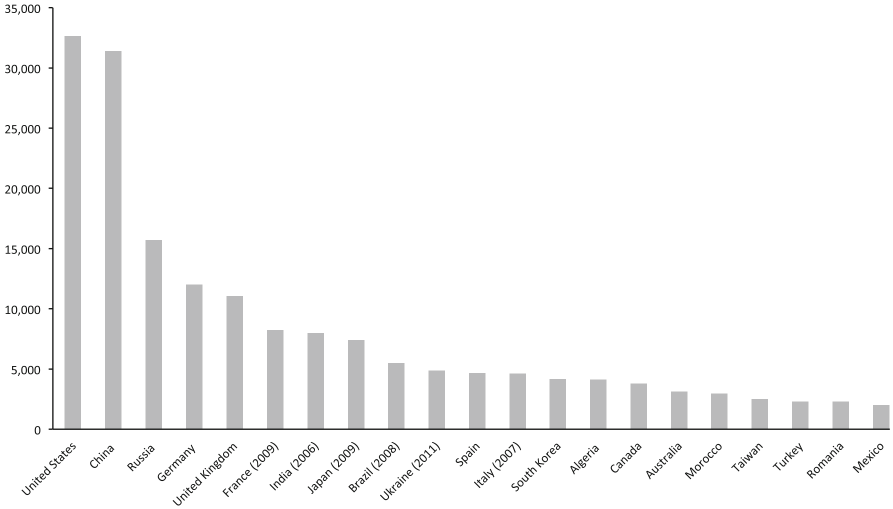


Fig. 6.1 Number of science and engineering doctorates granted in 2010, by nation. *Source*: *National Science Board 2014*, Table 2-39, doctorates granted in 2010 unless indicated otherwise

6.1.1 Mathematics Doctorates

A less comprehensive compilation of statistics from the European Union shows the United States as the largest producer of doctorates in mathematics, followed by the United Kingdom, Germany, and France (see Fig. 6.2 and Appendix). Producing a relatively high number of science and engineering doctorates does not always imply doing the same for mathematics—and vice versa. For example, Denmark is not shown in Fig. 6.1 because it produced a relatively low 728 doctorates in science and engineering, but is noticeable in Fig. 6.2 because 261 of those doctorates were in mathematics. Nonetheless, the history of mathematics (Parshall and Rice 2002) and the prominence of China and Russia in Fig. 6.1 suggest that they may also be major grantors of mathematics doctorates. Further statistical information about mathematics in these countries is not readily available, which is one reason why they receive little discussion in this chapter.

Another reason is that this chapter focuses on the United States. Like Germany in the nineteenth century, the United States is a center of mathematical activity that attracts talented people from many countries. *The Mathematical Sciences in 2025*, a recent report on the mathematical sciences, concluded:

> In spite of concerns about the average skill of precollege students, the United States has an admirable record of attracting the best mathematical and statistical talent to its universities, and many of those people make their homes here after graduation. Assessments of capabilities in mathematical sciences research find the United States to be at or near the top in all areas of the discipline. (2013, p. 25)

However, as will be discussed later in this chapter, US tertiary institutions are many and varied. Not all are designed to support the best mathematical and statistical talent.

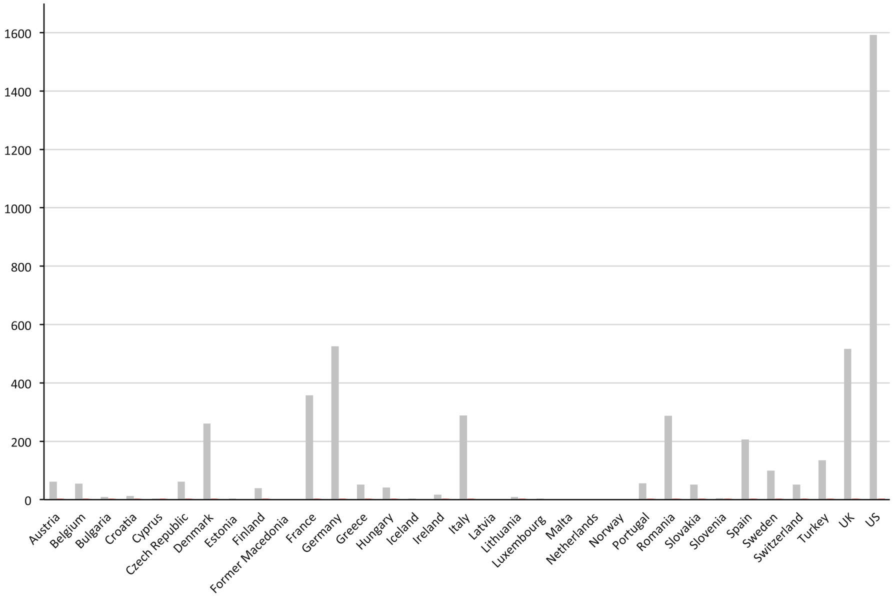


Fig. 6.2 Number of mathematics doctorates granted in 2010, by nation. *Source*: *European Commission 2013*, Annex 2.3

National origins of US doctorates. Annual surveys conducted by the American Mathematical Society (AMS) indicate that at least half of mathematics Ph.D.s granted by US universities are earned by people who are not citizens or permanent residents of the United States, and that this has been the case for at least 30 years.[2] Table 6.1 gives some sense of their relative proportions by showing the national origins of temporary or permanent US residents who were granted Ph.D.s from US universities between 1991 and 2011.

Surveys of recent US doctorates in mathematics show that many intend to remain in the United States (NSB 2014, Table 3-22), although this varies with national origin. These responses are consistent with findings from annual surveys of new doctorates conducted by the AMS. For example, of the 1,623 doctorates from 2012 who responded to the survey, 1,300 reported taking a job in the United States. Only 211 reported non-US jobs. Others were not seeking employment or still seeking it (see 2012 Survey, Table E.3; also 5-year trends in Cleary et al. 2013).

Similarly, about 45% of UK mathematics doctorates go to students from outside the United Kingdom (McWhinnie and Fox 2013). It may also be the case that the large numbers of doctorates granted by countries with relatively small populations such as Germany and France are due in part to large proportions of foreign graduate students.

---

[2] See surveys at http://www.ams.org/profession/data/annual-survey/annual-survey. Note that students in the United States generally fall into one of three categories: citizen, permanent resident, or temporary resident. In contrast to permanent residents, temporary residents are permitted to stay only for a specific purpose such as graduate study or a particular job.

Table 6.1 US mathematics doctorates with non-US origins, 1991–2011

Country of origin	Number of doctorates
Middle East	741
North and South America (outside USA)	1,058
Europe	3,015
Asia	7,356

Source: *National Science Board 2014*, Tables 2-14, 2-15, 2-16

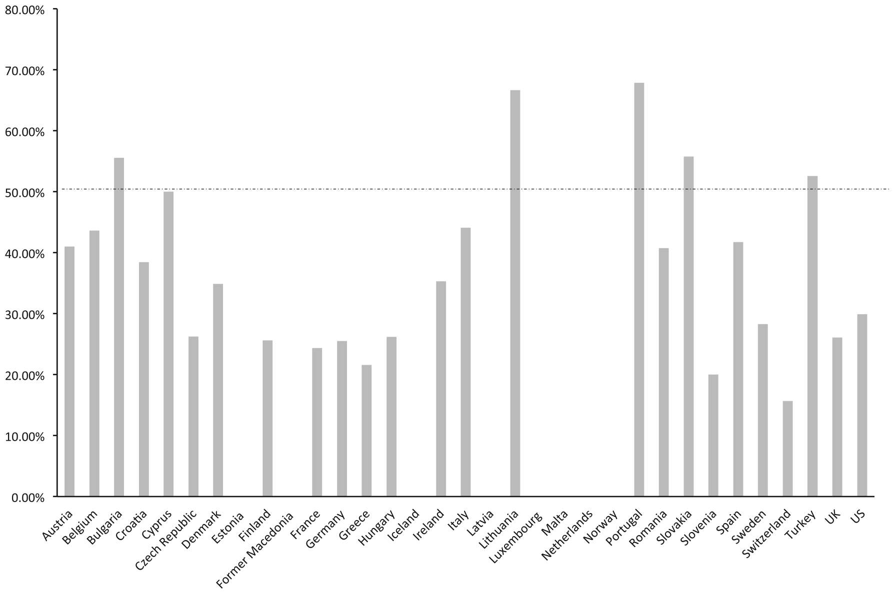


Fig. 6.3 Percentages of mathematics doctorates granted to women, 2010. *Source*: *European Commission 2013*, Annex 2.3. The dashed line at 50% is shown for reference

6.1.2 Doctorates Granted to Women and Gender Segregation

As illustrated in Fig. 6.2, annual numbers of mathematics doctorates granted vary considerably by country. So do women's shares of these degrees (see Fig. 6.3). For 2010, the highest percentages occurred in Portugal where women earned 38 of 56 doctorates granted (68%) and Lithuania where women earned 6 of 9 doctorates granted (67%). The lowest non-zero percentages occurred in Slovenia (20%, 1 of 5) and Switzerland (16%, 8 of 51). Women earned no mathematics doctorates in countries such as Estonia, Iceland, and Malta but these countries granted (respectively) 2, 1, and 0 doctorates. (Details for other EU countries are given in the Appendix.)

Each of these percentages can be considered within the context of its country. For example, in Turkey almost equal proportions of men and women earned doctorates in mathematics. We might wonder if gender ratios for other fields of study were also close to parity in Turkey, and in fact, most were (see Fig. 6.4). In contrast, more fields of study in Switzerland had gender ratios that were far from parity. These differences between nations can be described in terms of *gender segregation* (also called *horizontal segregation*), e.g., Turkey shows less gender segregation among doctorate fields of study than does Switzerland. This suggests that the percentages shown in Fig. 6.3 may be, at least in part, associated with national characteristics rather than characteristics particular to mathematics. We return to this point at the end of this chapter.

Differences between domestic and foreign doctorates. We should not conclude, however, that percentages shown in Fig. 6.3 are simply proxies for measures of gender segregation within a given country. The percentages shown by country conceal an important source of variation: doctorates awarded to foreign students. In the United Kingdom and United States, women occur in greater proportions among doctorates granted to foreign students than to resident students (see Table 6.2). In 2011, women earned one fourth of all mathematics doctorates granted in the United Kingdom, but less than one fifth of doctorates granted to UK residents were granted to women. Women from outside the United Kingdom earned a much larger share of doctorates than resident women: 31% of the doctorates granted to EU-domiciled recipients, and 33% of the doctorates granted to those domiciled outside the United Kingdom and European Union. Without its foreign students, the UK percentage would be between the two lowest in Fig. 6.3: Slovenia and Switzerland.

Statistics reported for the United States do not show such a pronounced difference between US citizen graduates and non-US citizen graduates. However, for both the United States and United Kingdom, statistical differences between resident and foreign graduates suggest other differences between countries.

6.2 Differences in Cultural Attitudes

As already mentioned, studying mathematics in a foreign country may involve learning in a different language and a different culture. The latter may include different attitudes about women and mathematics. Women arriving for graduate study in the United Kingdom and United States are sometimes surprised to learn that, in the words of a British mathematician, it is considered "rather odd for a woman to be mathematical" (Case and Leggett 2005, p. 136). For instance, writing in 1992, a mathematician from Brazil described her experiences in England:

> I had never thought there was anything special in being a woman mathematician until I arrived in Warwick to do my PhD. At a party organized … for women graduates in the Maths Institute I asked why the other women had not come. To my surprise they had all come. That year had been particularly good, with five new female graduate students (there were over twenty men). (Case and Leggett 2005, p. 131)

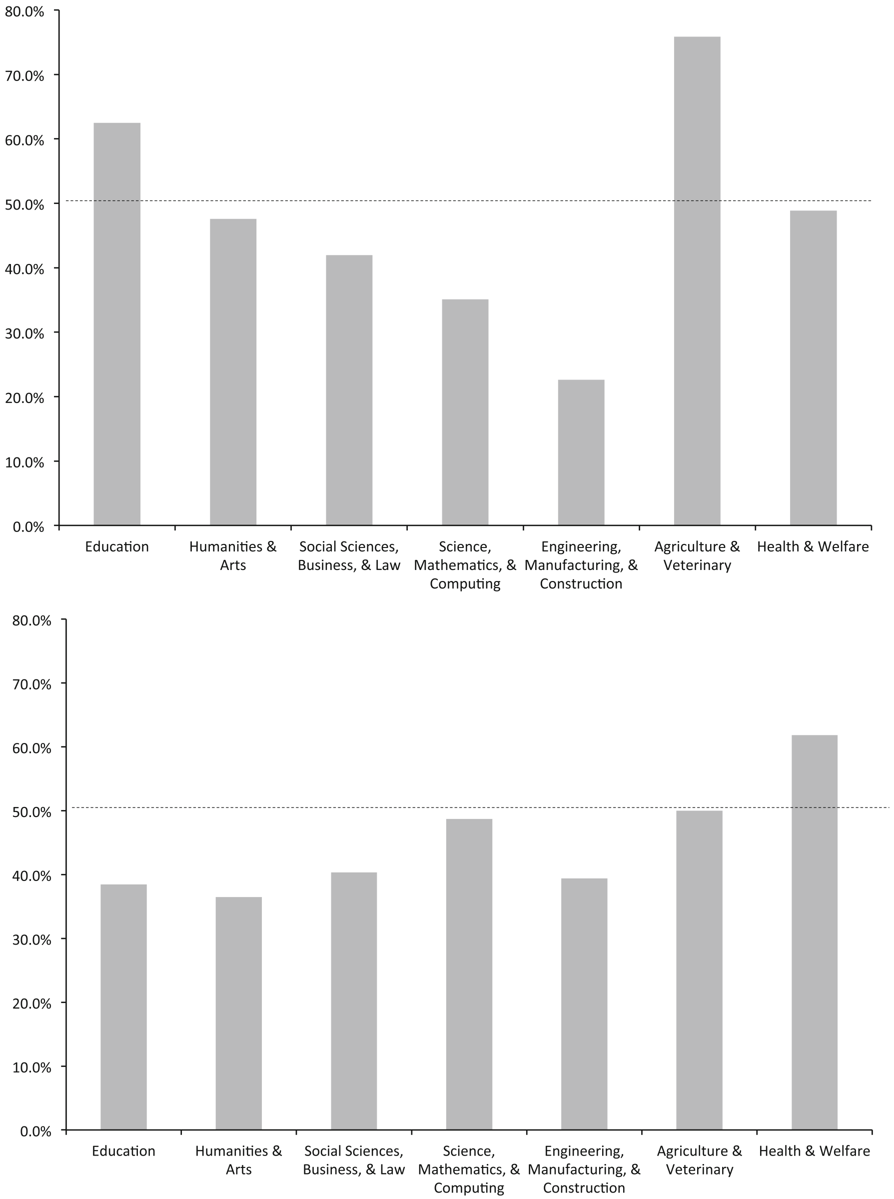


Fig. 6.4 Doctorates granted to women by broad field: Switzerland and Turkey, 2010. *Source*: *European Commission 2013*, Annex 2.2. The dashed line at 50% is shown for reference

Table 6.2 Number and percent of mathematics doctorates granted to women, 2011

	Resident women	Non-resident women	Total women Ph.D.s
UK	50 (19%)	70 (33%)	120 (25%)
USA	228 (28%)	296 (34%)	524 (32%)

Sources: Computed from McWhinnie and Fox (2013); AMS Annual Survey of the Mathematical Sciences 2011, Supplemental Table D.2

Table 6.3 Percent women in mathematics: Ph.D.s, 2010; faculties, 2005

Nation	Ph.D.s	Lecturers	Senior lecturers	Professors
Czech Republic	26	37.2	11.9	2.2
UK	25	24.8	12.6	2.8
Switzerland	16	26.7	14.3	3.1
Australia	–	28.5	22.9	3.6
Denmark		19.6	7.7	3.8
Germany	26	19.5	13.1	6.8
USA, top 100[a]	30	26.8	18.4	7.1
Canada	–	18.5	11.9	8.8
France	24	16.1	30.7	10.3
Spain	42	31.0	25.9	12.9
Italy	44	50.4	40.3	15.1
Portugal	68	50.4	45.9	32.1

Sources: *European Commission. 2013*, Annex 2.3; Hobbs and Koomen (2006, Table 2); Nelson and Brammer (2010, Table 11)

[a] US faculty for top 100 departments, 2007

A decade and a half later, a mathematician from Romania described similar experiences in the US:

> As a child growing up in Romania, she liked mathematics, and her parents encouraged her interests through participation in mathematics camps and enrollment in a high school for science and mathematics. However, if she stayed in Romania, her only option would have been to teach; doctoral studies were not an option. Cojocaru made the difficult decision to leave the familiarity of home, traveling first to Italy to continue her studies and later to Canada. It was not until she entered a program at Princeton University that she was ever confronted with being female and a mathematician. For Cojocaru, the gender component was not something about which she had ever really given much thought. (Kirkman and Scriven 2008, p. 15)

Table 6.3 illustrates how proportions of women on university mathematics faculties vary by nation. Countries are ordered by percentage of female professors, from the Czech Republic (2.2%) to Portugal (32.1%). Table 6.3 includes percentages from the top 100 US departments, with the US assistant, associate, and full professor listed, respectively, as lecturer, senior lecturer, and professor. The percentages at Princeton during Cojocaru's time, however, were far smaller (Andreescu et al. 2008; Case and Leggett 2005, pp. 169–170).

In the United States, the low numbers of female mathematics professors at elite universities are accompanied by the popular belief that women are not expected to do mathematics. Even 6-year-old children may show awareness of the stereotype "Girls don't do math" (Cvencek et al. 2011) or cultural stereotypes such as "Asians are good at math" (Ambady et al. 2001).

The apparent paucity of women in mathematics is sometimes explained, even by mathematicians, in terms of "hard-wired" biological differences, e.g., "male and female human brains are physically different … biology cannot readily be changed"

(Hill and Rogers 2012, p. 23).[3] Such explanations are offered by psychologists in popular books such as *The Female Brain* and *The Essential Difference*: *Men*, *Women and the Extreme Male Brain*, despite the shakiness of their evidence (Buchen 2011; Else-Quest 2007; Tallis 2012; Young and Balaban 2006).

Newspapers discuss claims such as "the leakage of women continues even after starting careers as assistant professors—especially in math and physical sciences, and this trend continues as women advance through the ranks" (Ceci and Williams 2011). Juxtaposed statistics suggest that leakage is occurring. "Only one-fifth of physics Ph.D.s in this country are awarded to women … of all the physics professors in the United States, only 14% are women" said the *New York Times*, a prominent US newspaper (Pollack 2013). *Nature*, a major international science journal, also juxtaposes percentages of doctorates and professors: "women earn about half the doctorates in science and engineering in the United States but comprise only 21% of full science professors and 5% of full engineering professors" (Shen 2013). Another example occurs in a prestigious US science journal:

> Today, half of all MD degrees and 52% of PhDs in life sciences are awarded to women, as are 57% of PhDs in social sciences, 71% of PhDs to psychologists, and 77% of DVMs to veterinarians…. Among the top 100 US universities, only 8.8–15.8% of tenure-track[4] positions in many math-intensive fields (combined across ranks) are held by women, and female full professors number ≤10%. (Ceci and Williams 2011, p. 3157)

These are dramatic differences. However, they are not, in fact, evidence that disproportionate losses are occurring now, although such losses have occurred in the past. The proportions of women in mathematics have increased, but have been masked by two types of phenomena: demographic inertia and gender stratification.

The next section reviews the evidence and illustrates these phenomena. Although their context is US academic mathematics, these phenomena can and do occur in other disciplines and other countries. The final section of the chapter discusses such national variations.

6.3 Change, Demographic Inertia, and Gender Stratification

In the United States, there are three main postsecondary degrees granted in mathematics: baccalaureate (B.A.), master's degree (M.A.), and doctor of philosophy (Ph.D.).

---

[3] This neglects findings about plasticity. The neuroscientist Lise Eliot notes:

> The notion that sex differences in the brain, because they are biological, are necessarily innate or fixed is perhaps the most insidious of the many public misunderstandings on this topic. Neuroscientists know that, in the absence of proof of genetic or hormonal influence, any sex difference in adult neural structure or function could be shaped through experience, practice, and neural plasticity. (2011, p. 897)

[4] "Tenure-track" has two different meanings in the United States. Here it means "faculty who are tenured or eligible for tenure." Because the other meaning is "eligible for tenure," this statement affords the very discouraging (and incorrect) interpretation that, relative to their shares of doctorates, women are currently underrepresented in junior faculty positions at top universities in fields such as mathematics, physics, computer science, and engineering.

6.3.1 Change in the Pipeline: Tertiary Education to Assistant Professor

Women have earned about 40% of baccalaureates in mathematics for at least 40 years. In contrast with the trend for undergraduate degrees, percentages of women earning Ph.D.s in mathematics have more than tripled over the past 40 years, from 8% in 1971 to 31% in 2010. As noted earlier, these percentages differ by nationality. Women earned 28% of Ph.D.s awarded to US citizens and 34% of those awarded to non-citizens in 2011.

Recent surveys find that women's share of tenure-eligible positions is similar to their share of new doctorates (see, e.g., Blair et al. 2013, Table S.16). Even at the top 50 mathematics departments, the proportions of female assistant professors now reflect their share of Ph.D.s (Nelson and Brammer 2010).

The trajectory from baccalaureate to Ph.D. to first academic position is often construed as a pipeline. Percentages of women at each stage are compared (e.g., 40% earning baccalaureates vs. 30% earning Ph.D.s) and differences interpreted as leaks. Thus, the pipeline appears to be leaking between undergraduate and graduate school, without obvious leaks between entrance to graduate school and first academic job (Cleary et al. 2013).

6.3.2 Demographic Inertia in the Trough: Faculty Employment

Overall, women are currently 23% of full-time doctorate-holding mathematics faculty in 4-year colleges and universities (Blair et al. 2013, Table F.1).[5] We might consider this to be evidence of a leak: 31% of Ph.D.s now go to women but 23% of doctorate-holding faculty are women—a difference of 8 percentage points. And, as noted earlier, such differences have, in fact, been interpreted as indicating that women are leaving mathematics, leading to well-publicized articles that offer explanations.[6]

These differences in percentages are not, however, unambiguous evidence of recent leaks. This is because the pipeline metaphor does not work well in interpreting statistics for all faculty, tenured faculty, or full professors rather than a cohort of doctorates. Comparing only percentages of women in faculty positions and among recent Ph.D.s omits past history. In typical departments (as opposed to newly created departments), preparation pipelines from four decades feed into the same "trough." Some faculty members were hired during the 1970s when women were earning 8% of Ph.D.s; some during the 1980s when women earned 20% of Ph.D.s; and some when women earned 30% of Ph.D.s.

---

[5] This figure includes only tenured and tenure-track faculty at 4-year institutions who hold Ph.D.s. It does not include postdocs or other full-time faculty.

[6] See Kessel (2014) for examples.

Rates at which women were hired and retained in mathematics also differ according to decade. During the 1970s, women who had earned doctorates did indeed leave academic mathematics more than men. In contrast, a longitudinal survey conducted in 1995 found that equal proportions of women and men who had earned Ph.D.s in 1980 were tenured or had tenure-track jobs 15 years later. But, the same survey found that men who earned Ph.D.s in 1985 were more likely to have tenure 10 years later than their female counterparts (Long 2001, pp. 127, 153, 167). Analyses of cross-sectional statistics for new doctorates' first jobs found that gender differences in unemployment rates were 2% or less for 1991–1995 and 1996–2008 (Flahive and Vitulli 2010).

In interpreting trough statistics, the notion of *demographic inertia* is useful. This is "the tendency for current population parameters, such as growth rate, to continue for a period of time; there is often a delayed population response to gradual changes in birth and mortality rates" (Glossary n.d.). Because of demographic inertia, workforce or academic demographics must change slowly if no new positions are created and there is no forced retirement, even assuming equitable outcomes at every stage of hiring and promotion.

Consider the following example for the decade of 1999–2009. The AMS reports that between about 1.25% and 4% of mathematics department faculty members retire or die each year.[7] Suppose that all of these faculty members are male,[8] they are replaced by new hires, and women do not leave after they are hired. Since 1999, the lowest annual percentage of Ph.D.s earned by women was 27% and the all-time high was 34%. These yield 3% and 14% as lower and upper bounds for percentage point increase in female faculty members after 10 years.

Statistics from the Conference Board of the Mathematical Sciences surveys show an increase of 6 percentage points between 2000 and 2010. In 2000, women were 17% of tenured or tenure-track faculty members at mathematics departments, increasing to 20% in 2005, and to 23% in 2010 (Blair et al. 2013, Table F1.1; Lutzer et al. 2007, Table F.1).

Consistent with these figures for mathematics, a detailed statistical study of academic sciences in the US between 1980 and 2005 finds "Much of the current underparticipation of women in academia can be explained by the time lags associated with overcoming historically very low representation" (Shaw and Stanton 2012, p. 3739).[9]

---

[7] See e.g., 2009 Survey Third Report, Figure 6.2. The rates for Groups I, II, III, IV, and Va are between 1.25 and 2.5%. These rates increase when M.A.- and B.A.-granting institutions are included.

[8] A look at Blair et al. (2013, Table F.4) suggests this is a correct assumption for Ph.D.-granting institutions, but less so for departments which grant B.A.s and M.A.s.

[9] Although it does not report these trends for mathematics, this may be due to the study design which combines NSF figures for mathematics and statistics with figures for computer science. Many more undergraduates earn B.A.s in computer science than in mathematics and statistics (e.g., in 2001, 43,597 vs. 11,437). But the reverse holds for Ph.D.s (e.g., in 2001, 768 vs. 1,001).

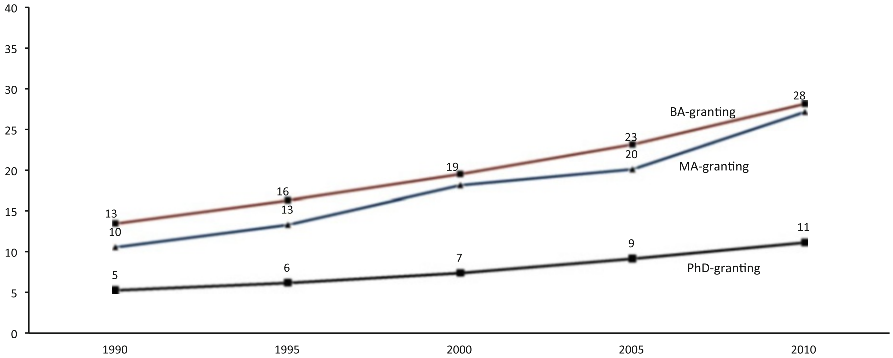


Fig. 6.5 Percent women in tenured positions, by department type, 1990–2010. *Source*: American Mathematical Society annual reports, http://www.ams.org/profession/data/annual-survey/annual-survey

6.3.3 Stratification in Academic Employment, Awards, and Degrees

Although the overall percentage of faculty members who are women has increased, tenured women are not uniformly distributed by type of department. As shown in Fig. 6.5, tenured women tend to be scarce in departments that grant Ph.D.s. Currently women are about 11% of the tenured faculty members at these departments. Like Mary Winston (the first US woman to be awarded a Ph.D. at Göttingen), women are disproportionately represented at less prestigious institutions. These institutions tend to have fewer resources such as journal subscriptions and funding for professional travel. This type of phenomenon, in which women within a profession tend to be clustered in less prestigious and advantageous positions, is known as *gender stratification* (also *vertical segregation*).[10]

Stratification also occurs for awards in mathematics. Relative to their presence as tenured faculty members, women are overrepresented as recipients of service awards, but underrepresented when it comes to awards for scholarship.

Figure 6.6 shows percentages of awards given to women by three professional societies. Each society has a different focus and thus a different primary nominee pool for awards. The AMS focuses on research in pure and applied mathematics. Its primary nominee pool is members of Ph.D.-granting mathematics departments, each of which has an AMS classification as Group I, II, or III.[11] Group I departments are the most prestigious. As shown by the horizontal dotted line in Fig. 6.6, less than 6% of the faculty in these departments is female. As shown by the grey bars, fewer than 5% of AMS awards for research go to women, but at least four times as many awards for service.

---

[10] Examples for other professions are given in Kessel (2014).

[11] Note that AMS classifications changed in 2012 to include applied mathematics in Groups I, II, III. See http://www.ams.org/notices/201209/rtx120901262p.pdf.

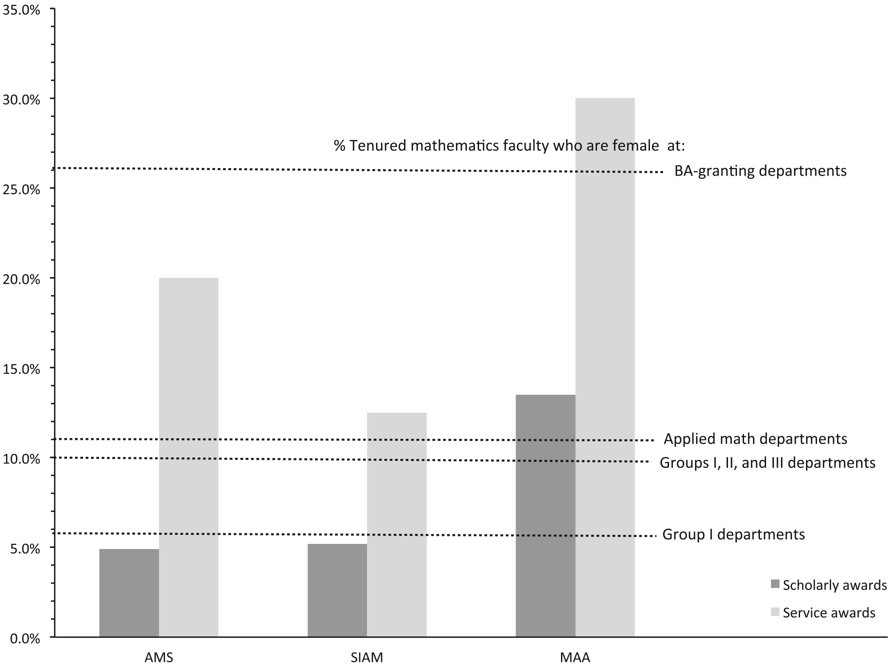


Fig. 6.6 Women's awards vs. women's representation. *Source*: Redrawn from Popejoy and Leboy 2012. "BA-granting department" is their "4-year institution"

The Society for Industrial and Applied Mathematics (SIAM) focuses on applied mathematics. Among academic departments (as opposed to government or industry) its primary nominee pool includes faculty in departments of pure or applied mathematics.

The Mathematical Association of America (MAA) focuses on advancing mathematics, especially at the undergraduate level. Its nominee pool is thus larger than that of AMS and its awardees more often include members of B.A.- and M.A.-granting departments.

Stratification also occurs for degrees in mathematics. Percentages of baccalaureates awarded to women vary by type of department: higher in B.A.- and M.A.-granting and lowest in Ph.D.-granting. Similarly, percentages of doctorates awarded to women vary by type of Ph.D.-granting department, as shown by AMS annual surveys (e.g., Supplemental Table F.1).

6.4 Concluding Remarks

This chapter has reviewed variation in gender segregation across nations; and two phenomena that occur within nations: gender stratification; and differences in percentages of women earning Ph.D.s and on department faculties. How do these phenomena vary and what might cause variation?

Gender segregation, *GDP*, *and societal attitudes*. The sociologists Maria Charles and Karen Bradley studied educational outcomes in countries from all five continents and Oceania.[12] They identified an association between gender segregation in tertiary education outcomes for 44 countries and industrialization: increased gender segregation occurs with increased gross domestic product (GDP). Charles (2011) sets this finding in a larger context of trends in education and labor force participation, offering the explanation that developed societies have an ideology of free choice but deeply seated beliefs and unconscious biases about gender which affects a woman's evaluation of her own abilities—and their evaluation by others. Examples of such beliefs were given in this chapter's Sect. 6.2.

Charles and Bradley (2009) note that economic necessity seems to play a larger role in developing or transitional societies. However, it should be noted that their study combines first, second, and third tertiary degrees (B.A.s, M.A.s, and Ph.D.s in US parlance). It seems easier to explain choice of field for a first than third degree in terms of financial incentives. In many fields, a doctorate is generally a path to an academic career, and the salient financial difference may be between academic and nonacademic occupations rather than between fields. However, the pathway to a third tertiary degree generally includes a first degree and is likely to be smoothed by the presence of same-gender peers and social acceptability. This may help to explain the cultural differences that surprised the two graduate students arriving from Brazil and Romania, and why percentages of women are larger among foreign doctorate recipients at UK and US universities (as in Table 6.2).

Are these differences due to more women from countries with less gender segregation? If so, research in mathematics education suggests a possible mechanism: women arriving from countries with less gender segregation may be more likely to already see themselves as part of the mathematical community (Herzig 2004), thus more likely to finish their graduate studies.

Gender stratification, *unconscious bias*, *and demographic inertia*. As a student becomes more deeply involved in mathematics, the effects of gender stratification may become a more salient part of daily experience—at least in developed countries, as illustrated by the US examples. One explanatory mechanism for gender stratification is unconscious bias in professional judgment. In the US, the latter has been documented by several studies with similar design and similar findings. An example is a recent study of the psychologist Corrine Moss-Racusin and colleagues (2012). Two groups of physicists, chemists, and biologists from research-intensive US universities evaluated an application for lab manager from a student. The materials given to the two groups were identical, except for the name of the applicant: Jennifer or John. "Jennifer" received lower ratings than "John" on competence and hireability. She was offered less mentoring and a lower salary.

Although large percentages of men in academic departments may be more due to demographic inertia than unconscious bias or attrition, causal differences are not

---

[12] These were countries which participated in the Trends in International Mathematics and Science Survey (TIMSS), thus very low income countries are underrepresented.

readily distinguishable. A further complication is that, independent of their cause, large proportions of males in an academic department may contribute to unconscious bias (Banaji and Greenwald 2013). In some countries, higher education is rapidly expanding and new universities are being created (e.g., China, UNESCO Institute of Statistics 2014). In such institutions, demographic inertia need not play a large role in determining proportions of faculty men and women, especially at the junior level, providing the potential to avoid reinforcing stereotypes unconscious bias and stereotypes about fields of study.

Change. Within the United States, the United Kingdom, and many European nations, proportions of female mathematicians and mathematics professors have generally increased between 1993 and 2005 (Hobbs and Koomen 2006).[13] In the US, a notable change is the increase in women at junior levels at elite mathematics departments over the past decade. Practices that reduce the effects of unconscious bias may be part of the explanation (see Kessel 2014).

Returning to the mathematicians whose stories began this chapter, we can interpret their choices as occurring in national contexts with different affordances and constraints. At the same time, their stories suggest possibilities for the future. Kovalevskaya emigrated from her homeland (marrying in order to be allowed to do so), studied in one country, and obtained a university post in another—both in locations of substantial mathematical activity. Chisholm studied abroad and returned to her homeland, maintaining an active mathematical life and contact with other mathematicians, but without an academic position. Winston also studied abroad and returned to her homeland (not then a center of mathematical activity), obtaining undistinguished academic posts—a form of gender stratification. Although Haynes did not leave her country to earn a doctorate, she undoubtedly encountered cultural obstacles in education and employment due to her minority status.

Which of these are stories that must be as higher education expands? Mathematicians and policy-makers will have important roles in determining the answer.

Acknowledgments Thanks to Sylvia Bozeman, Janet Mertz, and two anonymous reviewers for thoughtful comments on an earlier version of this chapter. Portions of the section on “Change, Inertia, and Gender Stratification” are revisions of the section on “Women in Mathematics: A Statistical Picture” in “Understanding Underrepresentation,” an article in the Springer journal *The Mathematical Intelligencer*. These are reused by kind permission from Springer.

---

[13] The Czech Republic is a counterexample.

6.5 Appendix: Mathematics Ph.D.s in 2010, by Gender and Nation

Nation	Women	Men	All Ph.D.s	% Women
Austria	25	36	61	40.98
Belgium	24	31	55	43.64
Bulgaria	5	4	9	55.56
Croatia	5	8	13	38.46
Cyprus	1	1	2	50.00
Czech Republic	16	45	61	26.23
Denmark	91	170	261	34.87
Estonia	0	2	2	0.00
Finland	10	29	39	25.64
Former Macedonia	0	0	0	0.00
France	87	270	357	24.37
Germany	134	391	525	25.52
Greece	11	40	51	21.57
Hungary	11	31	42	26.19
Iceland	0	1	1	0.00
Ireland	6	11	17	35.29
Italy	127	161	288	44.10
Latvia	0	0	0	0.00
Lithuania	6	3	9	66.67
Luxembourg	0	2	2	0.00
Malta	0	0	0	0.00
Netherlands	0	0	0	0.00
Norway	0	0	0	0.00
Portugal	38	18	56	67.86
Romania	117	170	287	40.77
Slovakia	29	23	52	55.77
Slovenia	1	4	5	20.00
Spain	86	120	206	41.75
Sweden	28	71	99	28.28
Switzerland	8	43	51	15.69
Turkey	71	64	135	52.59
UK	135	382	517	26.11
USA	476	1,116	1,592	29.90
Total	1,548		4,795	32.28

Source: *European Commission. 2013*, Annex 2.3

Chapter References

Ambady, Nalini, Margaret Shih, Amy Kim, and Todd L. Pittinsky. 2001. Stereotype Susceptibility in Children. *Psychological Science* 12(5): 385–390.

Andreescu, Titu, Joseph A. Gallian, Jonathan M. Kane, and Janet E. Mertz. 2008. Cross-cultural Analysis of Students With Exceptional Talent in Mathematical Problem Solving. *Notices of the American Mathematical Society* 55(10): 1248–1260.

Banaji, Mazarin, and Anthony Greenwald. 2013. *Blindspot: Hidden Biases of Good People*. New York: Delacorte Press.

Blair, Richelle, Ellen Kirkman, and James Maxwell. 2013. *Statistical Abstract of Undergraduate Programs in the Mathematical Sciences in the United States: Fall 2010 CBMS Survey*. Providence: American Mathematical Society.

Buchen, Lizzie. 2011. When Geeks Meet. *Nature* 479: 25–27.

Case, Bettye Anne, and Anne M. Leggett (eds.). 2005. *Complexities: Women in Mathematics*. Princeton: Princeton University Press.

Ceci, Stephen, and Wendy Williams. 2011. Understanding Current Causes of Women's Underrepresentation in Science. *Proceedings of the National Academy of Sciences* 108(8): 3157–3162.

Charles, Maria. 2011. A World of Difference: International Trends in Women's Economic Status. *Annual Review of Sociology* 37: 355–371.

Charles, Maria, and Karen Bradley. 2009. Indulging Our Gendered Selves? Sex Segregation by Field of Study in 44 Countries. *American Journal of Sociology* 114(4): 924–976.

Cleary, Richard, James W. Maxwell, and Colleen Rose. 2013. Report on the 2011–2012 New Doctoral Recipients. *Notices of the American Mathematical Society* 60(7): 874–884.

Cvencek, Dario, Andrew Meltzoff, and Antony Greenwald. 2011. Math–Gender Stereotypes in Elementary Children. *Child Development* 82(3): 766–779.

Eliot, Lise. 2011. The Trouble with Sex Differences. *Neuron* 72: 895–898.

Else-Quest, Nicole. 2007. Biological Determinism and the Never-Ending Quest For Gender Differences [Review of *The Female Brain*]. *Psychology of Women Quarterly* 31: 322.

European Commission. 2013. *She Figures 2012: Gender in Research and Innovation. Statistics and Indicators*. Brussels: Publications Office of the European Union.

Flahive, Mary, and Marie Vitulli. 2010. An Update: Are Women Getting all the Jobs? *Notices of the American Mathematical Society* 54(8): 984–986.

Glossary. n.d. *Colorado Greater Sage-Grouse Conservation Plan,* http://wildlife.state.co.us/SiteCollectionDocuments/DOW/WildlifeSpecies/SpeciesOfConcern/GreaterSageGrouse/StatewideConsPlan/Glossary.pdf (accessed January 2014).

Green, Judy, and Jeanne LaDuke. 2009. *Pioneering Women in American Mathematics: The Pre-1940 PhD's*. Providence: American Mathematical Society and London Mathematical Society.

Green, Judy and Jeanne LaDuke. 2011. Newsom, Mary (Winston). In *Supplementary Material for Pioneering Women in American Mathematics: the pre-1940 PhD's*, 453–458. http://www.ams.org/publications/authors/books/postpub/hmath-34-PioneeringWomen.pdf. Accessed 24 March 2014.

Herzig, Abbe. 2004. Becoming Mathematicians: Women and Students of Color Choosing and Leaving Doctoral Mathematics. *Review of Educational Research* 74(2): 171–214.

Hill, Theodore, and Erica Rogers. 2012. Gender Gaps in Science: The Creativity Factor. *The Mathematical Intelligencer* 34(2): 19–26.

Hobbs, Catherine and Esmyr Koomen. 2006. *Statistics on Women in Mathematics*. European Women in Mathematics. http://www.europeanwomeninmaths.org/women-in-math/report/statistics-women-in-maths-in-europe-1993-and-2005. Accessed 5 April 2014.

Kessel, Cathy. 2009. Notes on the Two-Body Problem. *Association for Women in Mathematics Newsletter* 39(6): 14–16.

_____. Kessel, Cathy. 2014. Understanding Underrepresentation. *Mathematical Intelligencer*, 36(4): 10–18.

Kirkman, Ellen E., and Olivia A. Scriven. 2008. *Promoting Diversity at the Graduate Level in Mathematics: A National Forum*. Berkeley: Mathematical Sciences Research Institute.

Koblitz, Ann Hibner. 1999. Science, Women, and the Russian Intelligensia. In *History of Women in the Sciences: Readings from* Isis, ed. S. G. Kohlstedt, 201–219. Chicago: University of Chicago.

Long, J. Scott (ed.). 2001. *From Scarcity to Visibility: Gender Differences in the Careers of Doctoral Scientists and Engineers*. Washington, DC: National Academy Press.

Lutzer, David, Stephen Rodi, Ellen Kirkman, and James Maxwell. 2007. *Statistical Abstract of Undergraduate Programs in the United States. Fall 2005 CBMS survey*. Providence: American Mathematical Society.

McWhinnie, Sean, and Caroline Fox. 2013. *Advancing Women in Mathematics: Good Practice in UK University Departments*. London: London Mathematical Society.

Moss-Racusin, Corinne A., John F. Dovidio, Victoria L. Brescoll, Mark J. Graham, and Jo. Handelsman. 2012. Science Faculty's Subtle Gender Biases Favor Male Students. *Proceedings of the National Academy of Sciences* 109(41): 16474–16479.

Murray, Margaret A. M. 2012. Women Mathematicians on the Web, Part II: Finding the First. *Association for Women in Mathematics Newsletter* 42(4): 11–15.

National Research Council. 2013. *The Mathematical Sciences in 2025*. Washington, DC: National Academies Press.

National Science Board. 2014. *Science and Engineering Indicators 2014*. Washington, DC: National Science Foundation.

Nelson, Donna J., and Christopher Brammer. 2010. *A National Analysis of Minorities and Women in Science and Engineering Faculties at Research Universities*. Norman: Diversity in Science Association and University of Oklahoma.

Parshall, Karen, and Adrian Rice (eds.). 2002. *Mathematics Unbound: The Evolution of an International Community, 1800–1945*. Providence: American Mathematical Society and London Mathematical Society.

Pollack, Eileen. 2013. Why Are There Still So Few Women In Science? *New York Times.* October 3

Popejoy, Alice, and Phoebe Starbird Leboy. 2012. Is Math Still Just A Man's World? *Journal of Mathematics and System Science* 2: 292–298.

Shaw, Allison, and Daniel Stanton. 2012. Leaks in the Pipeline: Separating Demographic Inertia from Ongoing Gender Differences in Academia. *Proceedings of the Royal Society B* 279: 3736–3741.

Shen, Helen. 2013. Mind the Gender Gap. *Nature*, 475: 22–24.

Tallis, Raymond. 2012. Wit and Wickedness: Is it All in the Brain? *Brain* 136: 980–984.

UNESCO Institute of Statistics. 2014. *Higher Education in Asia: Expanding Out, Expanding Up. The Rise of Graduate Education and University Research*. Montreal: Author.

Walker, Erica N. 2009. 'A Border State': A Historical Exploration of the Formative, Educational, and Professional Experiences of Black Mathematicians in the United States. *International Journal of the History of Mathematics Education* 4(2): 53–78.

Wiegand, Sylvia. 2005. My Grandmother, Grace Chisholm Young. In *Complexities: Women in Mathematics*, ed. B. A. Case and A. Leggett, 39–45. Princeton: Princeton University Press.

Young, Rebecca M., and Evan Balaban. 2006. Psychoneuroindoctrinology [Review of The Female Brain]. *Nature* 443(12): 634.

Vignette 6.1

Importance of HBCUs in the Development and Nurturing of African American Women Mathematicians

Tasha R. Inniss

In this article, I explore those common themes that contributed to the success of African-American women mathematicians. In particular, I discuss how HBCUs and their nurturing environment encourage women of color to pursue and attain doctorates in mathematics. I consider African-American women who received their doctorates in mathematics in the first decade of the new millennium (2000–2010). In 1943, the first African American woman, Euphemia Lofton Haynes, earned a Ph.D. in mathematics from the Catholic University of America (Williams 2001). It was another 6 years before the second African American woman, Evelyn Boyd Granville, earned her mathematics' doctorate from Yale University (Williams 2001). By 1973, there were less than 20 African American women with Ph.D.s in the mathematical sciences. Though the numbers have improved somewhat in the last few decades, the percentages of all science and engineering (S&E) doctorates awarded to African American women in mathematics remains low. According to Fig. 6.7, in the decade 2001–2010, the percentage of all S&E doctorates awarded to African American women in mathematics never exceeded 0.09% (NCSES 2011). The decadal average is only 0.04%.

Between 1974 and 1978, no Black women earned Ph.D.s in mathematics (Kenschaft 1981, p. 593). In 2000, I was one of the first three African American women who were awarded Ph.D.s in mathematics from the University of Maryland, College Park. Based on my own experiences as well as those of my sister mathematicians, I surmise that persistence to the doctorate is related to our undergraduate experiences. In the first decade of the new millennium, the vast majority of the African American women earning doctorates in mathematics that I know received

---

T.R. Inniss (✉)
Department of Mathematics, Spelman College, Atlanta, GA 30314-4399, USA
e-mail: TInniss@spelman.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_6

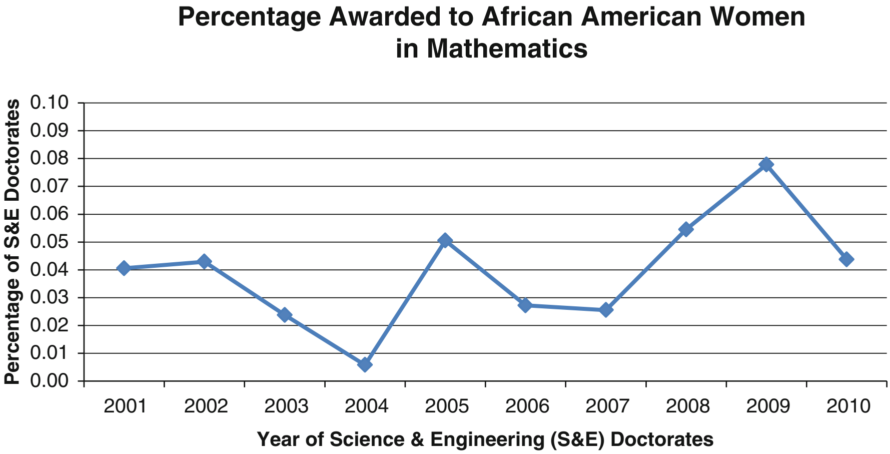


Fig. 6.7 Percentage of all S&E doctorates awarded to African American women in mathematics. *Source*: National Science Foundation, National Center for Science and Engineering Statistics (NCSES) *Doctorate Recipients from U.S. Universities*: *2011*

their bachelor's degrees in mathematics from Historically Black Colleges or Universities (HBCUs).[14]

The question now becomes, "what aspects of the HBCU environment and experience promote persistence among African American women who successfully attain doctorates in mathematics?"

According to Cooper (2004), Black graduate students reported that undergraduate professors were a significant influence in their decision to pursue a mathematics doctorate. Many of the Black women mathematicians who received their doctorates during the 2000–2010 time frame credit their undergraduate institutions for providing them not only with a strong academic foundation, but also with self-assurance in their mathematical abilities. In personal communications (August 2003), several of my sister mathematicians shared their undergraduate experiences and opinions about why they persisted to the Ph.D. in mathematics. Of the 33 African American women I know who completed their doctorates in the mathematical sciences during the years 2000–2010, 11 of them received their bachelor's degree from Spelman College, a Historically Black College for women. Kimberly S. Weems, Spelman Class of 1993 and one of the three University of Maryland, College Park doctorate recipients, said: "my classes were rigorous, and my professors always had high expectations of me. My African-American female professors were my role models." She goes on to state that the "emphasis…on being able to explain and teach that

---

[14] According to the Higher Education Act of 1965, institutions are defined as HBCUs if they were "established prior to 1964 [and the] principal mission was, and is, the education of Black Americans…" *Source*: http://www.house.gov/legcoun/Comps/HEA65_CMD.pdf.

which [she] had learned [as well as on] undergraduate research during the academic year and summers" really strengthened her knowledgebase in preparation for graduate school. Kim Woodson Barnette, Spelman Class of 1992, feels that her mentors and the professional mathematical activities in which she was able to participate as an undergraduate, (interacting with NASA scientists, giving research talks at conferences, and publishing) really prepared her well for graduate study in mathematics. "…My mentors Dr. Teresa Edwards and the late Dr. Etta Falconer challenged and nurtured me and gave me the confidence that if I can do math, I can do anything!… This high self-esteem helped when I was in academic settings that weren't culturally sensitive nor gender diverse." Her business partner in Delta Decisions of DC, a consulting firm, is mathematician Shree Whitaker Taylor, an alumna of the HBCU Clark Atlanta University, Class of 1995. Taylor explains: "I had extraordinary professors … who challenged me beyond my limitations. …My professors and mentors helped to further develop my self-esteem." Calandra Tate Moore, an alumna of my alma mater Xavier University of Louisiana, the only Catholic HBCU, states that her "experience with conducting research, attending conferences, and presenting [her] work was perhaps the most beneficial preparation for graduate school." Shea Burns received both her undergraduate degree and doctorate in mathematics from HBCUs: North Carolina A&T State University (NCA&T) and Howard University, respectively. She feels that NCA&T's "[encouragement of] the math majors to form study groups…created good study habits [which] made [her] comfortable with talking about mathematics with her peers." She also states that NCA&T "stressed the importance of building a support system of mentors and peers" that could help her "to deal effectively with racial or gender bias."

In sum, attending a college, especially an HBCU, with a rigorous curriculum, nurturing environment with high expectations, mentors, research experiences, and preparation to handle nonacademic issues, tend to promote persistence. Instituting these strategies may prove to be promising practices for any college committed to increasing the number of African American women who earn doctorates in mathematics. It is evident that for women who attended HBCUs, smaller class sizes and a more nurturing environment contributed to them proceeding and receiving their doctorate in mathematics (Borum and Walker, 2012). HBCUs are unique American institutions that have been overwhelmingly successful in graduating African Americans who pursue and attain Ph.D.s in science and engineering.

References

Borum, Viveka and Walker, Erica. 2012. What Makes the Difference? Black Women's Undergraduate and Graduate Experiences in Mathematics. *The Journal of Negro Education* 81(4): 366–378.

Cooper, Duane A. 2004. Recommendations for Increasing The Participation and Success of Blacks in Graduate Mathematics Study. *Notices of the AMS* 51(5): 538–543.

Kenschaft, Patricia. 1981. Black Women in Mathematics in the United States. *American Mathematical Monthly* 88(8): 592–604.

National Science Foundation, National Center for Science and Engineering Statistics (NCSES). 2011. *Doctorate Recipients from U.S. Universities: 2011,* http://www.nsf.gov/statistics/sed/digest/2011/nsf13301.pdf (accessed May 2013).

Williams, Scott W. 2001. Martha Euphemia Lofton Haynes, First African American Woman Mathematician. *Mathematicians of the African Diaspora*, http://www.math.buffalo.edu/mad/PEEPS/haynes.euphemia.lofton.html (accessed July 2013).

Vignette 6.2
Mexican Women in Mathematical Research

Patricia Saavedra Barrera

In 1971, when I attended my first class at National Autonomous University of Mexico (UNAM) there were only three full-time professors who taught mathematics at the Faculty of Science, the rest were hired by hours. Most of them were male; even though, nearly 30% of the students were women. At that time, mathematics was offered by only two universities in Mexico City, and at eight universities in the rest of the country. Things have changed considerably during the last 40 years. Today, mathematics is offered in 35 universities. In most of the departments, at least 30% of their members are full-time teachers and 25% of them are women.

The first university that offered undergraduate studies in mathematics was UNAM. The program was created in 1949. In fact, the first graduate student was a woman. For many years, most of the women who studied mathematics were interested in teaching at high schools or universities. It was not until 1973 that the first woman was hired as a professor at the Mathematical Institute at UNAM. Slowly, but steadily, an increased number of the women who earned a doctoral degree, continued to do research in mathematics. This article presents the evolution and the future perspectives of women in mathematical research in Mexico.

6.6 The National System of Research

Data from ANUIES 2010 showed that almost 40% of the students inscribed in undergraduate studies related to mathematics are women. This percentage decreases to 25% for graduate studies. Because women have a higher graduation rate, they earn nearly 28% of the new doctoral degrees in mathematics. To have a good

---

P.S. Barrera (✉)
Departamento de Matemáticas, Universidad Autónoma Metropolitana,
Iztapalapa, Distrito Federal, Mexico
e-mail: psb@xanum.uam.mx

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_6

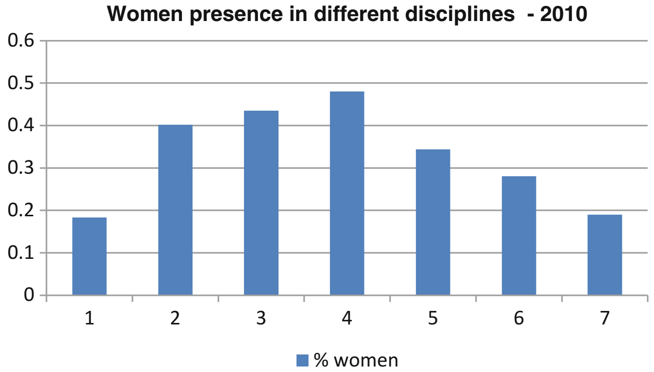


Fig. 6.8 Percentage of women in each group of SNI

estimate of the number of women who are active in research, National System of Researchers (SNI) data must be consulted. In 1984, SNI was created in order to recognize and encourage scientific and technological research. To be a member of SNI, it is necessary to work in an educational institution or in a national research center. Members of SNI are classified in three levels depending on their productivity. The higher the productivity, the higher the level. Members of SNI receive a monthly payment depending on their level. Additionally, there is a special category, called candidate, for young researchers who have obtained their doctoral degree in the last 3 years. Not all researchers are SNI members, but most of the members of the academic community belong to it.

SNI classifies disciplines in seven different areas: (1) physics-mathematics and earth sciences, (2) biology and chemistry, (3) medicine and health sciences, (4) psychology and human studies, (5) social sciences, (6) biotechnology, agriculture and animal sciences, and (7) engineering. In 1990, women accounted for approximately 20% of all members of SNI. By 2010, this percentage had increased to 33%. Figure 6.8 shows the percentage of women in each group of the SNI. It can be observed that the lowest number is for the first group composed by disciplines as astronomy, earth sciences, physics, and mathematics where only 18.3% of the members are women.

6.7 Mathematicians as Members of SNI

In 2010, there were 458 mathematicians as full members of the SNI, 18.3% of whom were women. As we can observe in Fig. 6.9, women represented 24.4% of the researchers in level 1, 13.8% of level 2, but only 4.3% of the highest level. It is important to point out that ever since SNI's creation women mathematicians have not been part of the evaluation committee of SNI. In 2009, there was optimism about the percentage of women at the candidate level would eventually reduce the gender gap. Data reveal from 2009 (27.5%) to 2013 (27.9%) there was virtually no change in the percentage of women in the candidate level.

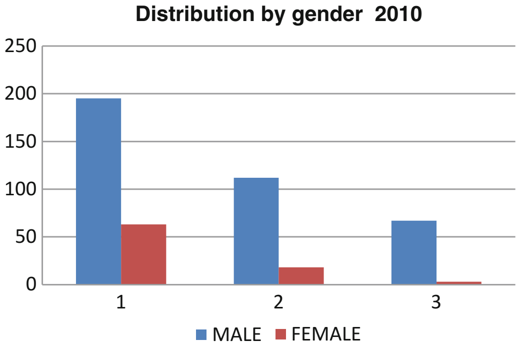


Fig. 6.9 Distribution by levels and gender of mathematician members of SNI

6.8 Programs to Promote Women's Participation

To encourage women's participation in science, SNI has taken some measures, such as giving 1 or 2 years of grace before evaluating women who have given birth in the last year. In 2004, the National Mathematic Society (SMM) created financial support for women in their last year as doctoral students or who have obtained their doctoral degree in the last 5 years in order to increase their presence in mathematical research. This program was supported by the Sofia Kovalevskaya Foundation. The institution was establish by Ann Hibner and Neal Koblitz, who have been active in supporting women in science in developing nations. Since 2004, 38 women have obtained support. Most of them have a position at a university or a national research center. The results of these programs are slow and until now have not had a direct impact in increasing the presence of women in research.

Finally, how are numbers in Mexico in comparison with the United States? We do not have accurate data of the number of women members of SNI that have tenure, but I estimate that probably half of them have earned it. This would be lower than the 14% reported for the United States by the American Mathematical Society (2010).

References

Anuario Estadístico Licenciaturas y Tecnológicos. ANUIES. 2010. http://www.anuies.mx/content.php?varSectionID=166.
Anuario Estadístico Posgrado. ANUIES. 2010. http://www.anuies.mx/content.php?varSectionID=166.
Data from SNI. 2009-2013. Personal Communication. 2013.
2010 Annual survey of the mathematical sciences in the United States. AMS. http://www.ams.org/profession/data/annual-survey/2010Survey-DepartmentalProfile-Supp-TableFF1-3.pdf.

Vignette 6.3
Women and Mathematics in Cambodia

Chantara Tann

6.9 Girls' Education in Cambodia

Female literacy rates in Cambodia have always been marked by struggle, and the unfortunate truth is that they have improved very little over time. In a 2003 study, Oxfam GB noted that only 22% of Cambodian women could read a newspaper or write a simple letter. The situation today is much the same. In addition to this sad condition, literacy rates in rural areas are even lower, with a considerable gap between male and female literacy levels: 20.6% points. In older populations, the gender disparities are even more stark. "Among those 65 years and older, only 15.7% of females are literate compared to 71.4% among males" (NIS 2013).

There are specific reasons accounting for the low literacy and, also, high dropout rates among women in Cambodia. The first factor is rooted in traditional stereotyping of women. In rural areas, women are expected to only undertake domestic work around the home. In some instances, education is even viewed as a hindrance to women, especially since some men may not wish to marry an educated woman. Therefore, in poor households priority is given to educating sons, whereas daughters can be kept home to assist in domestic chores. Furthermore, parents cling to the idea that, even if girls are well educated, they would still marry and remain as a housewife in the home—so educating girls would just be a waste. The second factor is the availability of schooling. Underpaid and under-resourced teachers ask for informal enrollment fees from students to help maintain the school and staff. In addition to these fees are expenses for stationery supplies such as pens, for textbooks, and for uniforms. Therefore, practically speaking, education can place large financial burdens on poor families that in many instances cannot be met.

C. Tann (✉)
Institute of Technology of Cambodia (ITC), Russian Blvd, Phnom Penh, Cambodia
e-mail: tann_chantara@yahoo.com.au

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_6

6.10 Why Do Girls Like and Dislike Studying Mathematics?

In the past, Cambodian women simply were not allowed to study at school. They studied only what their parent could offer at home and parents typically would tell them that they could not get a higher education. That is, they should marry and have a happy family, deterring any possible interest in science and mathematics. Nowadays, despite their overall low representation, the number of female students has increased and some are interested in mathematics. However, they often find it difficult because they have little time to study such that, even if they actually finish high school, they would lack preparation and tend to choose other fields.

Cambodia is a developing country where science and information technology have improved in a remarkable way. According to statistical data on student enrollments in the 2012–2013 academic year (NIS 2013), in primary school there were 2,173,384 students of which 1,022,983 (47.07%) were girls; in high school, there were 508,448 students of which 263,369 (51.8%) were females. Based on my own experience, girls are interested in mathematics and science, but they think that mathematics is just too difficult to study and that they may not be as good as the boys.

However, there are some points that might draw them to study mathematics. The first one is that they believe that it is an important subject and come to the realization that it can aid them in understanding other subjects. Secondly, they will have opportunities to sit for both national and international outstanding student examinations. Thirdly, although they might find studying mathematics difficult, they know that finding a job would be easier if they continue their education and finish their bachelor's degree in mathematics. Lastly, if they happen to have parents who are educated, then they may well follow in their footsteps; parents can provide encouragement and time for daughters to study.

According to 2012 statistical reports from the Royal University of Phnom Penh (RUPP), the number of females studying the natural sciences has been less than in the social sciences and in humanities and foreign languages. The total number of students in the social sciences and humanities was 2,343, of which 981 were females; the total number of students in the natural sciences was 3,688, of which 640 were females. More specifically, of 648 students (both scholarship and paying) studying mathematics, only 120 students were women. The report made it clear that fewer female students compared to male students continued study in the natural sciences. Among the female students, some chose to study the natural sciences due primarily to their own interests, and others did so as a familial obligation. One more thing: some female students chose to study mathematics in RUPP simply because they thought that there were fewer females in the field. After they graduated, they could find jobs and have opportunities for scholarships to go abroad, especially since the RUPP curriculum consisted of mathematics and physics, which appear as subjects on every related examination.

6.11 Why Did I Study Mathematics?

I was interested in mathematics because of my mother. She always told me to do mathematics exercises every day when I was young. She told me that if I was not good at mathematics, I would face a lot of problems in the future. I started learning mathematics every day until it essentially became my hobby. I was very happy whenever I could solve a mathematics problem. In my class, I always received high scores in mathematics and other subjects as well. When I finished primary school, the school had prepared an awards ceremony for outstanding students; I was honored in that ceremony and received a certificate. This experience at a young age was very motivating. I was very happy and it made me try harder and harder and I ultimately became one of the outstanding students in mathematics in my province. Unfortunately, I was not recognized as an outstanding student at the national level, but it did not stop me from studying hard. After I finished high school, I decided to study at RUPP and graduated with an outstanding result. With the strong support from teachers at RUPP (especially from Mr. MAUK Pheakdei) and my family, I decided to pursue the master's degree in mathematics at RUPP, the success of which led me to become a teacher at the Institute of Technology of Cambodia (ITC).

My dream of becoming a good mathematics teacher came true and I was able to prove that a female could also be a clever mathematics teacher. I am very proud to be a teacher at ITC. I have had a variety of experiences and have received recognition from the director and especially from Mr. MOEUNG Noi, head of the foundation year department. He has allowed me opportunities to conduct research for the subjects that I teach. At ITC, I have always encouraged all of my students to keep on learning mathematics, stressing that it provides long-term benefits in life. I always hope that other Cambodian women will follow me and choose to study science more and more in the future in order to help this small country progress.

References

National Institute of Statistics (NIS). 2013. *Summary Statistics 2012/2013, Kingdom of Cambodia*.

Royal University of Phnom Penh (RUPP). 2012. *Student Statistics*, http://www.rupp.edu.kh/stu_statistic.php (accessed 1 March 2014).

World Pulse. 2009. *Girls' education in Cambodia*, http://worldpulse.com/node/14678 (accessed 1 March 2014).

Chapter 7
Women in Statistics: Scientific Contributions Versus Rewards

Lynne Billard and Karen Kafadar

> *Since the days of Snedecor and Cochran*
> *the "best person" has frequently been a woman*
>
> —Salsburg (2001, p.206)

7.1 Introduction

Despite the fact that the early years of statistics were dominated by men, who were more likely to be admitted to and receive advanced degrees from universities, a few notable women statisticians made extremely important and critical contributions to the diverse fields of science. As noted by Salzburg (2001, p.197), "Many women were working in the field, but they were almost all employed in doing the detailed calculations needed for statistical analysis, and were indeed called 'computers'." In fact, all the women we discuss in this chapter started their careers in exactly this way. Yet, some of these women broke out of their "computer" roles and rose to the most prestigious ranks of academe and government, where they made fundamental contributions to statistics and science. Due to the earlier accessibility of university admission to women in England and America (which, even there, was limited in many departments), most of these women came from these two countries. In this chapter, we describe briefly the careers of some of these women, noting their contributions and the influences that led them to make them. Regrettably, however, at least in the United States, salaries have not kept pace with the significance of the contributions of these women. In the second part of this chapter, we describe the

---

L. Billard
Department of Statistics, University of Georgia, Athens, GA 30602, USA

K. Kafadar (✉)
Department of Statistics, University of Virginia, Charlottesville, VA 22904, USA
e-mail: kkafadar@virginia.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_7

data on salaries that have been collected only 20 years after the 1972 passage of Title IX Affirmative Action in the United States (Billard 1994), and more recently, in the 20 years since then.

7.2 Scientific Contributions of Some Women Statisticians

7.2.1 Florence Nightingale

Florence Nightingale (1820–1910) was an English statistician and the first woman member of the Royal Statistical Society. Her name is most frequently associated by the lay public with her establishment of a nursing school in London, but her true love was mathematics and in quantifying social phenomena by objective measurement and analysis. In collecting mortality statistics and presenting them with informative displays, she was able to persuade influential nineteenth-century British Members of Parliament of the need for health policy reform among soldiers in the Crimean War. She developed clever displays of numerical information (e.g., pie charts) to emphasize her messages. She led the efforts to improve medical care in India, and later she provided a convincing report of sanitary reform: "Nightingale reported [in 1873] that mortality among the soldiers in India had declined from 69 to 18 per 1,000" (Cohen 1984). Her recognized success in this regard prompted the US government to consult her on matters of army health during the Civil War. Salsburg (2001, p.iv) colorfully opened his book with a quotation from her: "To understand God's thoughts, we must study statistics, for these are the measure of his purpose."

Interestingly, Florence Nightingale credited "the friendship of power men" with her success: "I have never found one woman who has altered her life by one iota for me or my opinions" (Wikipedia, accessed 30 December 2013, citing Cook (1913) and McDonald (2005)). She believed strongly that women had a responsibility to "bring the best that she has" regardless of "whether it is 'suitable for a woman' or not".[1]

7.2.2 F.N. David

English mathematician and statistician F.N. David (1909–1993) was named for Florence Nightingale, whom her parents admired and knew well. Although she showed a remarkable aptitude for mathematics at an early age, she drifted into statistics because she wanted to do something practical with her mathematical training, which ultimately led her to Karl Pearson at University College, London.

F.N. David made theoretical contributions to the fields of combinatorics, probability, and statistics, most notably through her books *Table of Correlation Coefficients* (1938), *Combinatorial Chance* (with D.E. Barton 1962) and *Games, Gods, and*

---

[1] http://www.amstat.org/about/statisticiansinhistory/

Gambling: A History of Probability and Statistical Ideas (1962). She conducted critical work in London for the Home Office during World War II to estimate the effects of bombs on the public works systems as well as on the loss of lives. Her statistical models of these effects enabled the Allies to prepare effectively for the German offense in 1940–1941. She credits her remarkable career to her mentors, Karl Pearson, who hired her as his research assistant, and Jerzy Neyman, who encouraged her to submit her research papers for a Ph.D. degree and later hired her at University of California (UC) at Berkeley. She moved to UC Riverside in 1968, and in 1970 she founded and chaired the Department of Statistics where she continued to make fundamental contributions in mathematical statistics, as well as after her retirement in 1977. She spent her last years doing research at UC Berkeley.

7.2.3 Stella Cunliffe

Stella V. Cunliffe (1917–2012) was the first woman President of the Royal Statistical Society (1975–1977) and the first woman Director of Statistics at the Home Office London UK. After her economics degree from the London School of Economics and 5 years employment at the Danish Bacon Company, she volunteered in Europe with the Guide International Service (1945–1947), with which she remained involved as a member of its Governing Council. A large part of her career was at Guinness brewery (1947–1970), "a community in which the attitude to the statistician, because of the reputation of one Gosset, was one of reverence" (Cunliffe 1976, p.2). Disqualified from being Director due to her gender (Dorking and Leatherhead *Advertiser*, 26 January 2012), she left the brewery to head the research unit on crime at the UK's Home Office. Two years later, she was promoted to Director of Statistics, the first woman to reach this rank in the British Government Statistical Service. Working closely with Home Office Secretary Roy Jenkins, "her research helped to influence many of his key decisions, including the abolition of capital punishment" (Dorking and Leatherhead *Advertiser*, 26 January 2012). She remained in this post at the Home Office until 1977, when she became Statistical Adviser to the Committee of Enquiry into the Engineering Profession (1978–1980). She was appointed Member of the Most Excellent Order of the British Empire in 1993, a prestigious honor in Britain's order of chivalry.

Stella Cunliffe was, by all accounts of those who knew her, an amazing and remarkable person with a formidable character. Her research and interaction with her superiors brought her great respect for her judgment which usually was accepted. Her Presidential address to the Royal Statistical Society focused on the practical aspects of statisticians making an impact on society: by interacting with others, "wherever they find themselves; with other disciplines and with society" (Cunliffe 1976, p.1). In her view, Gosset's "sign of true brilliance" was his "rare ability to explain, to the uninitiated, the intricacies of the discipline" (p.3); she emphasized that "we must explain our findings in their language and develop the powers of persuasion" (p.11). In his remarks following the address (p.16), former Royal

Statistical Society President H.E. Daniels "congratulat[ed] the Society on, for the first time, electing as its President one of our most distinguished woman Fellows. Perhaps I should also reprimand it for taking so long to come to its senses!"

7.2.4 *Gertrude Cox*

Gertrude M. Cox (1900–1978) is a well recognized name in statistics as chairman and Professor of statistics at North Carolina State University (NCSU). She graduated from Iowa State University (ISU) with a B.S. in mathematics (1929) and ISU's first M.S. in statistics (1931), after having been convinced by George Snedecor that "statistics was more interesting [than missionary service]" (Salsburg 2001, p.196). After spending 2 years doing graduate work at UC Berkeley, she returned to ISU to work with Snedecor in setting up a Computing Laboratory. During this time she met William G. Cochran, with whom she later coauthored the classic text, *Experimental Designs* (1950). When Snedecor showed Cox his list of recommendations for candidates to chair NCSU's Statistics Department, she asked him why he did not recommend her. So it was that Snedecor wrote back on September 7, 1940: "if you would consider a woman, I know of no one better qualified than Gertrude M. Cox"[2]. Cox arrived at NCSU 2 months later and ended up building one of the largest and most distinguished statistics departments in the United States.

Gertrude Cox made many significant contributions throughout her career to the field of agricultural sciences. She also was a brilliant organizer: in addition to her roles in North Carolina, she was one of the founders of the International Biometric Society and provided enormous support through her role as Editor of *Biometrics* (Billard 2014). She served as International President of the International Biometric Society (1968–1969). Having also served as American Statistical Association President in 1956, she was only the second person to be distinguished by this dual honor (after Cochran, her illustrious aforementioned coauthor). Although she retired from NCSU in 1965, she remained active in the profession as a consultant to promote the development of statistical programs. Her valuable contributions to science were acknowledged with her election to the National Academy of Sciences in 1975.

7.2.5 *Elizabeth Scott*

Elizabeth L. Scott (1917–1988) spent her professional career at UC Berkeley where she collaborated with many researchers. The most notable among them was Jerzy Neyman, with whom she published many papers in astronomy and weather modification. In astronomy, she modeled elements of the universe as random processes, which led to important advances in our scientific understanding about the geometry of the universe as well as about the various cosmological theories. (More recent work

---

[2] http://gmclife.blogspot.com

in this area has been possible through the collection of massive data via the Large Synoptic Survey Telescope.) She was the first to describe the observational bias that arises when more distant systems that contain more galaxies will be brighter and hence easier to detect, a phenomenon that is called the “Scott effect.”

During the 1960s and 1970s, meteorologists were captivated by the possibility for weather modification, specifically for stimulating rainfall, which in turn led statisticians like Scott to characterize the significance of outcomes from “experiments” to stimulate rain. The design problem (Scott and Neyman 1961b) is extremely challenging, due to the presence of air navigation systems with which “treatments” cannot interfere. Moreover, weather patterns on given days hardly behave like typical random samples (they certainly are not “repeatable”), and the “treatment” (e.g., cloud seeding) will not take effect immediately, so treatment assignment and significance of effects can be evaluated only after several years and only via randomization tests. In a comprehensive study involving 23 experiments, Scott and Neyman (1961a) showed that cloud seeding increased rain in only six experiments, decreased rain in ten, and the effect was not significant in seven experiments. Later research suggested that “significance” was affected by cloud altitude and location, hence the need for properly randomized experiments to account for such factors (Breuer 1980). Scott also worked on the problem of modeling the effect of ultraviolet (UV) radiation on skin cancer incidence (Morita and Scott 1982), the results from which contributed to the current guidelines regarding UV exposure.

More than any others at the time, Scott worked tirelessly to promote the equal treatment of women in academe, with respect to both their professional advancement and their salaries (Billard and Ferber 1991). Mary Gray, a mathematician-statistician-lawyer who spent her career at American University, worked long and hard with Scott to implement procedures designed to bring equality and justice to women academicians overall, not just in statistics.

7.2.6 Margaret Martin

Margaret E. Martin (1912–2012) was tremendously influential in coordinating the Federal Statistical Agencies during her government service at the Division of Statistical Standards (DSS) at the US Bureau of Budget (which later evolved into the Office of Statistical Policy at the Office of Management and Budget, presently under the leadership of Chief Statistician Katherine Wallman). At a time when few women held professional positions, Martin began her career in 1938 as a junior economist in New York’s unemployment office in the office of research and statistics. (Coincidentally, one of her teachers was the mother of Joan R. Rosenblatt, an accomplished statistician in her own right who, during her career at the National Bureau of Standards (now National Institute of Standards of Technology), collaborated with physical scientists on numerous projects and on various electronic devices as well as, with colleague James J. Filliben, revised the procedures for the 1969 draft lottery; see Rosenblatt and Filliben (1971).

During World War II, Martin worked at the War Manpower Commission as a senior economist. At the DSS, she coordinated the development of key economic and labor surveys still in use today, most notably the Current Population Survey. When the accuracy of the government's unemployment statistics was challenged by *Reader's Digest* in September 1961, Martin collected most of the data from the various agencies for the President's Committee to Appraise Employment and Unemployment Statistics, which delivered its report to President Kennedy in 1962. The statistical information was found to be solid and in 1968 she received the Bureau of the Budget's Director's Exceptional Service Award (Muko 2011). She retired from government service in 1973 and directed the National Academies' Committee on National Statistics (CNSTAT) until 1978, and afterward continued her association through CNSTAT projects on surveys and research data sharing. She served as President of the American Statistical Association in 1980, and received its first Founders Award in 1989.

7.2.7 Janet Norwood

Janet L. Norwood (1923–) pursued a career in economic and labor statistics primarily at the US Department of Labor's Bureau of Labor Statistics (BLS), charged with the development, conduct, and analysis of key surveys that characterize the economic health of the country. In less than 10 years at BLS, she rose to the office of Associate Deputy Commissioner for Data Analysis in 1972, followed shortly by Deputy Commissioner for Data Analysis (1973) and then Deputy Commissioner (1975) where she oversaw multiple programs. First as Acting Commissioner, Norwood was confirmed as BLS Commissioner in 1979, a post she retained through three administrations until 1991. During her term, she developed and launched the annual Consumer Expenditure Survey (CES), on which the Consumer Price Index (CPI) is based. Because of her exceptional technical expertise as a statistician, she commanded tremendous respect from both BLS employees and policy officials, and did much to establish the credibility of BLS' reports on the economy by insisting on independence of the Bureau in conducting its work. She oversaw many other surveys throughout the agency, including the resurrection of the National Longitudinal Survey and the Quarterly Census of Employment and Wages. Her conversations with legislators at both the state and federal levels led to increased respect and attention for the importance of statistical methods. As a result of her efforts, BLS, Bureau of the Census, and the National Center for Health Statistics cooperate effectively to ensure accurate and timely delivery of key information to the public.

While Norwood worked assiduously to maintain integrity of data, their presentation, and their interpretation, she was equally vigilant in supporting and encouraging women to achieve what their talents deserved. As quoted in Snider (2005), Norwood believed "Women have to take advantage of the opportunities presented to them; it often isn't quite as straight a career path (for women) as it is for men." Indeed, one of us (LB) well remembers having this very same conversation with

Norwood in the late 1980s when discussing the opportunities allowed to women during their career. Though ensconced in different professional sectors (government and academe), Norwood was insistent that the two meet when both were in Washington; such was Norwood's interest in promoting junior colleagues. Norwood strongly advocated for and worked assiduously towards the gender equality that exists today in government ranks.

7.2.8 Other Women Statisticians

Several of the women previously mentioned served as President of their professional organizations. For the American Statistical Association, founded in 1839, women who served as President are: Helen Walker (in 1944, a statistical educator), Gertrude Cox (1956), Lynne Billard (1996), Mary Ellen Bock (2007), Marie Davidian (2013), as academic presidents; Aryness Joy Wickens (1952), Margaret Martin (1980), Barbara Bailar (1987), Janet Norwood (1989), Katherine Wallman (1992), Nancy Geller (2011), from government; and Sally Keller-McNulty (2006), Sally Morton (2009), elected as industry candidates. [The American Statistical Association's 3-year rotation for Presidents and Vice-Presidents through the academic-industrial-government sectors started in the mid-1980s.]

Women who have been elected International President of the International Biometric Society, formed in 1947, to date are: Gertrude Cox (1968, 1969), Lynne Billard (1994, 1995), Sue Wilson (1998, 1999), Nanny Wermuth (2000, 2001), Kaye Basford (2010, 2011), and Clarice Demetrio (2012, 2013). The International Biometric Society is organized into regions and groups worldwide, each with its own regional president. The two North American regions are being served increasingly by women, though only two members have gone on to serve as International President.

Founded in 1936, the Institute of Mathematical Statistics appointed Elizabeth Scott as its first woman President in 1978; Nancy Reid followed her almost 20 years later (1997). Since then, Nanny Wermuth (2009), Ruth Williams (2012), and Bin Yu (2014) have served as Institute of Mathematical Statistics Presidents. Denise Lievesley (2007–2009) has been the only woman among the 33 Presidents of the International Statistical Institute.

Though the oldest statistical society dating from 1834, it was not until 1975 that the Royal Statistical Society elected Stella Cunliffe as its first woman President (see above), followed 24 years later by Denise Lievesley (1999–2001) and by Valerie Isham (2011–2012). The Statistical Society of Canada appears to have had the highest proportion of women presidents, having elected five women among its 38 presidents since its formation in 1972: Agnes Herzberg (1990–1991), Jane Gentleman (1997–1998), Mary Thompson (2003–2004), Nancy Reid (2004–2005), and Charmaine Dean (2006–2007).

Apart from these women, rather few women have presided over statistical societies before the 21st Century. Until the mid-1980s when the American Statistical

Association established its rotation of candidates for President and Vice-President to come from academe, government and industry, almost all elected American Statistical Association Presidents come from academe. Yet as we show in Section 3, rewards in general remain scarce for women, and the greatest prize of election to a presidency is still particularly elusive for women statisticians. [Lists of society presidents can be found on the Wikipedia webpages, "List of Presidents of (name of society)."]

Election into prestigious national societies is even more elusive. Of the 21 statisticians elected to the National Academy of Science (under the encompassing named category "applied mathematics"), only four are women (Gertrude Cox 1975; Grace Wahba 2000; Elizabeth Thompson 2008; Bin Yu 2014). To date, no women statisticians have been elected to the UK's Royal Society.

7.3 Rewards

It is clear that, given opportunity and encouragement, women in statistics have made, and continue to make, significant contributions to science. Unfortunately, the rewards have not always followed women as directly as they have for their male counterparts. Despite the significance of the accomplishments by women in statistics, and the passage of Title IX legislation in 1972 that mandated equality in the United States, Billard (1994) showed 20 years later that salary discrepancies existed. Has the situation improved in the last 20 years?

First, what constitutes a reward? Clearly, one such reward is that women are promoted and tenured at a rate comparable to the rate of their male counterparts, and that salary levels are equally comparable. Twenty-five years ago, Bailar (1989) showed data that suggested equity had been approximately achieved in governmental ranks. Our focus here will be on the comparison of men and women in academe.

Our data are drawn from *Academe* (1971–2013) in the annual "Report on the economic state of the profession" (or similar title, in varying months, but lately in the March-April issue). These data are averaged over all reporting institutions, the number of which varies slightly in a given year but basically covers all institutions in the United States. These data are not separated by discipline, so are averaged across all disciplines.[3] Category I institutions are those offering doctoral programs. Categories II–III include institutions which may have graduate programs in some disciplines but not all; most have a teaching, non-research, focus. In Categories I–III, faculty are listed as Professor, Associate Professor, Assistant Professor,

---

[3] The American Statistical Association provides salary data (10th, 25th, 50th, 75th, 90th percentiles) by gender for academic departments of statistics alone (www.amstat.org), but only for 2010–2011, 2011–2012, 2012–2013 annual surveys (2013–2014 forthcoming as of this writing). None of the counts for women in these categories on which these percentiles are based exceeds 20. Due to the uncertainties in these reported figures, and for only 3 years, we rely on the data from Academe.

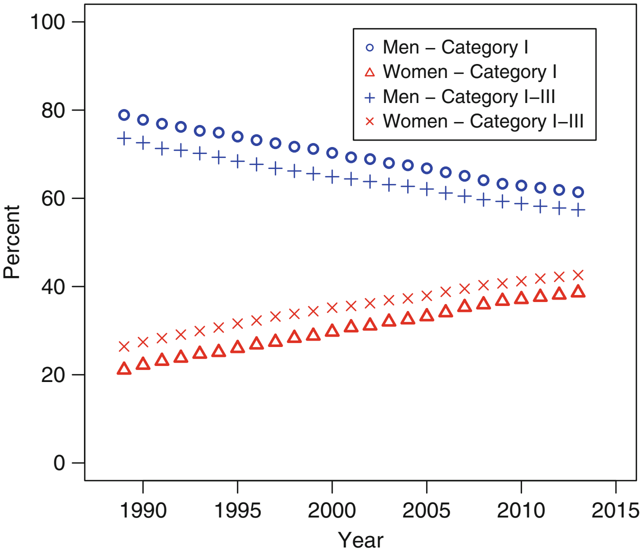


Fig. 7.1 All ranks distribution, by gender—Category I and I–III

Instructor, Lecturer, No Rank, and All Ranks; our analysis here will be confined to data on Professor, Associate Professor, Assistant Professor, and All Ranks.

We first consider the distribution of men and women at academic institutions. Figure 7.1 shows the proportion of faculty who are men and women over all ranks, for Category I institutions (outermost—upper and lower plots, respectively; see figure legends), for the years 1989–2013, and for Categories I–III (innermost—upper and lower plots, respectively). Note that the percent of men and women together add to 100%. Thus, as proportionately more women are being hired, the proportion of men faculty perforce decreases. Figure 7.2 shows these proportions for Professor, Associate Professor, and Assistant Professor ranks in Category I; those for Categories I–III are similar. In Fig. 7.2, the outermost plots refer to Professors, the innermost plots are for Assistant Professors, and between them lie the plots for Associate Professors, as one would expect by the relative ranks. As in Fig. 7.1, proportional gains over time have been made. For example, the proportion of women Professors is increasing with a commensurate decrease in the proportion of male Professors, a trend that occurs at all ranks.

The rising proportion of women in academe does not suggest that they are supplanting men from these positions. The (right-side) upper two plots in Fig. 7.3 show the numbers of men (top plot) and women (lower plot) faculty in Category I–III institutions, while the (right-side) lower two plots show the corresponding numbers for Category I institutions, for the years 1989–2013. Regardless of category, the actual number of women faculty today in 2013 is still lower than the number of men back in 1989. More women are indeed being employed by academic institutions,

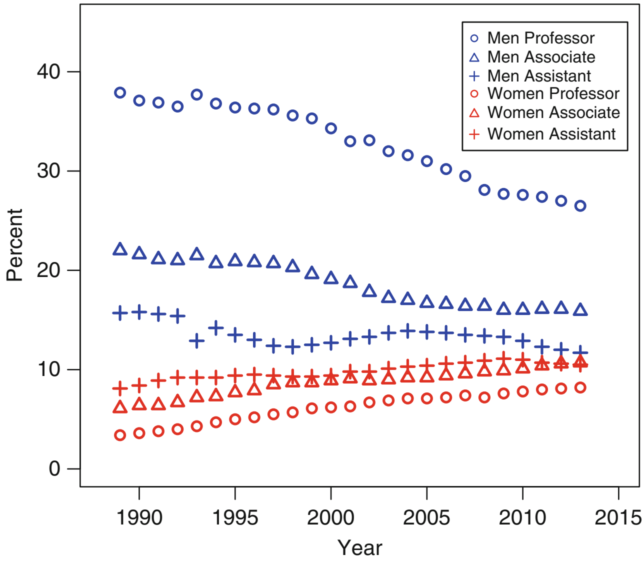


Fig. 7.2 Rank distribution of full/associate/assistant professor, by gender—Category I

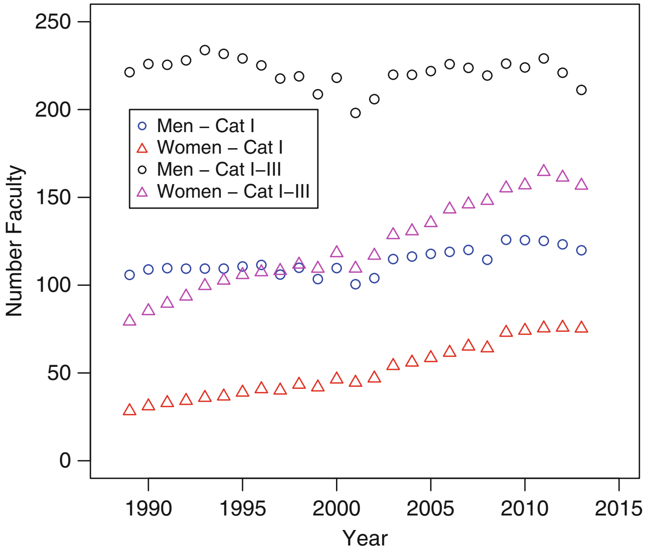


Fig. 7.3 $10^{-5} \times$ Number of faculty, by gender—Category I and I–III

but evidently not at the expense of men. A more definitive analysis could be possible if data for hiring rates by gender were available.

While it is clear that women are being hired, a crucial question related to "rewards" is: "Are women being promoted and tenured?" Unfortunately, the data

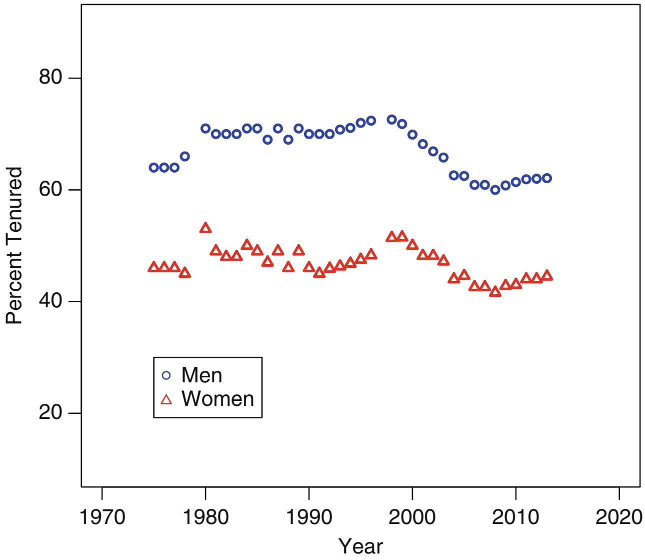


Fig. 7.4 Tenure rates by gender—Category I

suggest little progress on this front. Figure 7.4 shows the proportion of men (upper line) and of women (lower line) who are tenured, from 1975 to 2013. Although Figs. 7.1–7.3 show more women (in absolute numbers) are employed in the tenure ranks, the proportion of women who are tenured has not changed in the last 40 years since the passage of Title IX. Since tenure allows a faculty member the security to conduct research as his/her intellectual endeavors lead him/her without the constraint of being dismissed for what may be perceived as unimportant research areas, these data suggest that women are still being denied the most important reward of academic freedom through the tenure rank.

Are women being rewarded commensurately with respect to salary? Figure 7.5 shows the deficit of women's salaries relative to those of men as a percentage of their own salaries (i.e., men–women)/women × 100%) between 1975 and 2013, for Professors, Associate Professors, and Assistant Professors at Category I institutions; i.e., the average percentage raise a women has to receive to gain salary equity. The percentages lie around 10% for Professors today. The trend deficit is closer to 15% for Professors when all three Categories (I–III) are combined (Fig. 7.6). When looking at all ranks, these deficits hover around 30% for Category I and 24% for Categories I–III, again reflecting the fact that women constitute a disproportionately larger number of the faculty at the lower ranks.

The salary deficit in dollars (men's salary less women's salary) is shown in Fig. 7.7 for Category I, also for the years 1975–2013. (One recognizes that different styles of universities will offer different salary levels. *Academe* does break down institutions into public, private, and religious-affiliated so average salary deficits could be calculated within these three institution types. The data in Fig. 7.7 are averaged over

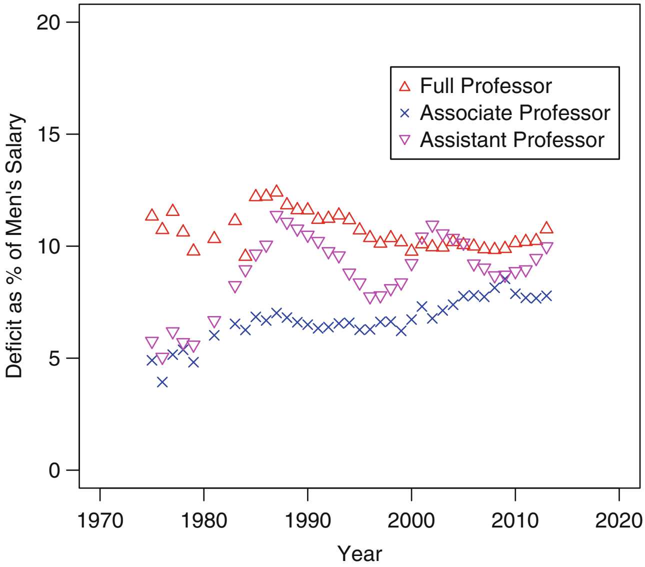


Fig. 7.5 Women salary deficit as % of women salary, by rank—Category I

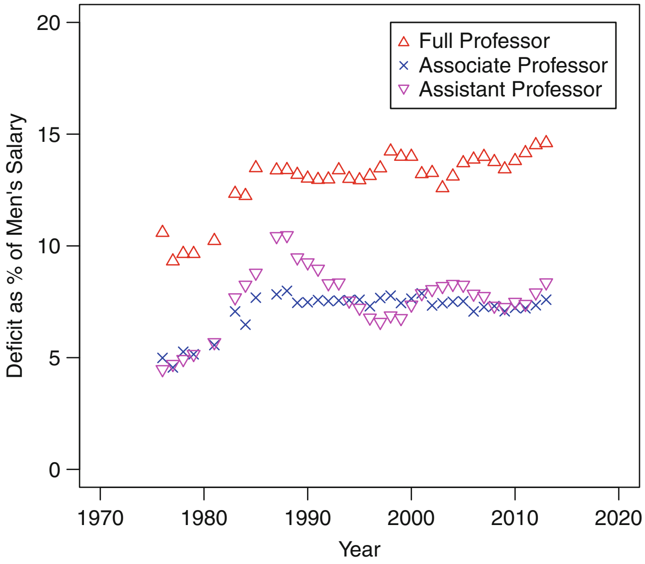


Fig. 7.6 Women salary deficit as % of women salary, by rank—Category I–III

all institution combined.) Similar trends pertain to Categories I–III combined, shown in Fig. 7.8, which reveals that the inequities have widened over the years, especially in take-home pay. The cumulative impact of these deficits over a career and on retirement income is obviously substantial.

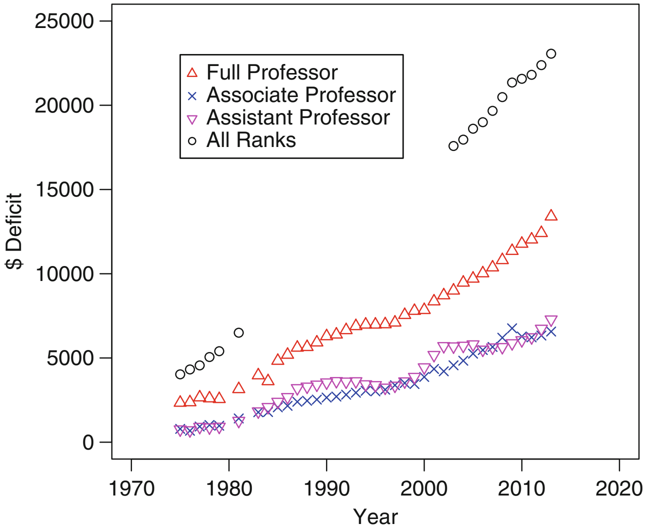


Fig. 7.7 Women $ salary deficit relative to men, by rank—Category I

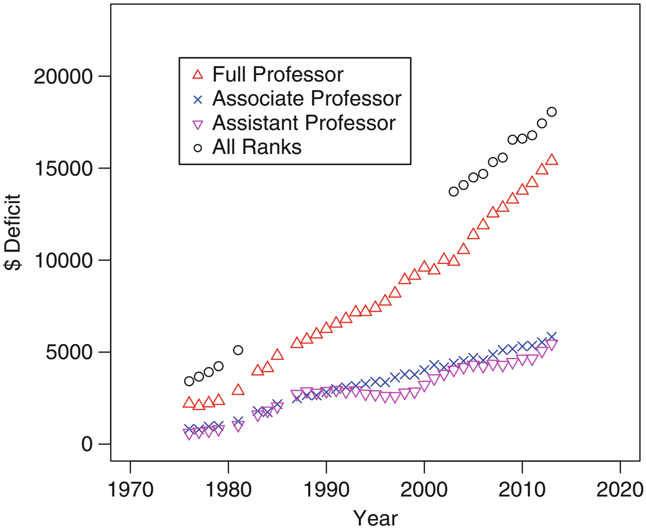


Fig. 7.8 Women $ salary deficit relative to men, by rank—Category I–III

A different type of reward applies to major awards and to invitation to present one's research in special sessions at research meetings and conferences. In its 50-year history, the Samuel Wilks Award (the American Statistical Association's most prestigious award for research contributions broadly defined[4]) has been awarded

---

[4] http://www.amstat.org/awards/samuelwilksaward.cfm

to only two women (Lynne Billard 1999; Nan M. Laird 2011). None of the 27 US Army Wilks Awards (for contribution to the practice of statistics in the Army[5]) has been awarded to a woman. More recently, among the 13 prestigious invited plenary lectures at the 2013 Joint Statistical Meetings, none were women. At its August 2013 Council Meeting, the Institute of Mathematical Statistics resolved to redress this imbalance with a series of proposed measures. Perhaps other societies will take similar steps to address this imbalance.

Until then, data such as these from *Academe* are valuable for raising awareness of the problem, and time will tell if such focused efforts will help to ensure that women are rewarded commensurately with men on these measures of rewards for research excellence. As Salsburg (2001) noted, sometimes the "best person" for the job really could be a woman.

Acknowledgements We acknowledge with thanks the suggestions from Bernard Silverman, Donna Stroup, and Barry Graubard. Much of this chapter was written when Kafadar was at Indiana University. Support for Kafadar from the National Institutes of Health, Grant Number 1R01MH 099436 awarded to Indiana University, is gratefully acknowledged.

Chapter References

Billard, L. 1994. Twenty Years Later: Is There Parity for Women in Academia? *NEA Higher Education Journal* 10: 115–144.

_____. 2014. Sir Ronald A. Fisher and the International Biometric Society. *Biometrics* 70(2): 259–65.

Billard, L., and M. Ferber. 1991. Elizabeth Scott: Scholar, Teacher, Administrator. *Statistical Science* 6: 206–216.

Breuer, G. 1980. *Weather Modification: Prospects and Problems*. Cambridge: Cambridge University Press.

Cohen, B.I. 1984. Florence Nightingale. *Scientific American* 250(3): 128–137.

Cook, Sir E.T. 1913. *The Life of Florence Nightingale, 1862–1910*. London: MacMillan.

Cunliffe, S.V. 1976. Interaction. *Journal of the Royal Statistical Society, Series A* 139(1): 1–19.

McDonald, L. 2005. *Florence Nightingale on Women, Medicine, Midwifery and Prostitution*. Waterloo, ON: Wilfrid Laurier University Press, 7, 48–49, 414.

Morita, J., and E.L. Scott. 1982. *A Comparison of Computed Sensed Flux with Robertson-Berger Meter Readings. Technical Report #16*. Seattle, WA: Department of Statistics, University of Washington.

Muko, M. 2011. Margaret Martin: A Leader in the Federal Statistical System. *Amstat News* 411: 5–7.

Rosenblatt, J.R., and J.J. Filliben. 2001. Randomization and the Draft Lottery. *Science* 171(3968): 306–308.

Salsburg, D. 2001. *The Lady Tasting Tea: How Statistics Revolutionized Science in the Twentieth Century*. New York: W.H. Freeman.

Scott, E.L., and Jerzy Neyman. 1961a. Some Outstanding Problems Relating to Rain Modification. In *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability*,

---

[5] http://www.armyconference.org/wilks.htm

Weather Modification, vol. 5, ed. Jerzy Neyman and L. Le Cam, 293–326. Berkeley: University of California Press.

_____. 1961b. Some Appendix: Planning an Experiment with Cloud Seeding. In *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability*, *Weather Modification*, vol. 5, ed. Jerzy Neyman and L. Le Cam, 327–350. Berkeley: University of California Press.

Snider, V. 2005. Janet Norwood (1923–): A Pioneer and Inspiration. *Amstat News* 339: 12–13.

Vignette 7.1

A Glimpse into Women Who Lay the Foundation for the Development of Statistics in Canada

C.B. Dean, David Bellhouse, Steve Brown, Susie Fortier, Sorana Froda, and Nancy Heckman

This vignette focuses on the early development of statistics in Canada, and specifically on five female statisticians who pioneered its advancement in the late 1970s and early 1980s. This period follows immediately the 1970 recommendation of the Royal Commission on the Status of Women that gender-based discrimination be prohibited across Canada. Vignettes on Estelle Dagum (*written by Susie Fortier*),

---

C.B. Dean (✉)
Office of the Dean of Science, University of Western Ontario, Western Science Centre
Room 191, London, ON, Canada N6A 5B7
e-mail: cbdean@uwo.ca

D. Bellhouse
Statistical and Actuarial Sciences, University of Western Ontario, Western Science Centre,
London, ON, Canada N6A 5B7
e-mail: bellhouse@stats.uwo.ca

S. Brown
Department of Statistics and Actuarial Science, 200 University Avenue West,
Waterloo, ON, Canada N2L 3G1
e-mail: ksbrown@uwaterloo.ca

S. Fortier
Chief-Time Series Research and Analysis Centre, Business Survey Methods,
R.H. Coats Building, Statistics Canada, 100 Tunney's Pasture Driveway,
Ottawa, ON, Canada K1A 0T6
e-mail: susie.fortier@statcan.gc.ca

S. Froda
Département de mathématiques, UQAM C.P. 8888, Succursale Centre-ville PK-5151,
Montréal, QC, Canada H3C 3P8
e-mail: froda.sorana@uqam.ca

N. Heckman
Department of Statistics, University of British Columbia, 3182 Earth Sciences Building 2207
Main Mall, Vancouver, BC, Canada V6T 1Z4
e-mail: nancy@stat.ubc.ca

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_7

Priscilla Greenwood (*by Nancy Heckman*), Agnez Herzberg (*by David Bellhouse*), Mary Thompson (*by Steve Brown*), and Constance van Eeden (*by Sorana Froda*) showcase the outstanding contributions made in an era when women were just beginning to enter scientific disciplines and when role models were practically nonexistent. There have been contributions made even earlier; for example, Isobel Loutit, born in Manitoba in 1909, obtained a B.A. in mathematics at the University of Manitoba in 1929 and went on to become chair of the Montréal Section of the American Society for Quality Control in 1969. As well, it is also notable that Sylvia Ostry, an economist, was the first woman working in Canada to be elected Fellow of the American Statistical Association; she was Chief Statistician of Canada from 1972 to 1975. And Audrey Duthie of the University of Regina, Kathleen Kocherlakota of the University of Manitoba and Gail Eyssen, now of the University of Toronto, provided leadership in the mid-1970s for the development of the Statistical Society of Canada.

7.4 Estelle Bee Dagum

Dr. Estelle Bee Dagum is a highly skilled specialist of Time Series Analysis and a prolific author. Her career includes more than 20 years in leadership and research at Statistics Canada (1972–1993). As the Director of the Time Series Research and Analysis Centre of Statistics Canada, she expertly led the development of the *X11ARIMA seasonal adjustment method*. This method was later incorporated into *X-12-ARIMA* which is currently used at Statistics Canada and at many other agencies for the seasonal adjustment of key economic indicators such as the Gross Domestic Product and unemployment rates. From 2007 to 2009, she returned to Statistics Canada as a Distinguished Alumna and worked as a consultant on various time series issues, including trend estimation and benchmarking. She also contributed to the training and development of the next wave of Time Series statisticians by leading a series of specialized lectures.

Being taught by Dr. Dagum was a privilege from which many of her students report to still benefit on a daily basis. Even now, her legacy is present in current work at Statistics Canada. As that agency is currently reviewing trend estimation techniques, it is impressive to see how the massive literature produced by Dr. Dagum continues to be both expanding and relevant to their current needs. Finally, the leadership and guidance provided her allowed not only the development of statistics but also provided an excellent role model for other women in statistics, economics and managerial positions at the agency and elsewhere. More often than not after Dr. Dagum's departure from her Director's position at Statistics Canada, the head position of the Time Series Centre was held by a woman, and her principles have followed through in various leadership roles there.

7.5 Priscilla Greenwood

Priscilla Greenwood, known to all as Cindy Greenwood, was born in 1937 in Lawrence, Kansas. She received her Bachelors degree at Duke in 1959, majoring in Mathematics and minoring in Physics. She received her Master's (1961) and Ph.D. (1963) degrees from the Mathematics Department of the University of Wisconsin, supervised with Joshua Chover, with her Ph.D. thesis entitled "A convolution equation on a compact interval." After a short time teaching at North Carolina College, Dr. Greenwood moved to the University of British Columbia's Department of Mathematics in 1966. She was the only female faculty member until the 1980s. In 2000, she retired from the University of British Columbia but did not retire from research. After 10 years as a visiting professor in the Mathematics and Statistics Department at Arizona State University, Dr. Greenwood returned to Vancouver and to the University of British Columbia, where she now divides her time between the Mathematics and Statistics Departments.

She is known for her research contributions in a range of topics, with the foundation being her expertise in stochastic processes. Dr. Greenwood's initial training in stochastic processes, in 1960 at MIT, is noteworthy and sets the historical stage for her work: she was taught by Henry P. McKean, of Ito-McKean fame. In her early years, her work centered on Levy processes, the Wiener-Hopf factorization and functional convergence in the context of evolving random fields.

Famous for her collaborative research style, Dr. Greenwood cultivates research collaborations around the globe via extensive travelling and hosting research visitors to the University of British Columbia. In the mid-1980s, she collaborated with many Russian researchers, including Albert Shiryaev, Mikhail Nikulin, Ildar Ibragimov, Alexander Novikov, and Igor Evstigneev. Her most long-standing collaboration is with Wolfgang Wefelmeyer on statistical problems for semimartingales, focusing on asymptotically efficient estimation in Le Cam's sense. Her more recent research centers on stochastic dynamical systems. With her formation of the Crisis Points group in the mid-1990s, she led a group of mathematicians, statisticians, and subject area researchers in studying physical systems via stochastic dynamic models with critical points. This research has been fruitful, driven by her enthusiasm, the novelty of the mathematics, and the recognized utility of the approach by subject area researchers.

On her 70th birthday, Dr. Greenwood was honored with a Festschrift. The resulting volume, edited by Egor Evstigneev, Nicholas H. Bingham, and Jim Pitman, highlights the many aspects of her work, research in stochastic processes, often at the interface of statistics and probability—she is a rare person who is at home in both environments, who has the "big picture" view of fundamental ideas and important questions, and the technical skills to move that interface forward.

7.6 Agnes M. Herzberg

Born in Saskatoon in 1938, Dr. Agnes Herzberg was the younger child of scientists Gerhard Herzberg and Luise Oettinger. When the family moved to Ottawa in 1948, where her father took up a senior research position in the National Research Council of Canada, she received the usual elementary and high school formal education. Less formally, through her parents' many illustrious and varied scientific friends, she received a very broad and general education in science. What she experienced in childhood, she practiced with great success over her academic career.

After completing high school, Herzberg went to Queen's University in Kingston where she obtained her B.A. (Honors). She earned her M.A. in 1963 and Ph.D. in 1966 from the University of Saskatchewan, the latter under the supervision of Norman Shklov, the first president of the Statistical Science Association of Canada, the precursor to the Statistical Society of Canada. Her thesis entitled, "On rotatable and cylindrically rotatable designs," and subsequent publications in the *Annals of Mathematical Statistics* stemming from the thesis, serve as a harbinger for many of her later publications in two ways. First, it announced to the statistical world that here was a serious researcher in experimental design. Second, from the acknowledgements in her papers, it showed her budding connections with leaders in the field. There, for example, she expressed her appreciation to Norman Draper for his comments on the paper. Later, she coauthored at least three papers with Draper and coauthored papers with several other leaders in the area of experimental design such as David Cox, David Finney, Cuthbert Daniel, and Henry Wynn. Subsequently, she contributed extensively to the theory of optimal experimental design, robust designs, experimental designs for medical experiments and model selection in regression.

During her academic career, Dr. Herzberg has made several contributions to the profession. For 26 years, she was Editor of *Short Book Reviews* published by the International Statistical Institute. In that position, she demonstrated her wide-ranging knowledge of statistics. Additionally, Dr. Herzberg served as an Associate Editor of the *Annals of Statistics* and *Biometrika* and was President of the Statistical Society of Canada in 1991–1992.

Dr. Herzberg has been instrumental in providing a forum for discussion and action in the wider sphere of science and public policy. Since 1996, she has organized and managed the annual international Conference on Statistics, Science and Public Policy. It is a small, elite conference held by invitation only at Herstmonceux Castle in the south of England. The success of the conference stems from Dr. Herzberg's ability to hand pick and bring together a widely diverse group of individuals—academics, public servants, elected officials, and representatives of government agencies, independent research laboratories and the media—to discuss an important topic to focus upon. The proceedings of each conference are published.

She went to Birkbeck College in February 1966 where David Cox and some others had positions. In September 1966 Cox, Agnes and others transferred from Birkbeck to Imperial College. In 1988, she returned to Canada to take up an academic position at her alma mater, Queen's University. Since 2004 she has been Emerita at Queen's.

7.7 Mary Thompson

Dr. Mary Thompson received a B.Sc. degree from the University of Toronto (1965) and completed graduate training at the University of Illinois (Master's degree, 1966 and Ph.D. degree, 1969). Upon graduation, she joined the Department of Statistics (currently the Department of Statistics and Actuarial Science) at the University of Waterloo where she spent her career, remaining actively involved even after her retirement in 2009.

Over the course of her distinguished career, Dr. Thompson made many important contributions to statistical methods for survey sampling, the theory of estimating equations, and statistical modeling and inference for stochastic processes. A novel aspect of her research is the integration of these themes, as exemplified in her work on the design and analysis of longitudinal surveys. Her book *Theory of Sample Surveys*, published by Chapman and Hall in 1997, deals with mathematical and foundational aspects of the theory of survey sampling, the use of estimating functions, and the role of the sampling design when survey data are used for analytical purposes. In addition to publishing highly influential statistical papers, Dr. Thompson has contributed widely to other areas of science, including gerontology, public health, sociology, biology, and medicine. Since 2002, she has been a lead investigator on a large *International Tobacco Control Survey*; as part of this work she has addressed issues associated with the design of longitudinal surveys to support causal inference.

Dr. Thompson has received numerous awards during her career. She is a Fellow of the Royal Society of Canada (2006), winner of the Gold Medal of the Statistical Society of Canada (2003), a Fellow of the American Statistical Association (1985), and a Fellow of the Institute of Mathematical Statistics (1998). In 2008, she was awarded the *Journal of Survey Methodology's* Waksberg Award, and 2 years later the Committee of Presidents of Statistical Societies Elizabeth L. Scott Award in recognition of her efforts to further the careers of women in academia. For work on the International Tobacco Control Project, she and colleagues G. Fong and D. Hammond received the Canadian Institutes of Health Research/Canadian Medical Association Journal Top Canadian Achievements in Health Research Award in 2009, and the 2012 Statistical Society of Canada Lise Manchester Award for excellence in statistical research that considers problems of public interest and public policy. She has been very active at the University of Waterloo. There, her research contributions were recognized by the award of a University Professorship (2004) and, upon her retirement, the designation of Distinguished Professor Emerita (2009). Dr. Thompson has supervised more than 25 Ph.D. students and numerous Master's students. For her exceptional support, encouragement and mentoring of graduate students, she received the Award of Excellence in Graduate Supervision from the University of Waterloo in 2007.

Dr. Thompson has also served the statistical sciences community in many other ways. She served as President of the Statistical Society of Canada (2003–2004), and held several other leadership positions in the Society including President of the

Survey Methods Section. In 2012, she was selected as the inaugural Scientific Director of the Canadian Statistical Sciences Institute. She has served as Associate Editor for the *Journal of the American Statistical Association* and the *Canadian Journal of Statistics* and *Survey Methodology*. She has chaired and served on the Statistical Sciences Grant Selection Committee of the Canadian Natural Sciences and Engineering Research Council and twice has served on the Advisory Committee on Statistical Methods for Statistics Canada. Within the University of Waterloo, Dr. Thompson served as Chair of the Department of Statistics and Actuarial Science, Associate Dean for Graduate Studies and Research, and Acting Dean of the Faculty of Mathematics. She was the founding Co-Director of the Survey Research Centre, and continued as Associate Director after her retirement. She has been an active member of many University-level committees, including the Advisory Committee for Women's Studies of which she was Chair in 1984–1985.

7.8 Constance van Eeden

Dr. Constance van Eeden was born on April 6, 1927, in The Netherlands. All of her studies were undertaken in The Netherlands: she passed the *candidaats examen* in 1949 at the Universiteit van Amsterdam, worked on her *doctoraal examen* and Ph.D. while being employed by the Mathematisch Centrum (now Centrum voor Wiskunde en Informatica) in Amsterdam; finally, she earned her Ph.D. *cum laude* in 1958 as one of David van Dantzig. After a period in the United States, she spent between 1965 and 1988 at Université de Montréal. In 1965, Montréal became a vibrant center for academic statistics thanks to her arrival and that of her husband, Charles Kraft, who died in 1985. Since 1998, the "Prix Constance van Eeden" is awarded yearly to the best B.Sc. graduate in statistics or actuarial science, in recognition of her contributions to the department. After her retirement in 1989, she became Professeure émérite at Université de Montréal, Professeure Associée at the Université de Québec à Montréal, and Honorary Professor (Adjunct in 1990–1995) at the University of British Columbia, where she has spent the fall term regularly for more than 20 years. In 1998, she established the Constance van Eeden Fund for Honouring Distinguished Achievement in Statistics at the University of British Columbia. The Fund promotes learning in statistical science, recognizes distinguished statistical scholars at all levels and celebrates extraordinary achievement in the discipline.

Her research career spans over 50 years. Dr. van Eeden's main fields of interest are estimation in restricted parameter spaces, decision theory, nonparametrics, and selection procedures. Her main coauthors are Charles Kraft and Jim Zidek. She published more than 80 articles (over 70 papers in refereed journals), wrote several sets of course notes, and contributed to the Encyclopedia of Statistical Sciences. Her thesis and subsequent published work establish her as a pioneer in estimation for order restricted parameters. In 2006 she published the book *Restricted-parameter-space Estimation Problems*, in the Springer Lecture Notes Series. In 1968, her book

A Nonparametric Introduction to Statistics (with C. Kraft) was published, a field where she has made many seminal contributions, published in first class journals. She contributed substantively to founding the Québec school in nonparametrics, as many of her students continue her work.

She has contributed to the statistical community as an Associate Editor for the *Annals of Statistics*, the *Canadian Journal of Statistics*, and *les Annales des Sciences Mathématiques du Québec*, as a General Editor of *Statistical Theory and Methods Abstracts*, as well as an active member of many committees and research councils. Dr. van Eeden has been an exemplary supervisor and mentor: she supervised more than 30 graduate students, but advised many more junior researchers. In Canada, her Ph.D. students held academic positions from Vancouver to St. John's, Newfoundland, in accordance with Canada's motto: *A Mari usque ad Mare*!

All her contributions received many awards: Institute of Mathematical Statistics and American Statistical Association (1972) Fellowships, Elected membership of the International Statistical Institute (1979) and that Institute's "Henri Willem Methorst Medal" (1999), and two Honorary memberships: the Statistical Society of Canada (2011) and the Dutch Statistical and Operations Research Society (2013). In 1990, Dr. van Eeden was awarded the Gold Medal of the Statistical Society of Canada, crowning a distinguished career in statistical research. Dr. van Eeden's 75th birthday was celebrated in 2002, in May (Montréal, Centre de recherches mathématiques) and November (Vancouver, University of British Columbia), reflecting her strong support of statistics in these two cities, and in 2003 a Festschrift in her honor was published in the Institute of Mathematical Statistics Lecture Notes and Monograph Series, Volume 42.

Vignette 7.2

The Status of Women Faculty in Departments of Statistics and Biostatistics in the United States

Marcia L. Gumpertz and Jacqueline M. Hughes-Oliver

According to the *2011 Survey of Earned Doctorates* (NSF 2012), 42% of doctoral degrees in Statistics granted in the United States were awarded to women. How does this translate to faculty in Departments of Statistics and Biostatistics? Data on faculty demographics from 29 departments,[6] including 21 departments of Statistics and 8 departments of Biostatistics, show that women do not make up as large a proportion of the overall faculty, comprising just 26% of tenured and tenure track faculty (Table 7.1). Twenty one percent of the departments have fewer than 15% women and 69% have fewer than 30% women; 15 and 30% are considered by many to be points of critical mass, where a qualitative shift occurs in the environment for women (Etzkowitz et al. 2002; Nelson and Brammer 2010). Biostatistics

---

[6] Departments include Boston University Biostatistics, Colorado State University Statistics, Columbia University Statistics, Emory University Biostatistics and Bioinformatics, Florida State University Statistics, George Mason University Statistics, George Washington University Statistics, Johns Hopkins University Biostatistics, Kansas State University Statistics, Michigan State University Statistics and Probability, North Carolina State University Statistics, Oregon State University Statistics, Penn State University Statistics, Purdue University Statistics, Rice University Statistics, Stanford University Statistics, University of California—Berkeley Statistics, UCLA Statistics, University of Connecticut Statistics, University of Florida Statistics, University of Georgia Statistics, University of Illinois—Urbana Champaign Statistics, University of Iowa Statistics and Actuarial Science, University of Minnesota Biostatistics, University of North Carolina Chapel Hill Biostatistics, University of Pittsburgh Biostatistics, University of Pittsburgh Statistics, University of Washington Biostatistics, University of Wisconsin Biostatistics and Medical Informatics.

M.L. Gumpertz (✉)
Office for Institutional Equity and Diversity, North Carolina State University, Campus Box 7530, Raleigh, NC 27695-7530, USA
e-mail: Gumpertz@ncsu.edu

J.M. Hughes-Oliver
Department of Statistics, North Carolina State University, Campus Box 8203,
Raleigh, NC 27695-8203

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_7

Table 7.1 Faculty demographics of 28 US Departments of Statistics and Biostatistics (number of faculty)

	US permanent resident						Non-US resident	
	Asian		White		Other			
	F	M	F	M	F	M	F	M
Non-tenure track faculty	13	12	66	80	6	4	5	18
Tenured/Tenure track assistant professor	9.25	22	17	31	3	7	14	23
Tenured/Tenure track associate professor	20	49	15	34	4	10.25	1	0
Tenured/Tenure track full professor	10	57	37	135	2	12.49	2	0

departments have higher proportions of female tenured and tenure track faculty than Statistics departments ($p = .04$); the estimated proportion female among Biostatistics departments is 32%, compared with 24% for Statistics departments.

Fifty seven departments of Statistics or Biostatistics were invited to submit faculty and graduate degree demographic data, 14 Biostatistics and 43 Statistics departments. All departments listed in the 2013 *U.S. News and World Report* (2010) top 50 departments of Statistics and Biostatistics were invited, along with all the departments profiled in the book *Strength in Numbers: The Rising of Academic Statistics Departments in the U.S.* (Agresti and Meng 2013). Twenty nine departments provided data. There was no significant difference in response rate between Biostatistics and Statistics departments ($p = .59$ Chi-square test).

Even at the rank of assistant professor women do not make up as large a fraction of the faculty as might be expected based on the national production of Ph.D.s. In this group of 29 institutions, women comprise 34% of the tenure track assistant professors. The proportion of women decreases with seniority to 30% of tenured associate professors and only 20% of tenured full professors. At the same time, women make up 44% of non-tenure track faculty, which is very similar to the fraction of doctoral degrees awarded to women in the United States.

Interesting relationships emerge when both gender and race are simultaneously considered while comparing department composition across different position types. Among US permanent residents, composition profiles across non-tenure track, tenure track assistant, tenured/tenure track associate, and tenured/tenure track full professors show significant differences according to whether faculty are Asian female or male, and White female or male ($p < .0001$, chi-squared test). More specifically:

- White females have *much* higher representation in non-tenure track positions than would be expected, and lower representation as tenure track full and associate professors.
- Asian females have higher representation as tenured associate professors than would be expected, and lower representation in tenured full professor positions.
- White males have higher representation as tenured full professors than would be expected, and lower representation in tenured associate professor positions.

Table 7.2 Demographics of Ph.D.s awarded in 29 departments of Statistics and Biostatistics

Demographic groups	Number of Ph.D.s awarded	Percent
White	51	25
Asian/International	121	60
Other race/ethnicity	29	14
Men	124	62
Women	77	38

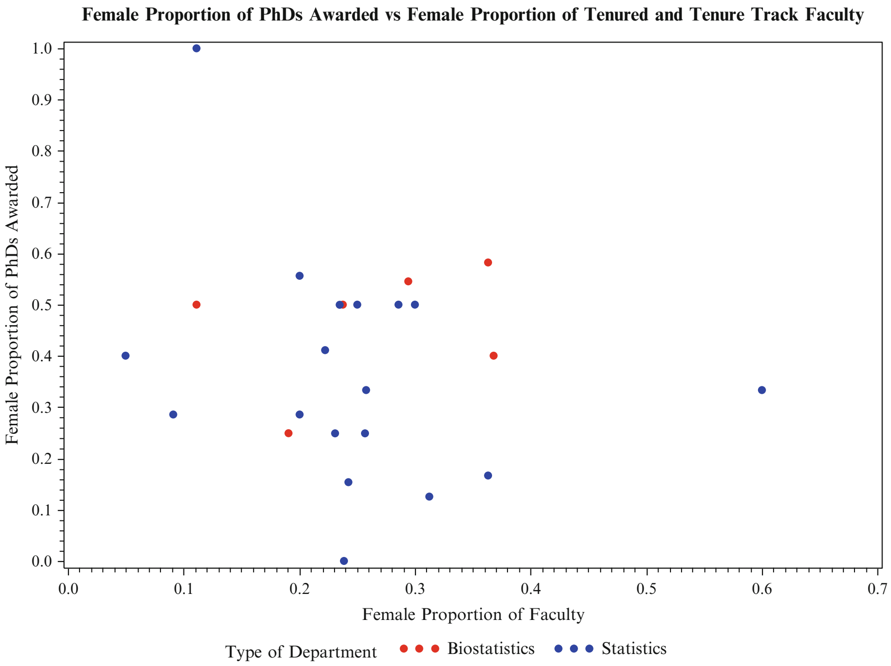


Fig. 7.9 Proportion of Ph.D.s awarded to women plotted against the female proportion of tenured and tenure track faculty. Biostatistics departments are shown in *red*; Statistics departments in *blue*

- Asian males have higher representation as tenured associate professors than would be expected, and *much* lower representation in non-tenure track positions.

In this group of highly ranked Statistics and Biostatistics Departments, women received 38% of the Ph.D.s awarded in 2012–2013 (Table 7.2), which is lower than the fraction reported in the *Survey of Earned Doctorates*. Asian and international students earned 60% of the Ph.D.s awarded by this group of institutions, whereas US white students received only 25% of the degrees. Students of all other racial and ethnic groups accounted for only 14% of the Ph.D. degrees awarded in Statistics and Biostatistics in 2012–2013.

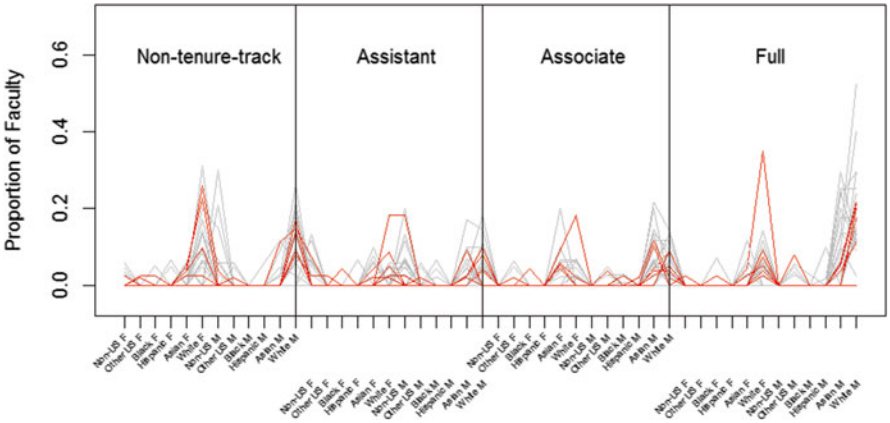


Fig. 7.10 Faculty composition according to position type and demographics for 28 departments (one department is missing). Departments with female leadership are shown with *red* profiles

There appears to be no relationship between the proportion of degrees awarded to women by a department and the proportion of women among tenured and tenure track faculty in that department (Fig. 7.9. *Note*: 5 departments did not award any Ph.D.s in 2012–2013).

We are particularly interested in female leadership and the question of whether having a female department chair and the presence of more than one or two female tenured full professors is associated with larger numbers of female junior faculty and doctoral degrees awarded to female graduate students. Neither the gender of the department chair nor the number of female senior faculty appeared to be associated with the proportion of Ph.D. degrees awarded to women. However, departments with female chairs *do* have significantly higher proportions of female tenure track assistant professors (logistic regression, $p = .032$). The proportion of tenure track assistant professors that are female also increases as the number of female full professors in the department increases (logistic regression, $p = .030$).

More generally, departments with a female chair have significantly larger proportions of tenured and tenure track faculty who are women ($p = .003$). The ratio of female-to-male tenured and tenure track faculty is 90% higher for departments with female chairs than with male chairs. Department distribution profiles (Fig. 7.10) suggest considerable overlap across departments, but with noticeable differences associated with female leadership.

With regards to female leadership and female tenured/tenure track faculty, one may ask “Is the gender of the chair a reflection of the fact that there is a larger proportion of females? After all, if there are no women, then the chair can’t be female. Does the chair being female indicate that the department is already receptive to women?” With regards to female over-representation in non-tenure track positions, is this because women, based on personal situations, are choosing to pursue nontraditional academic positions? Or are women deliberately avoiding tenure track positions because of the roles that will be expected of them in such positions, i.e., tenure track positions are undesirable?

For more insight into the role of department leadership, respondents were asked to comment on the effect of department leadership on the gender composition of their department. Eighteen chairs provided comments, and without exception, all responses indicated a desire to have a more diverse department, and most implied there are difficulties achieving this goal. The responses ranged from “There is no effect of department leadership on gender composition of our department.” to this statement from a Biostatistics chair about the ways that department leadership can influence the direction of the department:

> Department leadership has the power to move the needle a great deal on gender composition—through effects such as setting a cultural tone, creating recruitment packages that attend to flexibility needs, energetic outreach and inclusion of women in the recruitment process, and attentiveness to subtle and subconscious biases in the assessment process. However there are pipeline issues that are beyond department leadership to address fully whereby applications to tenure track positions in leading universities seem to not reflect the gender composition of those emerging with doctoral degrees in our fields, and the profession as a whole must address in the mentorship of graduate students and postdoctoral fellows.

One department chair made this comment showing how a chair can advocate for increasing the number of women faculty.

> When I started as chair of statistics in …, we had 11 male ladder faculty and 0 female. I considered dealing with our gender imbalance at the very top of my list of priorities, as I made clear in my initial greeting in our newsletter. This year we hired our lone female ladder faculty. So, sad as it may seem, 10 to 1 is actually a step in the right direction.

Discussing the issue of critical mass, one department chair mentioned faculty resistance to hiring more women faculty and also the change in climate that may come with more female faculty:

> Our department had 1 tenured/tenure track female ... [up until] 2006. Current tenured/tenure track female = 3. Critical mass for females seemed to be very important. The single female was not able to convince the faculty to hire more females. When a 2nd female came (in a spousal accommodation), that completely changed the climate and we were able to increase our numbers. We’ve had 3 or 4 female faculty since 2007. This change was not due to department leadership. There has never been much leadership about diversity from the department chair or by the college administration.

This study has revealed several interesting associations that can inform future practices and policy development. Causation, however, requires further study. We can say that departments headed by women have more female tenure-track assistant professors than departments headed by men. Department chairs pointed out several ways that senior faculty and chairs can “move the needle”: (1) setting department tone and expectations about department climate and recruitment efforts, (2) energetic outreach to potential women faculty, (3) flexible department policies and recruitment packages attending to the needs of faculty with families, (4) educating search committees about unconscious biases, and (5) mentoring female graduate students and postdoctoral scholars to prepare for faculty careers.

References

Agresti, Alan and X.-L. Meng. 2013. *Strength in Numbers: The Rising of Academic Statistics Departments in the U.S.* New York: Springer, 375pp.

Etzkowitz, Henry, Kemelgor, Carol, Neuschatz, Michael, Uzzi, Brian, and Joseph Alonzo. 1994. The Paradox of Critical Mass for Women in Science. *Science, New Series*. 266(5182): 51–54.

National Science Foundation (NSF). 2012. Science and Engineering Doctorate Awards: 2009–10. *Survey of Earned Doctorates,* http://www.nsf.gov/statistics/srvydoctorates/

Nelson, Donna J. and Christopher N. Brammer. 2010. *A National Analysis of Minorities in Science and Engineering Faculties at Research Universities*, 2nd ed. Jan 4, 2010, http://faculty-staff.ou.edu/N/Donna.J.Nelson-1/diversity/Faculty_Tables_FY07/07Report.pdf

U.S. News and World Report. 2010. Best Grad Schools. Ranking of Statistics Departments, http://grad-schools.usnews.rankingsandreviews.com/best-graduate-schools/top-science-schools/statistics-rankings?int=e6ce6e

Vignette 7.3
Women in Biostatistics: A Case of Success in the United States

Camille M. Moore, Brandie D. Wagner, Miranda Kroehl, Stephanie A. Santorico, Elizabeth Juarez-Colunga, Sharon Lutz, and Anna E. Barón

Anecdotal evidence suggests that women have rapidly become better represented and enjoy more favorable career paths in biostatistics compared to many other STEM disciplines. Up to the early 1980s, our department faculty at the University of Colorado, Denver was entirely male. Today, however, women comprise 71% of tenure track faculty and 67% of the department faculty overall. In the United States, the proportion of women earning doctorates in biostatistics and biometrics rose from 38% in 1992 (NAS 2013) to 57% in 2011 (ASA 2013). While these estimates are similar to those in all bioscience fields, they are much more favorable than in other mathematics fields (see Chap. 6). According to a recent American Statistical Association (ASA 2013) survey of Ph.D. granting departments, 39% of biostatistics faculty were female compared to only 26% in statistics departments (see Fig. 7.11). Seven of the 13 biostatistics departments consisted of greater than 40% female faculty, while two reported more than 50% female faculty (ASA 2013). Despite the increase in female faculty members, only 16% of chairs of Ph.D. granting statistics and biostatistics departments are women (Palta 2010).

Since 2010, the ASA has reported similar median salaries for male and female assistant and associate professors in academic biostatistics and biometrics departments (ASA 2002–2012). While these trends are encouraging, it is unclear whether similar advancements have been made in the government and private sectors of

---

B.D. Wagner, Ph.D. • M. Kroehl, Ph.D. • E. Juarez-Colunga, Ph.D. • S. Lutz, Ph.D.
A.E. Barón, Ph.D. • C.M. Moore, Ph.D. (✉)
Department of Biostatistics and Informatics, Colorado School of Public Health,
University of Colorado Denver, 13001 E. 17th Place, Campus Box B-119,
Aurora, CO 80045, USA
e-mail: Camille.moore@ucdenver.edu

S.A. Santorico, Ph.D. (✉)
Department of Mathematical and Statistical Sciences, University of Colorado Denver, USA

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_7

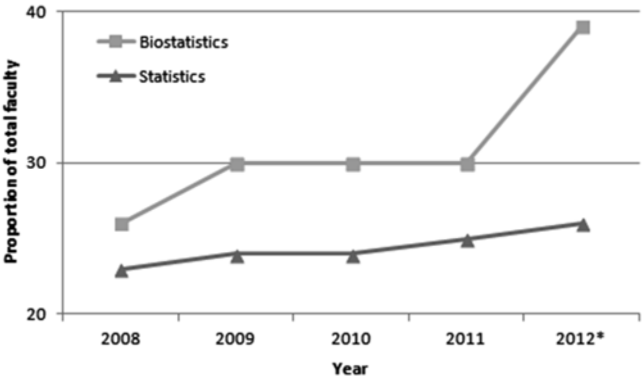


Fig. 7.11 Proportion of female full-time faculty at Ph.D. granting departments of statistics and biostatistics. *Note*: 2012 estimates from draft report (ASA 2013)

biostatistics, and many women in biostatistics still share similar concerns as women in other STEM disciplines. Gender disparities in salaries, career advancement and promotion, striving for work-life and work-family balance, recognition from and leadership roles in professional associations, as well as treatment, particularly in interactions with collaborators from predominantly male STEM fields, are still relevant issues for women in biostatistics. We spoke with women in our biostatistics department at the University of Colorado Denver, as well as colleagues working in industry and in other academic biostatistics and biometrics departments across the United States to better understand how female biostatisticians became attracted to the field and if and how gender has influenced their careers.

7.9 Educational Paths

The women we spoke with came to study biostatistics in a variety of ways. Biostatistics is a relatively new field, and there are few formal undergraduate programs. While some studied mathematics, applied mathematics or statistics as undergraduates, others had backgrounds in biology, chemistry, physics, engineering, computer science, psychology, economics, and even art history. Reasons for pursuing a graduate degree in biostatistics were equally varied, but commonly included a desire to combine mathematics with medicine and to utilize mathematics to impact society, excellent job opportunities, and a feeling that the field of biostatistics was more welcoming to women and students with diverse educational backgrounds. Many attributed their initial interest in STEM and biostatistics to supportive high school teachers, college professors, and other mentors who took notice of their aptitude in STEM disciplines and actively encouraged them to pursue degrees in mathematics and science.

7.10 Career Choices

Careers in biostatistics are attractive for a variety of reasons, including well paid and flexible job opportunities, the opportunity to work on interesting and important medical, epidemiological, and public health problems, and the collaborative nature of working in an interdisciplinary field. The biostatisticians in academia and industry who we interviewed felt they had excellent career opportunities. While none indicated that gender played a conscious role in their career decisions, many did note the difficulties in achieving a balance between work and family life while pursuing an academic career. Faculty in all fields work longer hours than their predecessors, with the proportion reporting working more than 55 h per week growing from 13% in 1972 to 44% in 2003, for men and women alike (Schuster and Finkelstein 2006). While both men and women are impacted by the stress of a demanding career, often a larger proportion of family and domestic responsibilities fall on women. Among university professors, the gender imbalance in the higher ranks can be largely explained by the reduction or halting of work responsibilities for women starting families, and in the STEM fields, women who were not currently working were far more likely than men to cite family responsibilities as the reason for not working (NSF 2013). The biostatisticians with whom we spoke felt their jobs were more flexible than most in terms of allowing for flexible working hours and telecommuting, perhaps due to the current high demand for qualified biostatisticians. However, many stated that they took breaks from their academic careers, moved closer to family, or had to hire outside help in order to start families and fulfill household responsibilities. Others noted that their spouses had more flexible jobs or worked from home, which allowed them to pursue more demanding career paths, or that they postponed having families in order to pursue their career goals.

While the proportion of women earning doctorates in biostatistics has rapidly risen over the past 20 years and numbers of women in biostatistics departments have increased, many women we spoke with found it difficult to maintain work family life balance while pursuing an academic career, and indicated a need for better maternity leave and family policies. We hope that as family friendly policies are more widely adopted, better gender balance will be achieved in the higher ranks in both university departments and industry. In recent years, women in biostatistics have assumed high profile roles, such as President of the American Statistical Association, Directors of NIH branches, Chairs of academic departments and study sections, and university Deans. It is our hope that the advancement of more women to higher level positions in our field provides encouragement to women in other STEM careers.

Many young women lose interest in math and science during middle school (James 2009), making role models and mentoring of female students, particularly at younger ages, very important. Graduate students and faculty in our Biostatistics and Informatics department at the University of Colorado Denver have become active over the last 3 years in pipeline activities designed for middle and high school students. We introduce them to key concepts in biostatistics, familiarize them with some ways to visualize data, and engage them with interactive individual and group activities. We also tell them about our current research projects and what got us excited about studying and working in the field. Encouraging young women in math and science and exposing them to interesting STEM career opportunities through avenues like this may motivate them to continue taking math and science courses throughout high school and college, bringing greater gender balance to all STEM fields.

References

American Statistical Association (ASA). 2002–2012. *Salary Survey of Biostatistics and Other Biomedical Statistics Departments and Units,* http://www.amstat.org/careers/salaryinformation.cfm (accessed 1 October 2013)

_____. 2013. *Survey Report: 2008–2012,* http://www.amstat.org/education/departmentsurveys.cfm (accessed 1 October 2013)

James, Abigail Norfleet. 2009. *Teaching the Female Brain: How Girls Learn Math and Science.* Thousand Oaks, CA: Corwin Press.

National Academy of Sciences (NAS), Committee on Women in Science, Engineering, and Medicine. 2013. *Doctorates Awarded to Women, by Field of Study and Year of Doctorate: 1992–2001,* http://sites.nationalacademies.org/xpedio/groups/pgasite/documents/webpage/pga_049185.pdf (accessed 1 October 2013).

National Science Foundation (NSF). 2013. *Women, Minorities, and Persons with Disabilities in Science and Engineering,* http://www.nsf.gov/statistics/wmpd/ (accessed 30 September 2013).

Palta, Mari. 2010. Women in Science Still Over Looked. *AMSTAT News.* October 2010. http://magazine.amstat.org/blog/2010/10/01/women-in-science/ (accessed 1 October 2013.

Schuster, J.H. and Finkelstein, M.J. 2006. *The American Faculty: The Restructuring of Academic Work and Careers.* Baltimore: John Hopkins University Press.

United States Department of Education (USDE), National Center for Education Statistics. 2011. *Integrated Postsecondary Education Data System (IPEDS), Fall 2011, Completions Component,* http://nces.ed.gov/programs/digest/d12/tables/dt12_317.asp (accessed 1 October 2013).

Chapter 8
Gender and Computing

Lisa M. Frehill and J. McGrath Cohoon

Worldwide, information technology (IT) has exhibited phenomenal growth over the past several decades. This growth underlies the creative and analytical processes for the full range of endeavors ranging from science to business and social interaction, and it powers the burgeoning IT economy. Other benefits include vast career opportunities (OECD 2012), and the implications associated with unparalleled access to information. Finally, a benefit noted in many nations is that women's access to IT and participation in computing can be an important mechanism of economic growth and societal development. Nevertheless, women and men are seldom equal participants in this boom.

Computing occupations differ greatly in the level of education needed for entry, ranging from short-term certifications to advanced research-based doctoral degrees. The gendered patterning of access to education, in general, combined with the relative importance of computing within a nation may, together, affect the representation and status of women in the field. In many nations, computing is a new discipline, arriving at a time when women's educational access has already been secured, while in other nations, computing has grown within an existing sex segregated educational context. This context may not affect women's computing participation in the manner one might expect, however. In this chapter we explore computing education, the relative status of computing within national contexts and the ways in which national policies associated with workforce development impact the level of sex segregation of jobs in computing.

Computing is a broad term that refers to a range of skills obtained in programs of various content and lengths, including those that are short-term certifications to

---

L.M. Frehill (✉)
Energetics Technology Center, 10400 O'Donnell Place, Ste 202,
St. Charles, MD 20603, USA
e-mail: lfrehill@etcmd.com; lisa.frehill@gmail.com

J.M. Cohoon
Science, Technology, & Society Department, School of Engineering & Applied Science,
University of Virginia, Charlottesville, VA 22904-4265, USA
e-mail: jmcohoon@virginia.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_8

advanced research training in computer science[1] doctoral programs. The term "computing" describes an activity as well as an academic discipline, while the term "information technology" (IT) has come to be the term commonly used to modify the word "workforce," and is in general use in the United States. Going one step further, the OECD (2010) and the United Nations (multiple references) use the acronym "ICT[2]" to reference the information and communications technology workforce, segmenting that workforce into three broad categories:

- Basic users of generic tools (e.g., WORD, EXCEL) necessary in the information society
- Advanced users of advanced, sometimes sector-specific tools
- ICT specialists develop, maintain, and operate ICT systems

We focus on the latter category to address gender stratification among creative specialists. ICT specialists can be further disaggregated by their role in developing, maintaining, and operating ICT systems. In this chapter we look at a relatively narrow slice of the overall ICT workforce, specifically those individuals who obtain training in the academic discipline of computer science in preparation for jobs as various types of ICT specialists. While this is likely to be a relatively small slice of the overall ICT workforce, we argue that those who obtain computer science degrees are advantaged in the ICT industry and, as well, are more likely to be those who exercise creative control within this field.

ICT work is foundational in the current global economy. Computers are powerful tools with which workers interact in various ways, ranging from simple input/output to complex design and analytical work. The stratification of computing work and the association of this stratification with gender and other bases of difference can impact the future direction of work, in general, and privilege, in particular. Finally, some elements of computing are not geographically bounded, while other elements are. For example, the brick-and-mortar network infrastructure for telecommunications is spatially specific, like any other construction. The information that flows through that infrastructure, however, is not only unanchored in a spatial sense, but also enables the global diffusion of knowledge. As a result, computing is a critical element of globalization, with its concomitant promises and potential dangers.

This chapter uses data from OECD, international and national reports, along with the current research literature to address three key questions about women's participation in computing compared to that of men:

Q1: What is the gender composition of computing? To what extent does this vary across nations?

---

[1] We use "computer science" recognizing that in many cases this term includes "information sciences," "informatics," and similar closely aligned disciplines. We mean it in the broad and inclusive sense for purposes of this chapter. We use gender to refer to the social construction of meanings associated with femininity and masculinity, which includes expectations, norms, attitudes, behaviors, and beliefs that are patterned by sex.

[2] Our use of ICT and IT are fundamentally interchangeable. Generally, though, when we are referencing the United States, we use "IT" and then "ICT" for the rest of the world, as is the custom in international publications.

Q2: What are the factors that encourage women's participation in computing and how do these vary as compared to the factors that draw men to the field?
Q3: To what extent does gender matter in computing?

The broad variations in women's participation in computing cross-nationally shed important light on the role of gender and culture in enabling or thwarting women's participation in this growing labor force. This chapter will not be able to provide a comprehensive answer to these questions; instead, we provide some provisional insights that could form the basis of additional research.

8.1 Gender and Computing

In the United States, up until the mid-1980s, there was a relatively large representation of women in computing, which, like most jobs, has been characterized by occupational segregation by sex. Prior to the boom in use of microprocessor-based desktop computers, computer users generally communicated with the machines using stacks of punch cards. Many equipment room operators, programmers, and data keyers were women, and this work—regardless of its level of actual intellectual complexity—was socially constructed as similar to secretarial labor (Bratteteig 2008). Women's early work in computing was foundational to the field (Abbate 2012; Fritz 1996; Ensmenger 2010), with such notable accomplishments as Rear Admiral Grace Hopper's invention of COBOL, among others. Women performed both routine and complex functions in early computer rooms. The large demand for programming talent and the concurrent professionalization of computing came to be bound up with the masculinization of the field. As with other fields, masculinization processes erected barriers to women's entry as men actively sought to exclude women (Frehill 2004; Oldenziel 1999; Tympas et al. 2010).

OECD's *Internet Economy Outlook, 2012*
A biennial volume describing recent market dynamics and trends in industries supplying IT goods and services and offers an overview of the globalization of the information and communication technology (ICT) sector and the rise of ICT-enabled international sourcing. It analyses the development and impact of the changing global distribution of services activities and the rise of China and India as significant suppliers of ICT-related goods and services. It also looks at the increasing importance of digital content in selected industries and how it is transforming value chains and business models. The potential of technological developments such as ubiquitous networks, location-based services, natural disaster warning systems, the participative web and the convergence of information technology with nanotechnology and biotechnology is also examined. This book includes StatLinks, URL's linking statistical graphs and tables to spreadsheets containing the underlying data.

Accessible online at
http://www.oecd.org/sti/ieconomy/ieoutlook.htm

In addition to the professionalization and concurrent masculinization, the digital revolution changed the nature of work in computing. Computer programmers and users were increasingly able to directly access computational power on their desks—or in their hands—that rivaled and exceeded the old punch-card and tape-driven systems. Hobbyists, who were predominantly men, too, drove change in the material conditions of computing, as new electronics components became increasingly widely available via retail outlets.

Evidence of this rapid change in the nature of work in ICT is reflected in the workforce publications of the European Union. Since 2000 the biennial report series *OECD Information Technology Outlook* was issued through 2010. In 2012, however, the report became the *Internet Economy Outlook*, reflecting the on-going migration from brick-and-mortar enterprises to the ever-expanding net.

8.2 Caveats: Information and Data Availability

The data about participation in computing greatly varies across the globe. Issues associated with gender and information technology and the ways in which countries are addressing these issues vary. To some extent, the issues described by Seely-Gant (2015) with respect to the UN millennium goals and gender impact these data issues. That is, in nations where the average girl is unlikely to receive much education beyond the primary level, where electricity is not universally reliably available, computing degrees are a less relevant metric to understand gender gaps in computing than is the extent to which girls have access to computers, as compared to boys. Hence, as will be discussed, below, data gaps in degree attainment are not surprising. Physical resources that are taken-for-granted in many OECD member economies shape the general access and outcomes of education and impact the gendered relations of computing (United Nations Economic and Social Council, Statistical Commission 2012, 2013).

Reports of women's participation in science and engineering vary in the level of detail about the constituent fields. When one is interested in computing, in particular, the level of aggregation can be more problematic because of the varied ways in which computing is "counted" in different countries or economic systems. For example, in some places, computing is counted within a larger "engineering and technology" category (e.g., China), while in others it is often (though not always) aggregated along with mathematics (e.g., United States) or with all of the natural sciences (e.g., European Union).

The OECD provides data on economic participation in 34 member nations, almost exclusively in Europe and North America. Degree data from these nations is generally available for the past 10–20 years (depending on the nation) about degrees awarded in computing at the Tertiary A level (generally equivalent to the US bachelor's degree) and doctoral (Advanced Research Programs) level by sex. Workforce data are often not available at the detailed occupational level in published international compendia; workforce information in such volumes typically aggregates workers to a relatively high level of detail (e.g., the "professionals" category includes individuals in computing). Finally, social scientists have completed studies of the ICT workforce in these nations, using more detailed data about workers to complete quantitative studies complemented by qualitative data collected using a plethora of methodologies to provide additional insights into the social forces associated with women's participation in computing and with the meaning of gender for the discipline and its products.

A large gap in data exists, however, since many economies that are in the midst of large-scale technological advancement are not members of the OECD. For example, the so-called "BRIC" economies, Brazil, Russian Federation, India, and China, are not members of OECD (Wilson and Purushothaman 2003). Therefore, OECD data collections do not, uniformly, include data from these economies, each of which is a sizable and growing economy and important in the ICT sector.

Similarly, high-quality data on computing degrees and workforce participation disaggregated by gender are scarce from much of Africa and the rest of Asia (i.e., beyond Russia, India and China). The World Bank Group, the International Labor Organization, and United Nations all collect and distribute some data on workforce and education across the globe, but, again, these data are often reported at a level of detail insufficient to understand the issues for specific fields like computing.

Data for African nations can be especially challenging to obtain. The centrality of the ICT sector in the global economy has led to a high level of interest; therefore, several studies provide some information about ICT in Africa but none provide data on computing degree attainment. As discussed earlier, access to basic education for girls, access to physical resources, in general, and to electricity, in particular, pose significant structural constraints on participation in IT. A 1999 UNESCO study of the scientific, technical, and vocational education of girls in Africa summarized findings from 21 separate country reports (Hoffman-Barthes et al. 1999). Later, infoDev completed a 2007 study with country reports about gender equity and ICT in 53 African countries. Finally the United Nations Economic Commission for Africa (UNECA 2008, 2009a, 2009b) has completed a series of studies that emphasize the connection between gender mainstreaming in ICT, national ICT policy development about standards and human resources, and desired outcomes such as economic development.

8.3 Cross-National Variation in Women's Participation in Computing

Even with the data limitations, just discussed, the cross-national data provide an initial answer to the question:

> Q1: What is the gender composition of computing? To what extent does this vary across nations? What do we know about sources of that variation?

Education (degrees) and work (jobs) are two ways in which we can conceptualize participation in computing. A third way, usage, including for leisure purposes such as gaming, is not considered in this chapter, although we acknowledge the importance of this third area in which a potential digital divide exists with which there may be subsequent issues for gendered stratification of computing.

We use data from OECD's online database Stat Extracts on degrees in computing at the Tertiary A (U.S. bachelor's degree) and Advanced Research Program (PhD) levels. Data on the research workforce were taken from the U.S. Bureau of Labor Statistics (BLS), the Government of India, and various offices of the United Nations.

8.3.1 Education

Figures 8.1 and 8.2 show data on the number of first tertiary (i.e., bachelor's) degrees and advanced research (i.e., doctoral) degrees in computing in the OECD member countries for 2011, the most recent year for which data were available. We have segmented these charts along the x-axis by the overall size of computing degree production in reverse order into four groups and then, within each of these groups ordered the nations by the percentage of women among degree recipients. Our objective is not to explain the differences in degree production between the countries shown but, rather, to provide these data as a way to contextualize the relative percentage of women who earn computing degrees in each nation. The bars

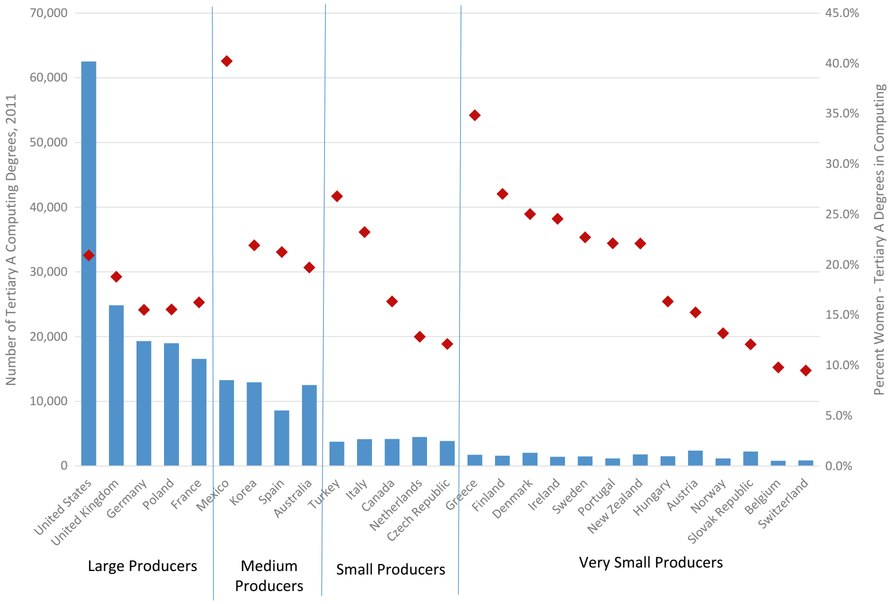


Fig. 8.1 OECD Tertiary A degrees in computing, 2011. *Source*: Frehill, LM. 2013. Analysis of OECD Degree Data. Original data accessed online at OECD Stat Extracts, http://stats.oecd.org/#

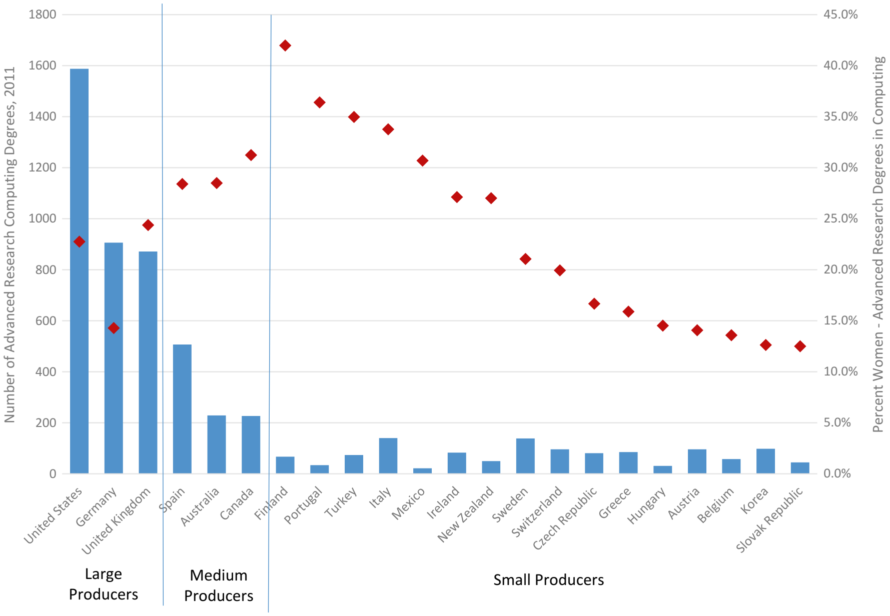


Fig. 8.2 OECD advanced research (doctoral) degrees in computing, 2011. *Source*: Frehill, LM. 2013. Analysis of OECD Degree Data. Original data accessed online at OECD Stat Extracts, http://stats.oecd.org/#

represent the total number of computing degrees at the bachelor's level (Fig. 8.1) and the doctoral level (Fig. 8.2). The diamonds show the percentage of women among degree recipients, associated with the *y*-axis on the right.

Data were not available for all 34 OECD member countries; therefore, Fig. 8.1 includes data on bachelor's degrees for 24 countries, while Fig. 8.2 reports on doctoral degrees awarded in 22 of these nations. Figure 8.3 shows data on the propensity of students, separately by gender, to earn Tertiary A degrees in computing.

Second, the order of magnitude for the number of degrees awarded in the United States (population 313.8 million) is substantially greater than for any other OECD member nation at both the bachelor's and doctoral levels.[3] The United States produced more than 60,000 bachelor's degrees and almost 1,600 doctoral degrees in computing in 2011.[4] The next largest OECD bachelor's degree producer was the

---

[3] We have not normalized the number of degrees (total) by population for each nation, as was suggested by one reviewer. We do not seek to explain differences in the number of degrees across countries but, instead, to provide these as a framework for viewing the relative levels of women's participation in computing. We have added Fig. 8.3 as an alternative way to contextualize the place of computing within all fields at the bachelor's degree level for each nation.

[4] Due to the inclusion of computing with engineering for education data from China, we were unable to determine the relative number of computing degrees awarded in China at either the bachelor's or doctoral level. We acknowledge that this number may be large, growing, and that, as with

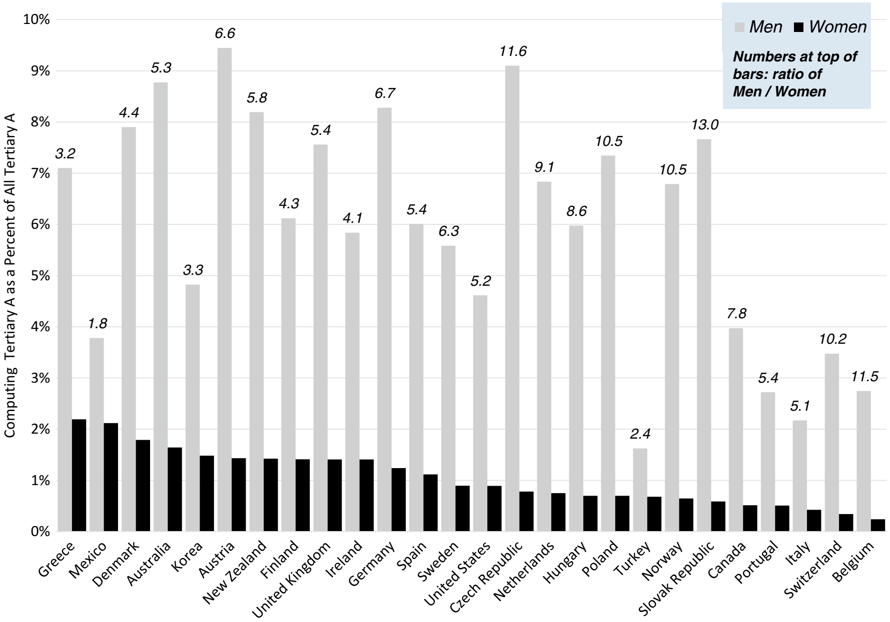


Fig. 8.3 Percentage of computer science majors among men and women Tertiary A recipients, 2011. *Source*: Frehill, LM. 2014. Analysis of data from OECD degree data extracted from OECD Stat Extracts, http://stats.oecd.org/

United Kingdom (population 63.2 million), with just over a third as many computing bachelor's degrees as the number awarded in the United States. Germany (population 81.9 million) and Poland, with just under 20,000 bachelor's degrees, and France (population 65.7 million) with ~15,000, were the next largest producers. Women's representation in computing in these four nations ranged from 15% (Germany, Poland, and France) to 21% for the United States and just under 20% for the United Kingdom.

Four nations are categorized as medium producers: Mexico (population 120.8 million), Korea (population 50.0 million), Spain (population 47.27 million), and Australia (population 22.68 million) all produced about 8,000–10,000 computing bachelor's degrees in 2011. Women's participation in computing in three of these nations was on par with that in the United States with women earning 21–22% of degrees in Korea, Spain, and Australia. Mexico was an outlier with women earning 42% of computing bachelor's degrees in Mexico, the largest representation of women among the OECD economies, with Greece (a "very small producer") the second largest at 37%.

---

engineering, degree quality could greatly vary across the institutions awarding such degrees. In 2011, according to the *China Statistical Yearbook 2012*, there were 15,804 engineering and 7,019 science doctoral degrees awarded in China.

The great variability in women's representation in computing at the bachelor's level is most evidenced among the "small" and "very small" degree producers—nations that produced ~4,000 ("small") or ~2,000 or fewer Tertiary A degrees in computing in 2011. Some of these nations had very low representations of women—for example, Belgium and Switzerland at just 10%—and others had much higher representation of women—for example, Turkey (27%), Italy (23%), Greece (35%), Finland (27%), Denmark, and Ireland (both ~25%). All of these nations are noteworthy for their policies that emphasize the central role for ICT in economic development as a means to national economic prosperity (OECD 2012).

Figure 8.2 shows data on doctoral degree production at 22 OECD member nations. As at the bachelor's level, the United States, Germany, and the United Kingdom were the largest producers of computing doctorates. The most recent year for which data were available for France was 2009, with 642 doctoral degrees in computing, not shown in Fig. 8.2.

Women's representation at the doctoral level for the top three nations mirrors that at the bachelor's level, with women earning about one-in-five computing doctoral degrees in the United States and the UK and just under 15% in Germany. Women's representation was higher in the "medium producers"—at around 25%—in Spain, Australia, and Canada, nations that produced between 200 and 500 computing doctorates in 2011.

The remaining OECD countries for which data on doctoral degree production were available for 2011 each produced under 200 computing doctorates in 2011. Italy and Sweden were the largest of these producers at 140 and 139, respectively. The wide range in women's representation is clear among these small producers. Women earned 37% of doctoral degrees in computing in Finland but just under 15% in Hungary, Austria, Belgium, Korea, and the Slovak Republic in 2011.

Figure 8.3 shows the percentage of all Tertiary A degrees awarded in computing to women and men, separately by gender. The dark bars show that 2.2% of Greek women but only 0.2% of Belgian women who earned Tertiary A degrees in 2011 did so in computing. The relative importance of computing as a Tertiary A field for men varied substantially more than for women, with a low of 1.6% of men in Turkey and a high of 9.4% of men in Austria earning Tertiary A degrees in computing in 2011.

The numbers on the top of the light bars indicate the ratio of men's to women's percentage of degrees in computing for each nation. A complicated picture emerges suggesting a need for greater case-by-case analysis to better understand the underlying labor market forces shaping the gendered patterning of degrees in computing in each nation. For example, as shown in Fig. 8.1, women in Mexico earned 40% of computing Tertiary A degrees in Mexico. Figure 8.3 shows that about 2% of Mexican women who earned Tertiary A degrees in 2011 did so in engineering. Men in Mexico, though, had one of the lower rates of participation among the OECD nations shown in these three figures: only 3.8% of Mexican men who earned a Tertiary A degree in 2011 did so in computing. At the other end of the spectrum, only computing accounted for just 0.6% of women's but 7.7% of men's Tertiary A degrees in 2011 in the Slovak Republic, which had the most pronounced gender gap. Additional detail about the nature of computing work, the structure of the national labor markets, the extent to which the computing jobs necessitate university training,

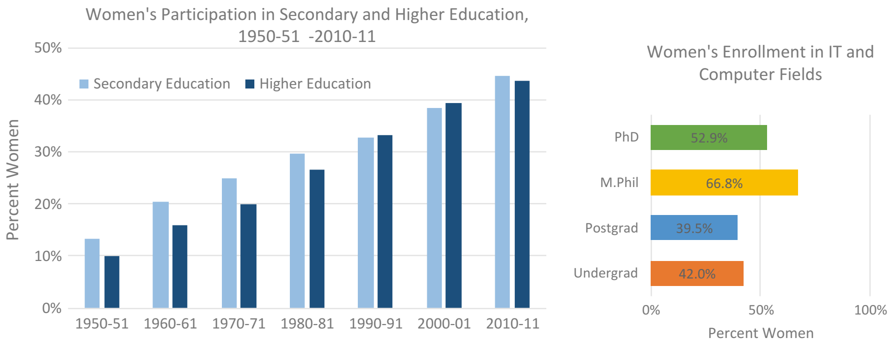


Fig. 8.4 Women's participation in education 1950–2010 and CS/IT in India 2011. *Source*: Frehill, LM. 2014. Analysis of data from: Government of India 2013a, 2031b, 2013c

and the way that gender is patterned in each of these areas suggests a need for more detailed case study analysis.

As discussed earlier, data comparable to that provided for OECD nations were not available for India, which reports on enrollments and not degree attainment. India has become a significant force in the global IT marketplace for both products and labor. Women's participation in education has been a focus of much policy work in India (Government of India 2010; Nayar 2011; Kumar 2008). Figure 8.4 shows the trend since the 1950–1951 academic year in women's participation in education in India. In that year, women accounted for just about 10% of all students in higher education but in 2011, the most recent year for which there are data, women accounted for 44% of students enrolled in higher education. For much of the time since 1950–1951, women's participation in higher education lagged that of their participation in secondary education, but the size of that gap has narrowed. In 2011–2012, 45% of students enrolled in higher education were women.

The second chart in Fig. 8.4 shows women's participation in IT and computer fields in higher education. Compared to the rates discussed, above, for OECD nations, women's participation in computing in India was relatively high in terms of the enrollment data shown here. The undergraduate and postgraduate levels include data from a heterogeneous set of institutions, representing various quality levels and areas of academic preparation (World Education Services 2007; Natarajan 2005). For example, the Indian Institutes of Technology (IITs) are considered the highest-quality institutions for engineering-related disciplines in the country, with some boasting programs that are on par with the best programs at institutions in other countries. Admission to the IITs is based on the results of a rigorous examination: in 2007–2008 only 3% of men and 1% of women who took the examination were admitted (Nayar 2011). In 2012, women accounted for one-third of candidates with marks on the examination high enough for entry; providing optimistic news that the historically low representation of women at the IITs of 10–12% will be increasing (Srivastava 2012).

8.3.2 Workforce

Women's participation in the computing workforce—just like their representation among those who complete academic credentials in the field—varies greatly across nations. To a large extent, the economic laws of supply and demand impact the labor market for computing in significant ways. That is, in the United States, for example, the demand for labor in computing has been and will continue to grow over the next decade (U.S. Bureau of Labor Statistics 2012a). Worldwide, too, the ICT workforce is growing, suggesting that gender equity in computing may be critical to the health of the world economy (OECD 2012).

The finer level of detail for US labor force data provides a useful illustration in Fig. 8.5 of sex segregation within computing. Figure 8.5 shows the relative size of subfields within IT in the United States and women's representation in each. Overall, women account for about 25% of workers in US computing occupations (hence, the red line as a point of reference) but women's representation in detailed computing occupations varies from 8% of computer network architects, to ~37% of database administrators. Referenced along the left axis, the bars show the number (in 1,000 s) of people employed in each subfield. The red diamonds, referenced on the right axis, show the percentage of women within each subfield, with the horizontal line at 25% showing the overall representation of women across all fields of computing occupations. The yellow bars indicate subfields in which the U.S. BLS reports that the customary educational credential is less than a 4-year college degree, while the

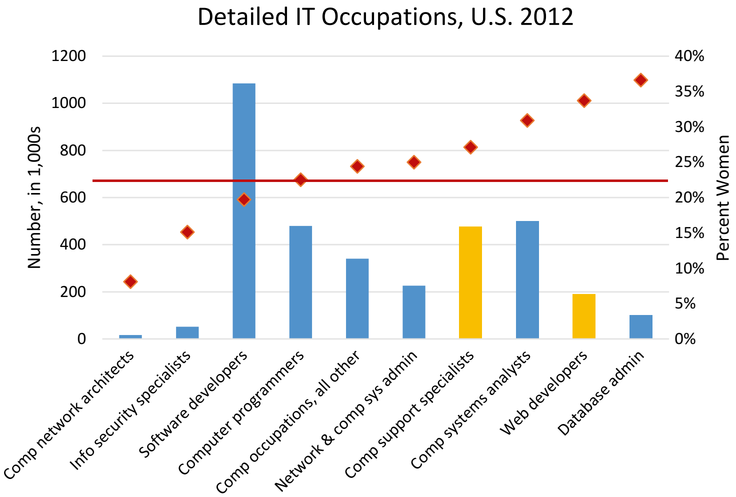


Fig. 8.5 Women's participation in U.S. computing occupations, 2012. *Note*: *yellow bars* indicate the customary education requirement is less than a bachelor's degree, the *blue bars* are those for which a bachelor's degree is the entry credential according to the U.S. Department of Labor Statistics. *Source*: Frehill, L. M. 2014. Analysis of BLS 2012c

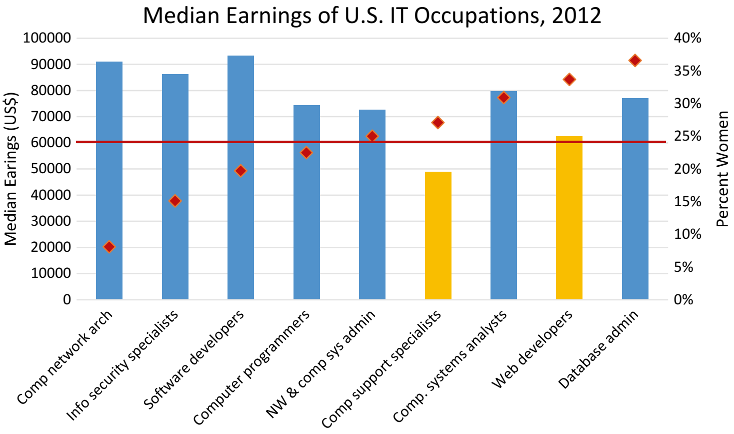


Fig. 8.6 Median earnings of U.S. IT occupations, 2012. *Note*: *yellow bars* indicate the customary education requirement is less than a bachelor's degree, the *blue bars* are those for which a bachelor's degree is the entry credential according to the U.S. Department of Labor Statistics. *Source*: Frehill, L. M. 2014. Analysis of BLS 2012b

blue bars indicate those fields for which a bachelor's degree or higher is typical. Women's representation is below the average of 25% in the following fields: software developers, applications, and systems software, the latter of which is the largest computing subfield. Women account for proportionately more than 25% of computer systems analysts and computer support specialists.

Figure 8.6 plots the median earnings of the same US IT occupations shown in Fig. 8.5, again, showing yellow bars for subfields for which U.S. BLS indicates that less than a bachelor's degree is a sufficient level of education and blue bars for those for which a bachelor's degree is the expected entry credential. Women's *representation* is *lowest* in the three *highest paid* occupations, which include two of the smaller occupations—computer network architects and information security specialists—as well as the largest one, software developers. Women's representation is higher than the 25% average in the two lowest-paid subfields—computer support specialists and web developers—the same subfields that, according to the U.S. BLS, are the only fields in IT that require less than a bachelor's degree.

Not shown in either Figs. 8.5 or 8.6 is "Computer and information research scientists," for which the customary credential is a PhD according to the U.S. BLS. With just 29,000 occupants, details about the gender and racial/ethnic composition of this subcategory were not provided by the BLS. Median earnings for these highly skilled professionals were the highest among US IT occupations at $102,190, which is more than twice the median for all US occupations of $45,790, to put this figure into a larger wage context.

The OECD completed a comprehensive report of women's participation in the ICT workforce in 2007. Fig. 8.7 is taken from the 2007 OECD report. Here, a

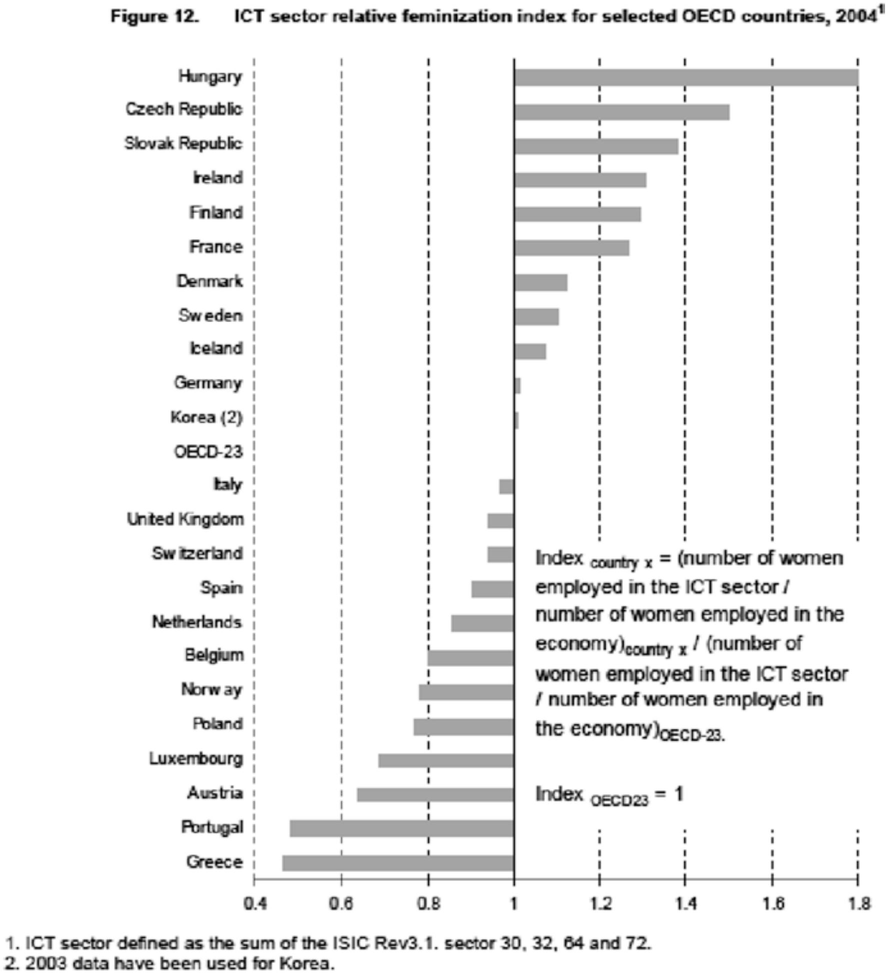


Fig. 8.7 Women's workforce participation in ICT as reported by OECD 2007. (1) ICT sector defined as the sum of the ISIC REV3.1. sector 30, 32, 64 and 72. (2) 2003 data have been used for Korea. *Source*: OECD, based on EULFS, and Korean Work Information Center, Human Resource Development Service

feminization index was used to normalize women's participation in the ICT sector in each country relative to the OECD participation rate. The index is computed as follows:

$$\text{Index}_c = \frac{\left[\dfrac{\#\,\text{Women}}{\text{Total}}\right]_c}{\left[\dfrac{\#\,\text{Women}}{\text{Total}}\right]_{\text{OECD}-23}}$$

Where: c = country
#Women = number of women in the ICT sector
Total = total ICT sector employment

As shown in the chart, Hungary, Czech Republic, Slovak Republic, and Finland are the OECD nations with a higher relative representation of women in the ICT workforce, while in Austria, Portugal, and Greece, women's ICT participation is lower than the average for the OECD. Recall, however, that the data on degree attainment shown in Figs. 8.1 and 8.3 for Tertiary A degrees suggests a need to better understand how educational credentials are mapped into the labor market. That is, the Slovak republic, for example, was a "very small" producer of computing degrees, with women accounting for just 12% of recipients of Tertiary A degrees. Men had a relatively high (7.7% of men's Tertiary A degrees) but women had a low (0.6% of women's tertiary degrees) in computing, suggesting that this credential may not be the critical entry point for the Slovak IT labor market, given the higher level of women's participation in IT work compared to other OECD nations.

In summary, women's representation in computing varies greatly across national contexts and, as illustrated with data for the US labor market, may differ within a nation based on the particular area of computing. These data underscore the importance of disaggregation: while women represented 25% of those in all US computing occupations, women's representation in detailed computing jobs ranged from a low of 8 to a high of 37%. The data from OECD illustrate the significant cross-national differences—in both computing higher education and labor force participation—in women's representation. Detailed data on subfield representation and the relative size of subfields across nations would provide useful additional data to understand the underlying dynamics of these cross-national differences.

8.4 Explanations for the Gender Gap in Participation in Computing

The previous section demonstrated the variability in women's cross-national representation in computing. Here we turn our attention to the question:

> Q2: What are the factors that encourage women's participation in computing and how do these vary as compared to the factors that draw men to the field?

A host of historical and psychological factors have been posited as potential explanations for the gender imbalance among ICT creators. In nations with high standards of living, history and social-psychological reasons are often cited. In the so-called developing nations, the literature has framed poor ICT, educational, and career access as either some of the negative impacts of societal devaluation of women and girls, or potentially like mathematics, the result of specific restricted agency of women in certain countries (Else-Quest et al. 2010).

Looking cross-nationally, researchers have noted that cultural beliefs about gender and gender appropriate labor combine with economic conditions, educational systems, and the characteristics of computing occupations to influence the gender composition of ICT (Charles and Bradley 2006; Charles et al. 2014). These national features are mutually reinforcing. Culture is transmitted through language and media (see Tympas et al. 2010 for an analysis of how Greek media portrays home computing), through the physical environment (Cheryan et al. 2011), through education and through our socialization of children, which makes them difficult to change.

Historical developments shaped computing fields' gender composition. ICT has academic, corporate, and hobbyist roots, each of which had its own gender compositions at the time ICT was forming in the OECD nations (Bratteteig 2008). Its academic roots in science, mathematics, engineering, and business disciplines have different patterns of gender representation as well at the university level. In nations where these fields were male dominated, the disciplinary roots grew into male majorities among computing leaders in academia.

In the corporate world, as ICT professionalized and boundaries were defined, women's computing work was devalued and deskilled (Ensmenger 2010). For example, this process was evident in the early feminization and later deliberate masculinization of computer work in the British civil service (Hicks 2010). When tinkerers and hobbyists led the shift to personal computers, women were further disidentified with ICT, because they were rarely members of these communities. Finally, as occupational gender segregation generally declined in industrialized nations, women had alternative professional opportunities and often chose careers in fields more closely aligned with longstanding feminine stereotyped abilities and interests (Sikora and Pokropek 2012).

Overall, women are attracted to ICT mostly by the same factors that draw men (Tillberg and Cohoon 2005; Cerinsek et al. 2013). According to Tillberg and Cohoon, those factors were: encouragement, perceived alignment with personal abilities and interests, positive initial experiences with computing, and expectations of a rewarding career. The attraction factors align well with an extensive body of knowledge about how people choose their occupations (Eccles 1994; Frehill 1996) and how those factors come into play in computing (Alexander et al. 2011).

Factors that drew women more than men to computing were perception of computing as a route to a helping career (Tillberg and Cohoon 2005; Cerinsek et al. 2013). For example, women but not men tended to mention they liked ICT as a form of communication, being recruited by friends, and defiance of gender-based expectations (Tillberg and Cohoon 2005). The first of these fits with a common gendered behavior in the United States—women's expression of interest in "helping" occupations (Eccles 1994). The second perception: computing as a form of communication fits with an observable gendered pattern in study of languages (Jacobs 1995). The third female-specific factor noted by Tillberg and Cohoon (2005)—defiance of gender-based expectations—exposes the social pressure steering most women away from computing occupations. These women, who were explicitly told that their gender prevented them from succeeding in computing, set out to prove that stereotype wrong.

Another example of common draws to ICT comes from a South African study that found women and men in ICT particularly enjoyed the intellectual stimulation, good salaries, flexible time and work environments, job security and satisfaction in ICT workplaces (Pretorius and de Villiers 2010). Again, there was tremendous overlap in the attractive features of ICT, although flexibility was emphasized by women more than men. This difference likely relates to the typically gendered expectations for balancing work and other aspects of life.

Gendered expectations about who has the ability to be an ICT professional predict the gender composition of the field. These stereotypes are often not even conscious, but affect preferences, confidence, and performance. In a cross-national study, Nosek et al. (2009) reported correlations between gender-science stereotypes and achievement differences by gender. They used the Implicit Associations Test,[5] which is grounded in experimental cognitive psychology, to measure test takers' facility or difficulty connecting science and masculinity versus science and femininity. Nosek and his colleagues examined data from 34 countries and more than a half million people, to find a strong relationship between an implicit connection of science and masculinity and the male advantage over women on the Test of International Mathematics and Science Study (TIMSS). These findings indicate that in nations where science is strongly associated with males, females perform poorly on tests of science, creating a self-fulfilling prophecy.

Another recent cross-national investigation reveals how the construction of gender impacts participation in computing. Charles et al. (2014) document that gendered interest and engagement in mathematics-related disciplines affect participation in computing. They found correlations among economic conditions and cultural beliefs about gender with attitudes and interest in math-based occupations as early as middle school. Their results show that, in countries where students have an economic means to choose careers based on self-expression, career choice is more likely to follow gender stereotypes.

If cultural beliefs and stereotypes affect the gender composition in computing, questions still remain about how those beliefs are formed and maintained, and how they might be overcome. In the United States, the National Center for Women in Information Technology (NCWIT) supports a Social Science staff and a Social Science Advisory Board, both of which work to accumulate and evaluate evidence about disparate participation in computing. Their goal is to motivate and inform other organizations' approaches to increasing women's participation in computing. The organization has compiled a body of literature on factors that create and maintain gender differences in ICT in the United States.

Others echo NCWIT's US findings for other nations, especially the European Commission (2012) and in the 2007 OECD publication on gender and ICT. The box on the "Latin American Women in Computing Congress" suggests that these same factors are hypothesized to be important outside those nations included in US and OECD analyses of gender and computing (Bonder 2003; United Nations Economic Commission for Latin American and Caribbean 2013). As a brief summary, these factors include:

- Cultural beliefs that link technology with masculinity (Frehill 2004; Oldenziel 1999; Oudshoorn et al. 2004; Sikora and Pokropek 2012; Wajcman 1991)
  - Funding practices that reflect those beliefs (de Bruin and Flint-Hartle 2005)
  - Hiring and promotion practices that reflect those beliefs (Reskin and Maroto 2011)

---

[5] https://implicit.harvard.edu/implicit/.

- Lack of widespread accurate information about computing opportunities and the nature of ICT study and work (Bratteteig 2008; Cuny 2011)
- Instruction that assumes prior knowledge, or at least motivated personal exploration (Bratteteig 2008; Margolis and Fischer 2002)
- Gender differences in access, exposure, and encouragement (Cohoon and Aspray 2006; Margolis and Fischer 2002)
- An environment tailored to the interests and lifestyles of the overwhelmingly dominant population in ICT—young, white males (Pretorius and de Villiers 2010)
  - Sexism, blatant and subtle (Cohoon et al. 2009)
  - Unattractive "Geek" culture of computing (Cheryan et al. 2009)
  - Emphasis on individual work and de-emphasis/devaluing of collaborative work
- Lack of secondary school computing requirements and the scarcity, more generally, of computer science and programming classes in US secondary schools (Cuny 2011; Margolis et al. 2011)

Findings from other important studies by Galpin (2002) and Trauth et al. (2009) reinforce the critical role of national culture in shaping women's participation in computing. Trauth and her colleagues used qualitative interviews with more than 200 women in IT in the United States, Australia, New Zealand, and Ireland, which included immigrant women from a number of nations, including China and India. Immigrant women interviewees made some personal cross-national comparisons, which offer tentative areas for future research.[6] Trauth et al. show that sociocultural moderators intervene with perceptions of women's general role in society to impact women's choice of careers in IT. In addition, the meaning of a career and the role of family in career choice were also described: in the United States,[7] for example, career choice reflects a job an individual wants to be in, while in other countries discussed by Trauth et al.'s respondents, families play a more active role in selection of a career. That is, respondents to Trauth et al. who had been raised in China and India reported that if an individual performed well in mathematics and science, then (s)he was expected to pursue a career in those fields. In other words, the dominant ethos, according to these respondents, was that young people are expected to pursue work in areas in which they have a measured potential, regardless of an individual preference or interest, findings that are underscored in work by Varma (2015) and supported in the earlier-referenced work by Charles et al. (2014).

---

[6] Attention to the potential for individualistic fallacy errors is important caution in such cases.

[7] Within working class families (Higginbotham and Weber 1992) and among Latinos (Santiago 2007), though, there are some areas of US society to which this understanding of "choice" is not applicable. In such families there are expectations more similar to those described here as the case in China and India.

Latin America: Latin American Women in Computing Congress

"This is an annual event that has taken place since 2009 within the framework of the Latin American Computing Conference (CLEI) organized by the Latin American Centre for Informatics Studies. Its main objective is to highlight women's research interest, and achievement in the different areas of information technology, with a view to encouraging more active participation from women. The papers presented are expected to identify the challenges facing women in the ICT field, in teaching, in the job market, and in research.

The fifth Latin American Women in Computer Congress (Naiguatá, Bolivarian Republic of Venezuela, October 2013) is part of Latin American Computing Conference 2013. Its topics will be:

- Encouraging the participation of women in the ICT sector
- Gender equality and ICTs
- Gender particularities in the development and deployment of ICTs
- Gender particularities in ICT education
- Analysis of the research activities of women in ICTs
- Gender and human–computer interaction
- Female leadership models in IT
- Internet social networking and the role of women
- Women's participation in decision-making at the national and international level in relation to the use of ICTs
- Public policies on ICTs".

Source: Latin American Computing Conference (CLEI), "V Congress de la Mujer Latinamerícana en la Computación," 2013 [online] http://clei2013.org.ve/v-congreso-mujer-latinoamericana-en-la-computacion/.

Reflecting and amplifying the impact of cultural beliefs, educational systems play a huge role in shaping a nation's ICT gender composition. Charles and Bradley (2009) found that horizontal gender segregation (clustering of men and women in different fields) correlates negatively to educational systems with low prestige and low entry barrier options. Likewise, having the luxury of career choice based on self-expression as opposed to economic or other practical considerations contributes to gender segregation in academic disciplines, including computing (Charles and Bradley 2006).

In India, for example, women's relative representation among those enrolled in computing and information technology is larger than that in many countries, but women are far less likely than men to attend the elite IITs. The gender gap in girls' versus boys' admission rates to the IITs is hypothesized to be due to less access for girls to the coaching that many boys receive to perform well on the examination (National Task Force for Women in Science 2010). The gap in access to coaching is due to both cost as well as "unfortunate timings," courses scheduled too late at night or early in the morning, which marginalize girls. Given the recent international news about violence against women in India (Lakshmi 2012a, 2012b; Sharma et al. 2013), such concerns about personal safety in public are an important practical concern.

The question about the quality of the credentials women earn in computing and IT in India suggests that researchers need to be attentive to the within-field stratification of computing jobs. Just as was shown in Figs. 8.5 and 8.6 for US computing occupations, if women are less likely to earn degrees from the best universities in the country, they may be relegated to lower-wage work in more routine jobs in computing than their male counterparts.

In India, "feudal, authoritarian values and hierarchy have characterized Indian society," which underlie the lower level of women's participation in science (Kumar 2008) and, consistent with Brownmiller's classic 1975 expose, buttress the societal acceptance of violence against women as a means of social control. Kumar argues that an ethos of masculinity permeates Indian institutions, into which gender is woven into the rigid, hierarchical structure, leading women to either suppress their aspirations or to cluster in fields with more women such as the life and medical sciences. The data in Fig. 8.4, as well as work by Varma (2010, 2015), suggests that IT may be a field into which Indian women may be clustering.

As a relatively new field ICT may be less laden with pre-conceived beliefs than more established fields. Ilavarasan's (2006) limited observations of women and men in the Indian IT workforce found that respondents had similar opportunities regardless of gender. Work by Munshi and Rosenzweig (2006) focused on local labor markets in Bombay to describe the relationship between caste, gender, and schooling. Munshi and Rosenzweig found that existing social networks that young men used to locate jobs enabled them to secure positions in traditionally male-dominated occupations. IT occupations, as relatively new occupations with high demand, lacked prior connections to social networks, thereby representing an opportunity for women—who were also new entrants to the paid labor market—serving as a driver for women to obtain relevant education.

Beyond the issue of educational quality, research on gender and computing in a number of global regions focuses attention on girls' and women's access to education in general, and ICT as a means of societal advancement and growth. According to the National Task Force on Women in Science (Government of India 2010), there are several issues unique to India in contrast to other large nations, but which are similarly important in other developing nations. These factors impact women's participation in education, generally, and pose implications for women's access to fields that require completion of progressively more complex education:

- The educational pipeline leaks in primary and secondary school
- Female children continue to be culturally considered a burden
- There is a high incidence of malnutrition in women and children
- As a summary, the World Economic Forum (WEF) Gender Gap Index ranks India 113 out of 130 nations

These issues related to gender, access, and development were prominent in UNESCO (1999) and infoDEV (2007) reports about African nations (Farrell and Isaacs 2007). State policies that impact the availability of education often have a disparate impact upon girls compared to boys. Just as the Indian government has taken steps to improve girls' access to primary and secondary education, differential access to these foundational experiences, in general, and to computers, in particular, hamstrings women's access to the ICT labor market. Nigeria and Ghana, for example, have taken steps to introduce girls and women to emergent economic sectors such as biotechnology, informatics, and computer technology as a means to national economic development.

8.5 Women's Impact on Computing

Consistent with Bratteteig's suggestion, we go a step beyond the equity approach implicit in the foregoing to ask how gender impacts how computing is done or what is produced by computing work, which was at the heart of our third question:

Q3: To what extent does gender matter in computing?

In this section, we provide a short overview of some of the themes that have been—and continue to be—explored that attempt to answer this question, as a means of motivating additional research in this area. As highlighted in Creager et al. (2001), it is important to avoid the tendency to essentialize gender in addressing this question. Instead, gender should be seen as one of many dimensions of diversity reference in the burgeoning "business case for diversity" literature, which has emerged over the past 25 years. While this is a vast and rapidly growing literature, the extent to which sources in this literature focus on IT in particular or provide cross-national analyses is somewhat limited but also growing given the centrality of IT for the world economy.

The business case is grounded in findings that diverse groups perform better than homogeneous ones, are more innovative, and, therefore, are better for the bottom line (profit) in business settings (see, for example, Catalyst 2013; Cox and Blake 1991; Herring 2009; Hoogendoorn et al. 2011). In IT, for example, Ashcraft and Breitzman (2007) examined IT patents in Japan and the United States by the gender composition of the patenting team and found that "Within the U.S. set, mixed-gender teams produced the most frequently cited patents—with citation rates that were 26–42% higher than the norm. Female-only teams had the lowest citation impact, followed by male only teams" (p. 5).

Many studies on the relationship between teams and innovation document the important role of diversity in the innovation process (see, for example, Bassett-Jones 2005; Gilbert 2006; Hoogendoorn et al. 2011; Marx 2013). Within this literature, which buttresses the "business case," it is rational for businesses to include women in the design process in order to develop products that will appeal to a wider market than those that might be designed by all-male teams. A similar argument is made—and supported by the literature—about other bases of social difference. Reflecting this bottom-line prerogative, corporations that are large investors in research and development (R&D) have established networks of research laboratories in multiple countries to take advantage of the varied workforces and ideas within those regions (Thursby and Thursby 2006).

Some studies that have attempted to answer this question often take the literature on the business case for diversity as a "given." According to a review by Maass et al. (2007), the affirmative answer to this question is common among policy makers and corporate advocates of women in computing who see women as being able to make potentially different contributions to computing. In their volume reporting on an international symposium on women in information and systems technology (IST) Maass et al. emphasize that "IST design is a highly prestigious activity. Information technology business offers positions of power and good incomes for those with the appropriate (technical) education and enough self-confidence" (p. 10).

Such a view is especially apparent in African nations, where policy makers see much promise for social and economic development associated with increasing access to information via ICTs for African nations. Publications that focus on ICT in Africa emphasize the need to include women in decision-making processes about national ICT infrastructure (i.e., gender mainstreaming), in particular, and at all stages of education and workforce for ICT (UNECA 2009a, 2009b).

Within the global context, ICTs have become ubiquitous. The UNECA has paid much attention to this issue, including documentation of the progress made in narrowing the gender digital divide. At a meeting in 1996, the UNECA Conference of Ministers passed Resolution 812 (XXXI) in Tunis, Tunisia. A gender mainstreaming approach was among the resolution's five points: "To establish a gender-balanced African technical committee to advise on programmes and projects and evaluate results." (UNECA 2008: 6). Gender mainstreaming, common in much of the world, is emphasized as the means by which women would have equal access to ICT as a means to societal advancement.

Figure 8.8 plots data included in UNECA (2009b) and shows the status—as of 2009—of policy progress in implementation of the Tunis Commitment. Ten policy features were examined as of August, 2009 and scored (0–2) by UNECA to develop an index that ranged from 0 to 20. The policy features were:

- Policy development
- Development of a plan
- Targets (gender)
- Institutional mechanisms
- Budget
- Human resources
- Research
- Involvement of civil society
- Information and dissemination
- Monitoring and evaluation

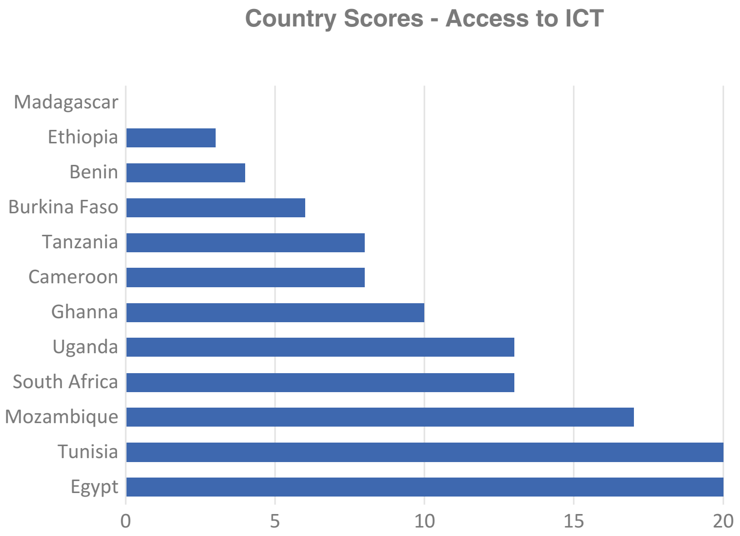


Fig. 8.8 Policy to increase women's access to ICT in selected African nations, 2009. *Source*: Frehill, LM. 2014. Analysis of data from UNECA. (2009). African Women: Measuring gender inequality in Africa: Experiences and Lessons from the African Gender Development Index. (Adis Ababa: UNECA)

After the events of the Arab Spring of 2011 and, particularly the backlash against women in Egypt since then (Dawoud 2012), it is interesting to note that Tunisia and Egypt had the highest scores on this policy scale. Mozambique's score of 17 places it in third position with respect to increasing women's access to ICTs, while South Africa and Uganda are in fourth position with a score of 13 each. Other nations, notably Madagascar, Benin, Ethiopia, and Burkina Faso all had relatively low scores (0–4), reflecting persistent gender equality issues.

8.6 Conclusion

We have shown that women's participation in computing varies greatly across national contexts and in various ways within nations. While women may not pursue computing degrees, the sheer size and significance of the ICT economic sector at the global level serves to pull women into the field. As these jobs become increasingly important and numerous globally, tied as they are to national economic prosperity, they are likewise important to women's and children's prosperity. Maass and her colleagues point out, for example, that almost any job in the new global economy necessitates that one use information technology, so, individuals need at least a working knowledge of ICT to survive. To thrive, though, being conversant in these technologies will be increasingly critical.

While women appear to be making inroads in computing education in some nations, these are generally in nations that are medium or small producers of degrees in computing and in which computing occupies a lower status than other areas of science. In other cases, such as in India, the extent to which women have access to education of a quality comparable to that of men remains an open issue. Women's overall participation in secondary and tertiary education has grown in India, as it has in much of the world, but women still have not reached parity with men. In addition, despite women's relatively high rates of enrollment in CS/IT fields (as shown in Fig. 8.4) they continue to be significantly underrepresented at India's most prestigious IITs.

The case of India, indeed, illustrates the need to be more cautious with data on gender and participation in science. Institutional differences have important ramifications for the likely career outcomes of students (see also Malcom et al. 2005 for a review of the impact of institutions on IT career outcomes in the US setting). The organization of IT within higher education, as a relatively new field, can both affect and be affected by the larger social organization of gender. This begs the question; to what extent are the cross-national variations in women's participation in computing an outcome of the different ways in which computing is organized within national education systems?

The labor market data for the United States, which further disaggregated computing into a number of subfields, provided another important analytical illustration. As has always been the case in occupational sex segregation research, the level of aggregation is a critical dimension; high levels of aggregation can often obscure key differences that are only revealed when one is able to more closely specify occupational categories at a finer level of detail. As shown in Figs. 8.5 and 8.6, for example, the distribution of women across subfields of IT work in the United States varied greatly across the ten detailed occupations shown in Fig. 8.5 (nine in Fig. 8.6).

These twin issues—the quality differences (stratification) of higher education institutions and the level of aggregation—pose challenges for researchers interested in understanding gender and computing. Yet, this chapter's analyses may offer useful starting points for subsequent researchers interested in the policy implications of the questions posed in this chapter.

The limitations of data availability pose challenges to those interested in cross-national occupational analysis. While we were able to disaggregate computing occupations in the US labor market, this was not possible with any other national labor market data to which we had access. Further, in fact, due to the level of general workforce data aggregation, it was not possible to look at employment in ICT. The most recent year for which sex-disaggregated data were available from the European Commission was 2006. Researchers interested in other dimensions of difference, such as immigration status or race/ethnicity, will find it even more challenging to find suitable data to understand how such dimensions affect access to the ICT workforce.

Additional research is needed to better understand the cross-national differences discussed here. Further, additional research needs to provide insights into the third question we posed; to what extent does gender matter in computing? In comparison to men, do women focus on different problems? Take different approaches? Use and develop different computing tools?

The omnipresence and rapid growth of ICT suggest that it is vital to ensure diverse individuals can access opportunities associated with the ICT labor market. Likewise, the pace of innovation suggests a need to tap a rich talent pool to ensure equitable advancement.

Chapter References

Abbate, Janet. 2012. *Recoding Gender: Women's Changing Participation in Computing*. Cambridge: MIT.

Alexander, P.M., M. Holmer, H.H. Lotriet, M.C. Matthee, H.V. Pieterse, S. Naidoo, H. Twinomurinzi, and D. Jordan. 2011. Factors Affecting Career Choice: Comparison Between Students from Computer and Other Disciplines. *Journal of Science Education Technology* 20: 300–315.

Ashcraft, Catherine and Anthony Breitzman. 2007. *Who Invents IT? An Analysis of Women's Participation in Information Technology Patenting.* Boulder, CO: National Center for Women in Information Technology, http://www.ncwit.org/sites/default/files/legacy/pdf/PatentReport_wAppendix.pdf (accessed 20 April 2014).

Bassett-Jones, Nigel. 2005. The Paradox of Diversity Management, Creativity and Innovation. *Creativity and Innovation Management* 14(2): 169–175.

Bonder, Gloria. 2003. *The new Information Technologies and Women: Essential Reflections*. Santiago, Chile: United Nations, Women and Development Unit.

Bratteteig, Tone. 2008. *Understanding Gender and IT*. OECD-CERI Conference 'Return to Gender: Gender, ICT and Education', Oslo, Norway, 2–3 June 2008, http://www.oecd.org/edu/research/41648818.pdf.

Brownmiller, Susan. 1975. *Against our Will: Men, Women and Rape*. New York: Simon and Schuster.

Bureau of Labor Statistics. 2012a. *Occupational Outlook Handbook*, http://www.bls.gov/ooh/ (accessed 24 January 2014).

_____. 2012b. *Computer and Information Technology Occupations*, http://www.bls.gov/ooh/computer-and-information-technology/home.htm (accessed 24 January 2014).

_____. 2012c. *Household Data Annual Averages, 11. Employed Persons by Detailed Occupation, Sex, Race, and Hispanic or Latino Ethnicity*. http://www.bls.gov/cps/http://www.bls.gov/cps/cpsaat11.

Catalyst. 2013. *Why Diversity Matters*, http://www.catalyst.org/knowledge/why-diversity-matters (accessed 20 April 2014).

Cerinsek, Gregor, Tina Hribar, Natasa Glodez, and Slavko Dolinsek. 2013. Which are my Future Career Priorities and What Influenced my Choice of Studying Science, Technology, Engineering or Mathematics? Some Insights on Educational Choice—Case of Slovenia. *International Journal of Science Education* 35(17): 2999–3025.

Charles, Maria, Bridget Harr, Erin Cech, and Alexandra Hendley. 2014. Who Likes Math Where? Gender Differences in Eighth-graders' Attitudes Around the World. *International Studies in Sociology of Education* 24(1): 85–112.

Charles, Maria, and Karen Bradley. 2006. A Matter of Degrees: Female Underrepresentation in Computer Science Programs Cross-Nationally. In *Women and Information Technology*, ed. Bill Aspray and Joanne McGrath Cohoon, 183–203. Cambridge, MA: MIT Press.

Charles, Maria, and Karen Bradley. 2009. Indulging Our Gendered Selves? Sex Segregation by Field of Study in 44 Countries. *American Journal of Sociology* 114: 924–976.

Cheryan, S., V.C. Plaut, P.G. Davies, and C.M. Steele. 2009. Ambient Belonging: How Stereotypical Cues Impact Gender Participation in Computer Science. *Journal of personality and Social Psychology* 97(6): 1045.

Cheryan, S., A.N. Melzoff, and S. Kim. 2011. Classrooms Matter: The Design of Virtual Classrooms Influences Gender Disparities in Computer Science Classes. *Computers & Education* 57: 1825–1835.

Cohoon, J.M., Z. Wu, and J. Chao. 2009. Sexism: Toxic to Women's Persistence in CSE Doctoral Programs. *ACM SIGCSE Bulletin* 41(1): 158–162.

Cohoon, Joanne McGrath, and William Aspray, eds. 2006. *Women and Information Technology: Research on Underrepresentation*. Cambridge: MIT.

Cox, T.H., and S. Blake. 1991. Managing Cultural Diversity: Implications for Organizational Competitiveness. *The Executive* 5(3): 45–56.

Creager, Angela N.H., Elizabeth Lunbeck, and Londa Schiebinger (eds.). 2001. *Feminism in Twentieth-Century Science, Technology, and Medicine*. Chicago: University of Chicago.

Cuny, Jan. 2011. Transforming Computer Science Education in High School. *IEEE Computer Society* 44: 107–109.

de Bruin, Anne, and Susan Flint-Hartle. 2005. Entrepreneurial Women and Private Capital: The New Zealand Perspective. *International Journal of Entrepreneurial Behavior & Research* 11(2): 108–128.

Dawoud, Aliaa. 2012. Why Women Are Losing Rights in Post-Revolutionary Egypt. *Journal of International Women's Studies* 13(5): 160–169, http://vc.bridgew.edu/jiws/vol13/iss5/14 (accessed 20 April 2014).

Eccles, Jacqueline. 1994. Understanding women's Educational and Occupational Choices: Applying the Eccles et al. Model of Achievement-Related Choices. *Psychology of Women Quarterly* 18: 585–609.

Else-Quest, Nicole M., Janet Shibley Hyde, and Marcia C. Linn. 2010. Cross-National Patterns of Gender Differences in Mathematics: A Meta-analysis. *Psychological Bulletin* 136(1): 103–127.

Ensmenger, Nathan L. 2010. *The Computer Boys Take Over: Computers, Programmers, and the Politics of Technical Expertise*. Cambridge: MIT.

European Commission. 2012. *She Figures 2012: Gender in Research and Innovation, Statistics and Indicators,* http://ec.europa.eu/research/science-society/index.cfm?fuseaction=public.topic&id=1282 (accessed 26 October 2013).

Farrell, Glen and Shafika Isaacs. 2007. Survey of ICT and Education in Africa: A Summary Report, Based on 53 Country Surveys. Washington, DC: infoDev/World Bank, http://www.infodev.org/en/Publication.353.html (accessed 4 January 2014).

Frehill, Lisa M. 1996. Education and Occupational sex Segregation: The Decision to Major in Engineering. *Sociological Quarterly* 38(2): 225–249.

_____. 2004. The Gendered Construction of the Engineering Profession in the United States, 1893-1920. *Men and Masculinities* 6(4): 383–403.

Fritz, W. Barkley. 1996. The Women of ENIAC. *Annals of the History of Computing* 18(3): 13–23.

Galpin, Vashti. 2002. Women in Computing Around the World. *SIGCSE Bulletin* 34(2): 94–100.

Gilbert, Juan E. 2006. Making a Case for BPC. *Computer* 39(3): 83–86.

Government of India, Ministry of Science and Technology, National Task Force for Women in Science. 2010. *Evaluating and Enhancing Women's Participation in Scientific and Technological Research: The Indian Initiatives*, http://www.ias.ac.in/womeninscience/taskforce_report.pdf (accessed 4 January 2014).

Government of India, Ministry of Human Resources Development. 2013a. *All India Survey on Higher Education, 2011-12 (provisional)*. New Delhi.

_____. 2013b. Higher and Technical Education. *Education Report to the People on Education, 2011-12*, 50–62. New Delhi.

_____. 2013c. *Educational Statistics at a Glance*. New Delhi.

Herring, Cedric. 2009. Does Diversity Pay? Race, Gender, and the Business Case for Diversity. *American Sociological Review* 74(2): 208–224.

Hicks, Marie. 2010. Meritocracy and Feminization in Conflict: Computerization in the British Government. In *Gender Codes: why Women are Leaving Computing*, ed. Thomas J. Misa, 95–114. Hoboken: Wiley.

Higginbotham, Elizabeth, and Lynn Weber. 1992. Moving up With kin and Community: Upward Social Mobility for Black and White Women. *Gender & Society* 6: 416–440.

Hoffman-Barthes, A.M., S. Nair, and D. Malpedes. 1999. *Science, Technical and Vocational Education of Girls in Africa: Summary of 21 National Reports*. Paris: UNESCO.

Hoogendoorn, Sander, Hessel Oosterbeek, and Mirjam van Praag. 2011. The Impact of Gender Diversity on the Performance of Business Teams: Evidence from a Field Experiment. *Social Sciences Research Network (SSRN) Working Paper Series*, 28 April 2011.

Ilavarasan, P. V. 2006. Are Opportunities Equal for Women in the IT Workplace? Observations from the Indian Software Industry. *IEEE Technology and Society* Winter: 43–49.

Jacobs, Jerry A. 1995. Gender and Academic Specialties: Trends Among Recipients of College Degrees in the 1980s. *Sociology of Education* 68(2): 81–98.

Kumar, Neelam. 2008. *Gender and Science in India*, http://www.nistads.res.in/indiasnt2008/t1humanresources/t1hr12.htm (accessed 1 January 2014).

Lakshmi, Rama. 2012a. National Uproar Over Young Woman's Death Triggers Public Conversation about Rape. *The Washington Post* (29 December 2012), http://www.washingtonpost.com/world/asia_pacific/national-uproar-over-young-womans-death-triggers-public-conversation-about-rape/2012/12/29/183f9762-51ab-11e2-835b-02f92c0daa43_story.html (accessed 11 April 2014).

_____. 2012b. 10 Reasons Why India Has a Sexual Violence Problem. *The Washington Post* (29 December 2012), http://www.washingtonpost.com/blogs/worldviews/wp/2012/12/29/india-rape-victim-dies-sexual-violence-proble/ (accessed 11 April 2014).

Maass, S., E. Rommes, C. Schirmer, and Isabel Zorn. 2007. Gender Research and IT Construction: Concepts for a Challenging Partnership. In *Gender Designs IT: Construction and Deconstruction of Information Society Technology*, ed. I. Zorn, S. Maass, E. Rommes, C. Schirmer, and H. Schelhowe, 9–31. Wiesbaden, Germany: Springer.

Malcom, Shirley, Albert H. Teich, Jolene Kay Jesse, Lara A. Campbell, Eleanor L. Babco, and Nathan E. Bell. 2005. *Preparing Women and Minorities for the IT Workforce: The Role of Nontraditional Educational Pathways*. Washington, DC: American Association for the Advancement of Science.

Margolis, Jane, and Allan Fischer. 2002. *Unlocking the Clubhouse: Women in Computing*. Cambridge: MIT.

Margolis, Jane, Joanna Goode, and David Bernier. 2011. The Need for Computer Science. *Education Leadership* 68: 68–72.

Marx, Elisabeth. 2013. *The Power of Global Teams: Driving Growth and Innovation in a Fast Changing World*. New York: Palgrave Macmillan.

Munshi, Kaivan, and Mark Rosenzweig. 2006. Traditional Institutions Meet the Modern World: Caste, Gender, and Schooling Choice in a Globalizing Economy. *The American Economic Review* 96(4): 1225–1252.

Natarajan, R. 2005. *The Evolution of Postgraduate Engineering Education and Research in India*. Paper Presented at International Conference: Challenges to Innovation in Graduate Education, Toronto, 2–5 November 2005.

Nayar, Anjali. 2011. Educating India. *Nature* 472: 25–26.

Nosek, Brian A., Frederick L. Smyth, N. Srirama, Nicole M. Lindner, Thierry Devos, Alfonso Ayala, Yoav Bar-Anana, Robin Bergh, Huajian Cai, Karen Gonsalkorale, Selin Kesebira, Norbert Maliszewski, Félix Netoh, Eero Olli, Jaihyun Park, Konrad Schnabel, Kimihiro Shiomura, Bogdan Tudor Tulbure, Reinout W. Wiers, Mónika Somogyi, Nazar Akramid, Bo. Ekehammard, Michelangelo Vianello, Mahzarin R. Banaji, and Anthony G. Greenwald. 2009.

National Differences in Gender-Science Stereotypes Predict National Sex Differences in Science and Math Achievement. *Proceedings of National Academy of Sciences of the United States of America* 106(26): 10593–10597.

Oldenziel, Ruth. 1999. *Making Technology Masculine men, Women, and Modern Machines in America, 1870-1945*. Amsterdam, The Netherlands: Amsterdam University Press.

Organisation for Economic Cooperation and Development (OECD), Directorate for Science, Technology and Industry, Committee for Information, Computer and Communications Policy. 2007. *ICTs and Gender*. DSTI/ICCP/IE(2006)9/FINAL.

_____. 2010. *OECD Information Technology Outlook*. Paris: OECD.

_____. 2012. *OECD Internet Economy Outlook 2012*. Paris: OECD.

_____. 2013. *OECD STAT.Extracts*. http://stats.oecd.org/# (accessed 26 October 2013, 4 January 2014, and 11 April 2014).

Oudshoorn, Nelly, Els Rommes, and Marcelle Stienstra. 2004. Configuring the User as Everybody: Gender and Design in Information and Communication Technologies. *Science, Technology, and Human Values* 29(1): 30–63.

Pretorius, H., and de Villiers, C. 2010. A South African Perspective of the International Discourse About Women in Information Technology. *Proceedings of SAICSIT 2010*, 265–274. New York: ACM Press.

Reskin, B., and M. Maroto. 2011. What Trends; Whose Choices: Comment on England. *Gender & Society February* 25(1): 81–87.

Santiago, Deborah. 2007. *Hispanic-Serving Institutions (HSIs): A Closer Look at Latino Students' College Choices.* Washington, DC: Excelencia in Education.

Seely-Gant, Katie. 2015. Road to 2015: Pre-college Gender Parity and UNESCO's Millennium Development Goals. In *Advancing Women in Science: An International Perspective*, ed. Pearson, Jr., Willie, Lisa M. Frehill, and Connie L. McNeely, 27–32. New York: Springer.

Sharma, Amol, Biman Mukherji and Rupa Subramanya. 2013. On India's Streets, Women Run a Gauntlet of Harassment. *Wall Street Journal* online (27 February 2013), http://online.wsj.com/news/articles/SB10001424127887324616604578302620513689386 (accessed 11 April 2014).

Sikora, Joanna, and Artur Pokropek. 2012. Gender Segregation of Adolescent Science Career Plans in 50 Countries. *Science Education* 96(2): 234–264.

Srivastava, V. (2012, April). This Year, Women Set to Break the IIT Gender Wall. Hindustan Times, http://www.hindustantimes.com/StoryPage/Print/837191.aspx?s=p (accessed 10 April 2014).

Tillberg, Heather K., and J. McGrath Cohoon. 2005. Attracting Women to the CS Major. *Frontiers: A journal of Women Studies. Special Gender and IT Issue* 26(1): 126–140.

Thursby, M., and J. Thursby. 2006. Where is the New Science in Corporate R&D? *Science* 314: 8.

Trauth, E.M., J.L. Quesenberry, and H. Huang. 2009. Retaining Women in the US IT Workforce: Theorizing the Influence of Organizational Factor. *European Journal of Information Systems*. Special Issue on Meeting the Renewed Demand for IT Workers (18): 476–497.

Tympas, Aristotle, Konsta Hara, Lekkas Theodore, and Karas Serkan. 2010. Constructing Gender and Technology in Advertising Images: Feminine and Masculine Computer Parts. In *Gender Codes: Why Women are Leaving Computing*, ed. Thomas J. Misa, 187–210. Hoboken: Wiley.

United Nations Economic Commission for Africa. 2008. *The African Information Society Initiative: A Decade's Perspective*. Ethiopia: Addis Ababa.

_____. 2009a. *African Women's Report: Measuring Gender Inequality in Africa: Experiences and Lessons from the African Gender and Development Index*. Ethiopia: Addis Ababa.

_____. 2009b. *Harmonization of ICTs Policies and Programmes in East Africa Subregion and Prospects*. Kigali Rwanda: UNECA.

United Nations Economic Commission for Latin American and Caribbean. 2013. *Women in the Digital Economy: Breaking Through the Equality Threshold*, http://www.eclac.cl/publicaciones/xml/1/51141/womaninthedigitaleconomy.pdf (accessed 23 January 2014).

United Nations Economic and Social Council, Statistical Commission. 2012. *Gender Statistics: Report of the Secretary-General*, http://unstats.un.org/unsd/statcom/doc13/2013-10-GenderStats-E.pdf (accessed 24 January 2014).

_____. 2013. Report of the Secretary-General on "*Science, Technology and Innovation, and the Potential of Culture, for Promoting Sustainable Development and Achieving the Millennium Development Goals*" for the 2013 Annual Ministerial Review.

Varma, Roli. 2010. Computing Self-Efficacy Among Women in India. *Journal of Women and Minorities in Science and Engineering* 16: 257–274.

_____. 2015. Making a Meaningful Choice: Women's Selection of Computer Science in India. In *Advancing Women in Science: An International* Perspective, ed. Pearson, Jr., Willie, Lisa M. Frehill, and Connie L. McNeely, 263–266. New York: Springer.

Wajcman, Judy. 1991. *Feminism confronts technology*. State College: Pennsylvania State University Press.

Wilson, D. and R. Purushothaman. 2003. *Dreaming with BRICs: The Path to 2050 Goldman Sachs*, Global Economics Paper No. 99.

World Education Services. 2007. *WES Evaluation of the Three-Year bachelor's Degree from India*. Bowling Green: WES.

Vignette 8.1
Faculty Wives of Computing

Betsy DiSalvo

“I am a faculty wife. My husband teaches and researches design and technology, he works on robots a lot.” For a many years, this is how I introduced myself to new acquaintances (all of our new acquaintances were in academia that is what happens when you are a faculty wife). Eventually, between him bringing home interesting questions and talking about exciting project, me feeling unfulfilled in my job with a desire to learn more, and the stars aligning in a certain pattern, I went back to school. I studied Human Centered Computing at Georgia Institute of Technology, eventually earned my Ph.D. and started as an Assistant Professor there in 2012. Before marriage, I never would have dreamed that I would earn a Ph.D., let alone a Ph.D. in computing. I credit (and some days blame) it on the exposure to new ideas I gained as a faculty wife.

I am not the first faculty wife in computing. To understand faculty wives’ role in computing, it is important to reflect on the history and development of computers during WWII. The University of Pennsylvania’s Moore School of Electrical Engineering was executing a military contract to develop ENIAC (Electronic Numerical Integrator and Computer) and required massive amount of hours on the part of mathematicians to calculate trajectories for military applications. With the lack of men available to work during the war, particularly men skilled in mathematics, these calculations were made by a large group of female mathematicians, called *Computers*. At the end of the war, men were available to do this work, but at this point the work was considered a traditionally female role, and women who had worked on the ENIAC programming were the most prepared to continue (Light 1999).

B. DiSalvo (✉)
Georgia Institute of Technology, Atlanta, GA 30307, USA
e-mail: bdisalvo@cc.gatech.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_8

A number of these young women working on the ENIAC project married more senior men working on the project, and these men moved to faculty jobs after the war, their wives helped with their husband's research. Adele Goldstine, who managed the female *Computer* team and wrote the technical documentation, was the wife of Herman Goldstine. She followed her husband from the ENIAC project to Princeton to work on the Institute of Advanced Study Electronic Computer Project (ECP). When asked about the programmers on the ECP in an interview in 1980, H. Goldstine commented:

> We had a couple; we had wives who were programmers. A couple of women. For instance, my wife worked for von Neumann as a programmer, on a Los Alamos contract. And then we had two other, Hedi Selberg and Margaret Lambe who were wives of professors. Hedi's husband was a professor at the Institute and Margaret's husband is now a Stony Brook. (Stern 1980, p. 52)

His statement is telling, in that it diminishes both the role of the programming and the role of the women in the projects. These collaborators were considered just wives of professors but not full team members. The job of programming was not given the same consideration as other work on the ECP; it was something left to the wives, who are described by their husbands' positions rather than their contribution. There were at least five women who developed programs for the ECP, all wives of professors, and no recollection of men who did this work from H. Goldstine or others who have been interviewed (Stern 1980a, 1980b, 1981).

A report by Burks, H. Goldstine and von Neumann, the *Preliminary Discussion of the Design of an Electronic Computing Instrument*, begins to outline a programming language, what they call "Symbolization" with their corresponding operation (Burks et al. 1986). While Von Neumann and others developed some test programs, the full programs were developed by the "wives" including Von Neumann's wife, Klara Dan von Neumann. The faculty wives that did this programming had to be fluent in the mathematical programs to translate them into machine language. In some ways the role of these women was less of a *Computer*, and more similar to that of a compiler; translating between mathematical functions and machine language.

As efforts to establish formal programming languages that were more similar to English, rather than machine language, began to succeed, the role of women diminished, until woman became the anomaly rather than the standard in computer programming. There are many contributing factors to this: most of the women who worked as *computers* during WWII went to work fulltime in their homes after the war; as the computer programming came to the forefront of technological development it was regarded as less of a clerical task; and computing was being established as an industry so the work of a computer programmer was seen as a job rather than patriotic service (Light 1999).

Looking back on this history, I wonder if these women had been given the agency to pursue independent intellectual questions, would the development of stored programming language begun sooner, moved faster, or had a different trajectory? I recognize that even with the advancement of women in computing, stepping out of my role as a faculty wife, into the role of a faculty member was unusual, difficult, and risky. While my husband is not as venerated as von Neumann, because of the sequence of our degrees and appointments and the choice to take his last name, people outside of my department frequently perceive my work as an extension of my husband's, or dismiss my appointment in academia as a courtesy. There is little I can do to change that perception.

And I am not alone, while women have certainly made progress, currently 36% of faculty have an academic partner, yet only 20% of wives said their career comes first compared with 50% of men (Schiebinger et al. 2008). These statistics, my experiences, and the history of women in computing leave me asking if women shortchange themselves or if perceptions that our work is less valuable shapes our choices?

References

Burks, Arthur. W., Herman H. Goldstine and John Von Neumann. 1986. Preliminary Discussion of the Logical Design of an Electronic Computing Instrument. In *Papers of John von Neumann on Computing and Computer Theory*, ed. William Aspray and Arthur Burks, 97–142. Cambridge: MIT Press.

Light, Jennifer S. 1999. When Computers Were Women. *Technology and Culture* 40(3): 455–483.

Schiebinger, Londa, Andrea Davies Henderson and Shannon K. Gilmartin. 2008. *Dual-Career Academic Couples: What Universities Need to Know*. Report from the Michelle R. Clayman Institute for Gender Research Stanford University, http://www.uiowa.edu/~dcn/documents/DualCareerFinal.pdf (accessed 31 August 2013).

Stern, Nancy, B. 1980a. *An Interview with Arthur W. and Alice R. Burks*. Charles Babbage Institute, The Center for the History of Information Processing, University of Minnesota, http://conservancy.umn.edu/bitstream/107206/1/oh075aab.pdf (accessed 31 August 2013).

_____. 1980b. *An Interview with Herman Goldstine*. Charles Babbage Institute, The Center for the History of Information Processing, University of Minnesota, http://conservancy.umn.edu/bitstream/107333/1/oh018hhg.pdf (accessed 31 August 2013).

_____. 1981. *An Interview with Willis H. Ware*. Charles Babbage Institute, The Center for the History of Information Processing, University of Minnesota, http://purl.umn.edu/107699 (accessed 31 August 2013).

Vignette 8.2

Making a Meaningful Choice: Women's Selection of Computer Science in India

Roli Varma

Low participation of women in computer science (CS) education is a pressing problem in many Western countries (Ahuja 2002; Lie 2003; Singh et al. 2007). By and large, the field of CS is perceived as masculine both by men and women in Western countries (Wajcman 2004). In contrast, women in India have increased their presence in CS education in most nationally accredited institutes and universities (Basant and Rani 2004; Varma 2009; Fig. 8.4). In general, the field of CS is perceived as women-friendly both by men and women in India (Varma 2010). Regardless of economic, political, and social advantages in the Western countries, women in India seem to have levels of success in CS education that appears to somewhat outstrip those of Western women. This paper uncovers why women in India are attracted to CS education and career.

8.7 Methodology

The paper is based on in-depth interviews that were conducted by the author with 60 female undergraduates majoring in CS in 2007–2008. The study took place in two engineering institutes and two universities that granted 4-year undergraduate degrees in CS. Random sampling was used to select 15 subjects who were in their second and later years of studies at each institution. Interviews were recorded, transcribed, and analyzed with Nvivo. All of the students interviewed were young, unmarried women between the ages of 19 and 22. Other than being a full-time student, none held a job while attending university. Almost all of them characterized

---

R. Varma (✉)
School of Public Administration, University of New Mexico, Albuquerque,
NM 87122, USA
e-mail: Varma@unm.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_8

their family background as in the middle- or upper-middle-class categories. Almost 75% of students were born to Hindu families, with the majority belonging to middle and high castes; remaining students were born to Sikh and Muslim families.

8.8 Findings

8.8.1 Why Do Women Choose Computer Science?

The findings show that some female students became interested in CS education because they had early exposure to computers either in their homes, cyber cafes, or friends' places. They used computers to browse the web, chat/email, and play games. A few took computer classes in their high schools to learn word processing, power point, and paint; however, they complained that the computer laboratories have poor resources with limited access due to power cuts. At least one-third of students were not exposed to a computer pre-college. A significant factor in most female students' entrance into CS involved encouragement from a parent, sibling, or cousin who owned a computer or studied in an engineering field. They influenced the students by narrating personal experiences or by conveying that CS has a great potential for women. Especially male family members described CS as an excellent major for women because it required merely mental power not physical, and because they could work indoors rather than outdoors on a construction site. Also, students made a pragmatic assessment of the CS with great potential for employment, the omnipresent presence of computers in government and industry, and the power to be on the cutting-edge modern technology. A few female students believed that a CS degree would let them have some social independence.

8.8.2 Why Do Women Perform Well in Computer Science?

Since female students had little experience with computers in high schools, did they feel prepared for CS study at the university? A large majority of students stated that either their schools did not prepare them well or only partially prepared them for university level CS. Yet, most of these students believed that their high school education in mathematics was strong, and thus critical to their ability to proceed into CS. They were extremely confident about their mathematical skills and, thus, logical thinking and analytical abilities. So, even though they found CS a hard, demanding, technical field, female students felt their mathematical training prepared them to do well in CS at the university level.

8.8.3 How Do Women Perceive Computer Science?

Female students view the typical CS culture as people-friendly especially women-friendly. It consists of dedicated, hard-working, intelligent, meticulous, and smart students who help those needing assistance. In addition to the CS study, these students are active in social events and sports and it is pleasant to be around them. According to them, women who study CS are well respected by faculty and peers in the educational arena and by family members, friends, and neighbors in the social arena. Also, female students believed that economic rewards for a woman with a CS degree are much higher than with a degree in other science and engineering fields. Some female students indicated that employment in information technology (IT) companies is well appreciated and it alleviates concerns their families had about the high cost of marriage.

8.8.4 Why Do Women Stay in Computer Science?

If female students do not like the CS or find CS difficult, would they try to avoid disappointment by switching their major? The findings show that an overwhelming majority of students had not entertained the idea of leaving CS to another major. The respondents reported it did not cross their minds to switch to something else because of the economic benefits, work opportunities, and social independence they could gain with a CS degree. Most students did not know anyone who changed majors or dropped out of CS, which was seen as a step backward.

8.8.5 What Women Hope to Get with a Computer Science Degree?

Upon completion of their CS degree, most female students planned on joining the workforce, with a few interested in moving directly into a graduate program, and the remaining students undecided about a job or higher education. Students were confident about receiving placement into good IT companies due to the frequent job placement campus visits by company recruiters. Students who expressed their desire to move directly into a graduate program felt it would allow them even more opportunity than their peers, along with a broader range of possible employment and higher pay. Students who were not sure whether to join the workforce or a graduate program wanted to decide on the strength of job placement and the admission to the university that they wanted to attend.

8.9 Conclusion

Women in India are enrolling in CS because it is a means for them to secure a friendly working environment, gain prestige, become career-oriented professionals, and attain an economically independent status. This shows that women in computing cannot be viewed as a globally homogeneous group. The gender imbalance in the Western countries is not a universal phenomenon as it has been presented in the scholarly literature.

Acknowledgments This research was supported by a grant from the National Science Foundation (0650410).

References

Ahuja, M. 2002. Women in the Information Technology Profession: A Literature Review Synthesis and Research Agenda. *European Journal of Information Systems* 11: 20–34.

Basant, R. and Rani, U. 2004. Labour Market Deepening in India's IT. *Economic and Political Weekly* 39, 5317–5326.

Lie, M., ed. 2003. *He, She and IT Revisited: New Perspectives on Gender in the Information Society*. Oslo: Gyldendal Akademisk.

Singh, K., Allen, K.R., Scheckler, R. & Darlington, L. 2007. Women in Computer-Related Majors: A Critical Synthesis of Research and Theory from 1994 to 2005. *Review of Educational Research* 77: 500–533.

Varma, Roli. 2009. Exposure, Training And Environment: Women's Participation in Computing Education in the United States and India. *Journal of Women and Minority in Science and Engineering* 15(3): 205–222.

_____. 2010. Computing Self-efficacy Among Women in India. *Journal of Women and Minorities in Science and Engineering* 16(3): 257–274.

Wajcman, Judy. 2004. *Technofeminism.* Cambridge: Polity Press.

Part III
Policies and Programs

Chapter 9
Promising Programs: A Cross-National Exploration of Women in Science, Education to Workforce

Daryl E. Chubin, Catherine Didion, and Josephine Beoku-Betts

9.1 The Issue

A "program" is an organized effort to improve delivery of a practice or service to a population. In the context of this volume, the central goal of programs is the participation of women (and girls) in a series of planned activities, which taken together, place or keep them on a path toward a science-based degree or career. To be sustained over time, a program must have financial support, consistent leadership, a visibility that attracts participants, exposes them to essential experiences, and facilitates the acquisition of skills and technical (disciplinary, occupational) culture.

Yet a program, however well-conceptualized, is essentially a trial-and-error undertaking that may or may not be research-based and is typically supported by resources provided by sponsors outside the institution offering it. Local context matters. It shapes how the program is executed on behalf of the served population, translating grand plans into on-the-ground delivery of services.

Effective programs are thus a universal vehicle for intervening in the status quo. But sponsors, performers, and the populations they are intended to serve bring different expectations to the programs in which they participate (DePass and Chubin 2009).

Programs to improve outcomes—student learning, career choice, information on opportunities—populate a continuum that spans preschool to the end of precollege

---

D.E. Chubin (✉)
Independent Consultant, 56 Crestwood Drive, Savannah, GA 31405, USA
e-mail: daryl.chubin@comcast.net

C. Didion
National Academy of Engineering, DC, Washington

J. Beoku-Betts
Florida Atlantic University, Boca Raton, FL

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_9

instruction, higher education at the postsecondary and graduate levels, and the workforce (from entry to retention, promotion, and ascendance to leadership).

As described below, "promising" programs are an empirical subset of all programs. They share key attributes of track record, data on outcomes and impacts, and continued financial support (Chubin and Ward 2009). Nevertheless, their promising status may be idiosyncratic to time and place. So we must look across cultural and political contexts to ask: What translates beyond a particular discipline and the unique conditions that engendered, and then sustained, a program?

We hope to identify patterns in programs that foster meaningful participation in what we call "careers" in science. Our analysis should complement and elaborate on the discipline-specific chapters elsewhere in the volume. In other words, we are slicing the program pie to highlight the characteristics of success in intervention programs designed to increase participation in the chemical sciences, computer science, and mathematics/statistics.

We also pose questions that connect programs to policies on the one hand, and to goal-directed practices on the other. This is because programs have their own "life cycle"—from design to implementation to evaluation to changes in policy/practice (government, institution, department, etc.)—that yields insights into what constitutes success and promise.

Ostensibly, the purpose of program interventions is to demonstrate an alternative social order where the innovations are "mainstreamed," i.e., funded and recognized as "best practices" in promoting participation, articulating educational opportunity with the fulfillment of career aspiration, and motivating institutional and cultural progress through the resident population.

9.2 Methodology and Empirical Challenges

Many questions may be raised about the origins, design, implementation, evaluation, and outcomes of a program. A fundamental question is: what is the population to be served, and how is this population linked to the intent of the program? The population should be a natural outgrowth of program intent. Ideally, the design and character of the program should cite evidence that supports whatever is planned as a means of advancing the policy or mission of the organization offering it, and should be tailored to accomplish that goal.

However, identifying limitations and strengths as determined by research and evaluation compounds the difficulty of declaring a program to be "promising." In most cases, data on program outcomes may be lacking. Even if they do exist, no systematic over-time analysis may have been conducted (Brainard and Carlin 1998). Evaluative data beyond anecdotes and testimonials of participants and alumni are needed. Typically, resource constraints force a choice between operating the program or diverting a fraction of funding to its evaluation. Too often the latter is sacrificed, which creates the quandary faced by this chapter and any effort to ascertain third-party evidence on "eye of the beholder" judgments of program effectiveness, quality, or success.

9.2.1 Some Historical Examples

Programs established in the 1980s, such as the UK's Women in Science and Engineering (WISE) 2006 Campaign,[1] indicated that approaches targeting individual women and girls for funding of research or other education interventions had little impact on increasing representation and advancement of women in academic and engineering fields. Scholarly thinking began to reject the "deficit model," which identified women as targets for intervention, and suggested that by transforming the attitudes and behavior of women, they will enjoy greater opportunity, success, and advancement in science careers (Phipps 2008). Simply out, this model characterizes an individual's lack of progress or achievement as her or his shortcomings—from motivation to capability—instead of deficits in the learning environment that are the responsibility of institutions and educators.

In contrast, a review of undergraduate science programs (Fox et al. 2007: 338) concluded that "most successful" programs focused on structural and institutional reforms as well as mentoring and other support activities. Using regression analysis, the authors identified the "most successful" programs by measuring "the difference between the pre- and post-program rates of growth in the percentage of women among bachelor's degree recipients." These programs, particularly their directors, were more focused on structural factors in the environment that created a less equitable environment for women.

Concluding that the directors of the "most successful" programs recognized the necessity to alter the institutional environment in ways that would create a more equitable environment for men and women science undergraduates, Fox et al. (2007) argued that this approach attempts to "adapt" the broader environment to meet the program goals.

9.2.2 Another Approach

Our approach to programs was structured by several dimensions that build on the above findings while honoring themes prominent in this volume:

- Three STEM disciplinary areas—chemical sciences, computing, and mathematics/statistics (v. all STEM)
- Two genres of programs—one targeting women and girls, the other seeking greater participation of all, regardless of gender, in STEM
- Two principal perspectives on program operation and effectiveness—*sponsor* (government, NGO, private foundation or company) or *performer*/funding recipient (university, specific academic department, professional association)
- Two geographic locations—the developed world of the Global North and the developing world of the Global South

---

[1] www.wisecampaign.org.uk

Data requirements impose other constraints. More data are collected and analyzed for all of science or STEM (science, technology, engineering, and mathematics) than for specific disciplines. US federal agency programs will support a portfolio of projects mainly at institutions of higher education that reflects a decentralized "experimental" approach to educational innovations. Some of these "projects" excel and thrive over time; most end as the grant expires, leaving little or no trace of impact.

This is why promising programs are the focus here. To identify them, we consulted the websites of sponsoring and performing organizations using the search queries "[US or international] programs for women in [science, or specific discipline]" and "data on women in … " Queries on "evaluations of programs … "yielded almost no literature, supporting our suspicion that few exemplary programs exist (or remain internal or proprietary documents). Sheer longevity does not equate with effectiveness, and data are insufficient to resolve claims. (Even the discipline-specific chapters of this volume hardly emphasize programs, focusing instead on international comparisons of workforces, women's distribution across academic ranks, and government investments in women relative to other social or science-based spending.)

We lack a sense of magnitude, i.e., how large is the population of program evaluations? While evaluators speak of comparison groups and controlled treatments (Chubin et al. 2010), basic data-collection on participants and outcomes over short periods are elusive. Therefore, we turned to a decade-old US example that offers a template for empirically characterizing "promising programs."

A public–private partnership was formed as a result of a congressionally mandated study, *A Land of Plenty* (CAWMSET 2000). Several authors represented in this volume participated in the effort known as BEST—Building Engineering and Science Talent. In the BEST higher education report, *A Bridge for All* (2004), evaluation criteria were developed based on a review of 120+ university-based STEM programs targeted to undergraduate students. All, however, apply to intervention programs targeted to underrepresented groups—women and persons of color—and to postgraduate and workforce-entry training.

Although the principles may be unique to the United States, its education system and economy, they are a fruitful starting point. The column in Table 9.1 labeled "promising" should particularly draw our attention in assessing any education program such as those highlighted below.

9.3 The State of Play

While the United States has been a beacon to the world on how intervention programs can change the trajectory of participation of all underrepresented groups, especially women (who today constitute more than half of the general US population and almost three out of five undergraduates), it has hardly succeeded in transforming the educational process, workplace settings, and career advancement into a bias-free utopia (National Research Council 2007). Sexism, stereotyping, and cultural biases clutter the road traveled to a career in science (Sandler 2009). For those women who

Table 9.1 Best evaluation criteria for assessing higher education programs/practices

Questions/Criteria	Exemplary actionable now	Promising	Not ready to adapt scale
1. Were expected outcomes defined before program launch	Yes	Soon after	Sort of/vague
2. Are outcome attributable to the program intervention	Far exceeded original expectations	Exceeded original expectations	Failed to meet expectations
3. Does it demonstrates excellence, which quality?—i.e., did it increase the diversity of the target population?	Chief outcome achieved and documented (positive trend)	Chief outcome achieved and documented (no monotronic trend)	Equity at core of program design not an add-on
4. What was the value-add of the experience to the target population?	Related outcomes that move treatment group to next competitive level	Majority (but not most) of individuals of treatment population enhanced	Gains for some individual that can be attributed to treatment
5. Is there evidence of effectiveness with a population different from that originally targeted?	Explicit scale-up strategy w/ evidence	Attempt to implement strategy and evaluate	Confined to a single suit
6. How long has it been in place	Planned and executed	Planned	Serendipitous
7. Were there unexpected consequences	Self-sustaining (10+ years)	Majority soft money (10+ years)	New (<3 years)
8. Were there unexpected consequences	Positive in intensity or extent (and measured)	Identification of possible/probable consequences	Evidence for systematic rather than random effect

Source: BEST Blue Ribbon Panel on Higher Education (2002)

thrive in the workplace, countless others are casualties of structures and practices that pose formidable barriers and thwart the development of talent. The results pervade science and create disciplinary faculties, and workforces generally, that challenge claims to meritocracy and incinerate aspirations of student cohorts who see too few women in professional roles they would like to emulate. And if they entertain such ambitions, they can be dissuaded by stories of the journey that women who have ascended are willing to share.

Data and analysis over 30+ years attest to the recurrent patterns that keep women out, down, or struggling to achieve positions of leadership in science (Etzkowitz et al. 1994; Burrelli 2008). This applies equally (and sadly) to stellar positions in different sectors of the economy, e.g., the chemistry department chair or the corporate chief technology officer. What has been documented, therefore, is a reminder that what a country practices is not necessarily what it preaches (CPST 2008). Furthermore, programs created to alleviate inequities and facilitate transitions have not, in the aggregate, produced the rates and quality of participation by women in science that most in the United States would find acceptable—despite isolate institutional transformations fostered, at least in part, by programs such as NSF ADVANCE (Frehill 2006).

The latest, and arguably the most comprehensive cross-national assessment on gender, science, technology, and innovation, was conducted by Women in Global Science & Technology,[2] or WISAT, in collaboration with the Organization for Women in Science for the Developing World.[3] With funding from the Elsevier Foundation, the 2013 report features a "full gender benchmarking" of opportunities and obstacles faced by women in science in Brazil, the European Union, India, Indonesia, South Africa, South Korea, and the United States.

In a nutshell, the report concluded that in all the countries reviewed, "the knowledge society is failing to include women to an equal extent, and in some cases, their inclusion is negligible".[4] The litany of reasons for women's under-participation are familiar: limited access to education, information, technology, entrepreneurship, and employment; lagging indicators on health, economic, and social status; and numerous barriers, including work and policy environments. A dearth of disaggregated data also obscures discipline and work sector comparisons.

Notably, if one examines the individual country reports, programs are seldom highlighted. Admittedly, the WISAT "big picture" examination was not focused on the granular level, yet some citing of signature national efforts would be expected. Instead, committees and structures–the apparatus of policy—are noted, but not linked to particular interventions.

Other international organizations offer *visibility* as their main support for women in science, but most are of small scale, favor anecdotes (stories with "faces") and fellowships, and do not publicize evaluation of their outcomes. While not featured here, we note the sustaining function of The World Bank,[5] Elsevier,[6] L'Oreal-UNESCO,[7] and USDA Borlaug (Africa—Women in Science) Fellows.[8]

In view of our appraisal, the key question becomes: Can we expect better outcomes either in the developed or the developing world, i.e., in nations with fewer resources but perhaps more resolve? Are there programs sanctioned by policy and validated in practice that afford women the education and training opportunities to excel, contribute, and change the face of their disciplines as well as their country's workforce? Clearly, a more top-down European approach will differ from more decentralized, grass-roots bottom-up approaches.

---

[2] www.wisat.org

[3] www.owsdw.org

[4] http://www.wisat.org/programs/national-assessments-on-gender-sti/

[5] http://datatopics.worldbank.org/gender/

[6] www.elsevier.com/connect/story/women-in-science

[7] www.unesco.org/new/en/natural-sciences/priority-areas/gender-and-science/

[8] www.fas.usda.gov/icd/borlaug/westafrica.htm

Ideally, one would seek congruence between context and goal, but politics—national and local—tend to get in the way. Different agendas can blunt the impact of policies and undermine even promising practices. While we seek to learn about promising programs that can be adapted for use in other countries and settings, we wonder how can the United States, which generates abundant claims of program outcomes and impacts, benefit from the lessons elsewhere? Just how culture-bound are these programs?

9.4 An Analysis of Select Programs

To guide the analysis below (based on US experience), we reiterate that the *same* program may be examined from different perspectives. A *federal agency program* presents a national blueprint for intervention through several funded projects. Each *recipient university* awarded funding under a program becomes a data point in serving the target population (e.g., women or girls in X), which is a small fraction of the national constituency. Some will excel, while others lag. We are interested in both, of course, but highlight projects distinguished by positive claims. Taken together, recipient universities are defined—more accurately, created—as part of a *performer community*, usually discipline-bound, that seeks improvement in recruitment and retention practices, as well as degree-completion and entry into relevant workforces.

To capture a program, we must slice deeper into nationally aggregated data characterized above and throughout this volume. Complementing global analysis by "calling out" a subset of promising programs illuminates key sponsors and/or performing bodies. Therefore, the program vignettes are a kind of triangulation that connects macro and micro data.

Because few studies track student progress longitudinally, we have selected examples judiciously to illuminate promising programs from different "angles," as it were. Displayed in Table 9.2 are the genres we feature, and (depending on the reader's disposition) the limits of generalizing from them.

Our effort to identify at least one promising program in each disciplinary area featured in this volume was not realized. For the Global North, information on programs emanating from the American Statistical Association and the Association for Women in Mathematics was so scarce that no assessment could be conducted.

Table 9.2 Promising programs by type and origin

Discipline	Program	Origin
Chemical sciences	COACh	Global North
Computing sciences	BPC-A/NCWIT	Global North
Mathematics/statistics	See below	
All STEM	ADVANCE/Wisconsin	Global North
	OWSD	Global South

Instead, we gleaned details on efforts that represent inputs, but not outcomes. This void demonstrates how, even in developed regions with long professional histories of organization and operation, putting programs on a firm empirical foundation has not occurred. This does not reflect well on either sponsors or performers.

Like many professional societies, the ASA has a committee on women and administers various awards, especially the Gertrude Cox Scholarship.[9] Yet as recently as 2012, laments about the invisibility of women in the association's conferences and other activities are well-documented.[10] Women comprise 30% of the membership, but the "big tent" is not consciously as gender-inclusive as it could be.

As the AWARDS Project[11] found in 2010 for six professional societies (including ASA) that host competitions for gender-neutral awards, committee composition influences awardee selection and nominations of women limit the pool of eligible (even if self-nominations are encouraged). Evidence of systematic bias in one aspect of professional life can have significant ripple effects on prospective recruits.

The Association for Women in Mathematics (AWM) was founded in 1971 and today has more than 3,000 members (women and men) from the United States and around the world. Often working in concert with the workforce-oriented century-old American Mathematical Society[12] and the undergraduate-focused Mathematical Association of America,[13] AWM plays a plethora of roles, providing educational resources, forums, travel grants, prizes, mentoring, and advocacy for girls and women in mathematics.

For example, for more than twenty years AWM has organized and sponsored Sonia Kovalevsky Days (SK Days[14]) held at colleges and universities throughout the country. SK Days consist of a program of workshops, talks, and problem-solving competitions for female high school and middle school students and their teachers, both women and men. Searching the website for evaluative or outcome data on any AWM program yields no information.

For the other entries in Table 9.2, we offer vignettes with evidence of programs showing promise through longevity and the measurement of performance.

9.4.1 COACh: Committee on the Advancement of Women Chemists

COACh was founded in 1997 at the University of Oregon to design and implement career development programs for women and minorities in STEM fields. Over 10,000 faculty, graduate students, undergraduates, and researchers have participated in

---

[9] http://www.amstat.org/committees/commdetails.cfm?txtComm=CCSAWD01

[10] http://magazine.amstat.org/blog/2012/07/01/statviewguide/

[11] http://www.amstat.org/committees/cowis/pdfs/AWARDSBackground.pdf

[12] http://www.ams.org/about-us/about-us

[13] http://www.maa.org/about-maa/maa-history

[14] https://sites.google.com/site/awmmath/programs/kovalevsky-days

COACh career-building programs conducted at professional meetings, universities, and laboratories in all 50 US states.

COACh International (iCOACh) works on projects around the globe to build scientific and engineering leadership capacity in scientific areas of global need and in countries where the need is the greatest. The projects are research-focused and aimed at catalyzing and sustaining scientific collaborations and networks across international and cultural boundaries, with women as leaders and active participants. Events have been held at academic institutions and federal laboratories in Africa, South America, Asia, and Europe.

Over 6,000 women faculty, graduate students, and postdoctoral associates have attended COACh workshops. Participating women include chemists, physicists, mathematicians, biologists, computer scientists, geologists, medical faculty and students, materials scientists, and engineers of all types.

Among the most prominent impacts[15] are:

- Over 70% of postdoctoral attendees have landed academic positions.
- 38% reported taking administrative posts after attending the Leadership Workshop. Eighty-six percent of these credited COACh with either the decision to take the position or in helping them be more effective leaders.
- 90% of attendees have mentored their students and other colleagues in skills learned in the COACh workshops.
- 90% said that the COACh skills helped them in addressing issues of committee assignments, developing supportive networks and improving departmental climate.
- Over 80% said that the workshops helped with issues of work-family balance.

Evaluation of the quality of these programs via surveys on the short- and long-term impacts (2–6 years after attending a workshop) reveals that COACh activities impart a range of skills vital for participants' careers while lessening stress (Greene et al. 2010). Today, COACh provides avenues for networking and mentoring of scientists and engineers at all levels to assist them in their research, teaching, and career advancement.

9.4.2 NSF Broadening Participation in Computing/NCWIT

The US NSF launched the Broadening Participation in Computing Alliances (BPC-A) in 2006. By 2010, 11 of the 12 original multi-institutional Alliances were serving the full range of underrepresented groups in computing (Chubin and Johnson 2010). This program sought nothing less than to change the face of computing. The Alliances represent returns on an NSF investment in terms of collective impact on computing nationally—human resources, practices in and out of the classroom, and institutional change.

---

[15] http://coach.uoregon.edu/coach/index.php?id=3

Girls and women at all stages of education and career advancement comprise the target population for one of these projects, which functions as a national clearinghouse for information and resources relevant to women in computing education, enrichment, and professional development.

9.4.2.1 NCWIT: The National Center for Women in Technology

The National Center for Women & Information Technology is a nonprofit community of more than 500 prominent corporations, academic institutions, government agencies, and nonprofits working to increase women's participation in technology and computing. NCWIT helps organizations recruit, retain, and advance women from K-12 and higher education through industry and entrepreneurial careers by providing community, evidence, and action.[16] NCWIT is the only national organization actively researching women and IT innovation, including women as IT patent holders, women's contribution to open source, women as authors of computing research papers, women starting IT companies, and women as technical conference speakers.

While NCWIT resources span K-12 to workforce, the most compelling hands-on tools have been produced within the past 5 years under the following titles[17]:

- How to Create and Sustain a Women in Computing Group on Your Campus (2013)
- Top ten Ways to Be a Male Advocate for Technical Women (2012)
- How Can Encouragement Increase Persistence in Computing? Encouragement Is Effective in Work Settings (Case Study 2) (2011)
- Strategic Planning for Recruiting Women into Undergraduate Computing: High Yield in the Short Term (2010)
- Women in IT: The Facts (2009)

NCWIT's age/grade-specific resources—scorecards, workbooks, tipsheets, recruitment strategies, entrepreneurship in IT, etc.—is a treasure trove of "how to" tools for a community in dire need of diversifying to tap the contributions of women. As a hub, NCWIT's record of performance is changing the face of the US computing workforce.

9.4.3 NSF ADVANCE

Perhaps the most promising gender-conscious science and engineering faculty-focused program in the United States is NSF ADVANCE. Established in 1995, the goal of ADVANCE is to increase diversity in the science, technology, and engineering workforce by increasing representation and advancement of women in academic

---

[16] https://www.ncwit.org/ncwit-fact-sheet

[17] http://www.ncwit.org/resources

and engineering careers. Initially, NSF pursued this goal by funding professional development awards to women and underrepresented minority scientists, but these efforts to fund individual women faculty had little impact on improving the representation of women in the academy.

Later, NSF implemented ADVANCE to specifically address gender inequities (Meyerson and Tompkins 2007) perpetuated by institutionalized structures and practices. Indeed, ADVANCE became synonymous with "institutional transformation," enhancing the climate for advancement through policy, changing attitudes, and increasing the percentage of women who are hired and promoted within the institution. The goal is to change the academic environment and not just those who populate it. The result would include increased participation and advancement of women (NSF 2001; Sturm 2006).

9.4.3.1 University of Wisconsin-Madison ADVANCE

Awarded as part of NSF's first cohort in 2001, the ADVANCE Institutional Transformation grant at the University of Wisconsin was named "Women in Science and Engineering Leadership Institute (WISELI)" and implemented to address institutional "climate." These included an examination of university policies, including a review of resource allocation to women and men faculty, increased emphasis placed on hiring women faculty, a workshop to train faculty to perform more thorough and fair evaluations of applicants, and workshops for department chairs designed to: (1) increase awareness of the experiences of faculty from underrepresented groups, (2) empower them to believe they could change the environment, and (3) inform them about perceptions of their faculty members (through a web-based survey). Participation in all of the workshops was voluntary.

Baseline data were collected prior to the ADVANCE interventions. In 2002, 26 women science faculty participated in in-depth interviews to assess their experiences and perceptions of the climate on campus. Findings of these interviews were used to develop a survey that was administered to all faculty at the institution. The 24-item survey assessed the climate of the department and institution for various groups (women and faculty of color) and for individual respondents. The survey was administered in the spring 2003 and generated at 59% response rate among science faculty. ADVANCE interventions followed and the university faculty were re-surveyed. Eleven "climate indicators" assessed individual faculty perceptions of how respected they felt by their colleagues, students, staff, and chairs; how included, valued, recognized, or isolated they felt; and whether they believed they "fit" in their departments (Sheridan et al. 2007).

Women faculty felt that the departmental "climate" was more negative than their male counterparts. They reported feeling less respected, excluded from informal networks and departmental decision-making, and perceived less fit with their departments. In contrast, men faculty and department chairs assessed the quality of the departmental climate for women as much more positive than did women faculty. The majority of the faculty and chairs perceived the experiences and climate as more positive for women faculty and lacked awareness of the negative institutional climate for women.

A 2006 survey of faculty (post-intervention) revealed modest change in perceptions. Women faculty were significantly more likely to say that department climate had improved than declined in the last 3 years. They also were no more likely to report the departmental climate as good than they were in the 2003 survey. Findings revealed that men faculty and chairs had not significantly changed their perceptions about the climate for women. They still perceived the institutional environment as "good" and lacked awareness of women's perceptions of fit in the department. For women faculty whose department chairs or hiring committee chairs had attended a WISELI workshop, findings indicated more positive perceptions of these women faculty, though not significantly so (Pribbenow et al. 2007). Participation in workshop interventions by chairs and senior faculty may have had an impact on the quality of experiences of women faculty with whom they interact.

Overall, Sheridan et al. (2007) concluded that the climate for women at the University of Wisconsin "improved slightly" between 2003 and 2006. There was, however, a decline among majority men in perceptions about the quality of the environment for women. These findings were not convincing that WISELI interventions had a positive impact on perceptions of climate among women and majority faculty at the University of Wisconsin. The authors also speculated that while there was a general openness to explore these issues, participation in some WISELI activities might have created backlash among faculty who see these activities as benefiting only women.

9.4.4 OWSD (TWAS) Postgraduate Training Fellowship Program

The Organization for Women in Science (TWOWS 1995) for the Developing World (OWSD, noted above), was created in 1989, consists of over 4,000 members, and works with its sister organization of TWAS (the academy of sciences for the developing world) to promote women's access to science and technology (TWOWS 1995). The OWSD Postgraduate Training Fellowship Program was established in 1998, and has been funded by the Swedish International Development Agency's Department for Research Cooperation (SIDA/SAREC) for young women scientists under the age of 40 to secure postgraduate training in centers of research excellence in the Global South. The Program seeks primarily to:

- Increase training and research opportunities for young women scientists living and working in countries in the Global South.
- Facilitate development of scientific and technological knowledge production in the Global South through training and exchange programs between scientists in the Global North and South.

Table 9.3 OWSD postgraduate fellowship training program: applications and awards

Applications (1998–2007/2008)	
Africa region	1,517 (83.5%)
Asia and Pacific region	288 (15.8%)
Arab region	12 (0.7%)
Awards (1998–2007/2008)	
Africa region	213 (81.6%)
Asia and Pacific region	45 (17.2%)
Arab region	3 (1.2%)
Awards by country	
Nigeria	16.8%
Sudan	8.6%
Bangladesh	7.9%
Kenya	7.2%
Cameroon	6.2%
Myanmar	4.8%
Tanzania and Uganda	4.5% (combined)

Over 80% of applications and awarded fellowships go to nationals from the Africa region. Nigeria, which has a strong educational system and is the most highly populated country in the region, dominates with over 25% of applications and almost 17% of awards (see Table 9.3). Disciplines favored in applications and awards are the biological sciences (cellular and molecular biology and systems biology) and agricultural sciences, followed by chemical sciences, and to a significantly lesser extent mathematical sciences and physics.

Despite a 50% attrition rate (of 261 awards accepted) due to award cancellations and departures from the program by applicants, since 1998 the OWSD Postgraduate Fellowship Training Program has demonstrated excellence as a model for training institutions in the Global South. Since 1998, 75 junior women scientists (<40 years old) have completed their Ph.D.'s in these training centers. In 2010, there were approximately 45 fellows undergoing training. While the Africa region is disproportionately represented, there is a significant gap in the Latin America and the Caribbean regions, where social and economic disparities within country and region are prevalent.

One of the unexpected outcomes of the OWSD Postgraduate Training Fellowship Program is that the majority of fellowship graduates fail to return to their countries of origin because the specialized training they receive makes it difficult for them to find suitable employment in their fields. The failure of graduates to return to their countries of origin is largely due to the unstable economic and political climates, which are conducive neither to advanced scientific research nor lucrative job opportunities. In addition, there is the prospect of dealing with inequalities of gender, class, and ethnicity in the labor market and patriarchal institutional culture of the scientific community (Huyer 2010: 18).

Drawing on data for the dominant Africa region, however, there is evidence of positive outcomes. Based on third-party evaluation and continuous monitoring of publication productivity, skills acquisition, and involvement in professional networking by the OWSD, Huyer (2010) found that 90% of fellowship graduates had published or were in the process of producing one or more peer-reviewed articles, and 66% of graduates had maintained professional relationships with their supervisors through research collaborations. Another outcome is that the majority of graduates are now working in university research institutes in the Global South, even though they may not be residing in their countries of origin. Thus, the program has generated some amount of South to South exchange, stemming to some extent the problem of "brain drain" to the North.

9.5 The "Life Cycle" of Programs: Policy and Practice

The data presented on the four programs above give hope … and pause. The BEST template set a high standard. While gender-focused programs in the United States have flourished, few have manifested the rigor of interventions that produce desired outcomes. This does not mean they have failed to occur, only that producers have not shared results in a public way. Data that are accessible, however, tend to suffer from a preponderance of self-reports, no comparison group, and short time-series. The upshot is that, even in the relatively resource-rich Global North, rhetoric about gender equality outpaces reality.

Within the ambitious and well-financed ADVANCE Program, some projects (like Wisconsin's) fared better than others in fostering or sustaining institutional transformation. COACh illustrates how pockets of success occur amidst the global landscape. "Successful" programs are clearly relative to time and place. What works for a targeted population in one site may or may not take root, may not transfer to other populations and sites, and may not be sustainable for reasons unrelated to the effectiveness of the interventions.

Similarly, the lesson of the OWSD Fellowship Training Program is a lack of uniformity in supporting individuals while exacerbating imbalances between host and "feeder" countries. And as NCWIT illustrates, broadening participation in computing must change not just practice but consciousness about how organizational structures unwittingly deter girls and women from aspiring to or persisting in a science-based career.

In short, context matters and may overwhelm the good intentions and arduous efforts to change culture, practices, and minds. From our modest examination, one key generalization is that participants may report positively on the experiences afforded by a program, but we know little empirically about the impact on career development and especially women's ascendance to leadership positions. For example, we might "start with data that permit pre-post comparisons of women deans correlated with women's share of undergraduate enrollments in those disciplines, and move to microqualitative data that begin to explain what is perceived and how participants act on those perceptions" (Chubin 2013).

9.5.1 Program Practice

If a program has a "life course"—a sequence of events that extend from its planning to its demise or transformation due to changes in organization, personnel, or support—then comparing even promising programs raises inevitable questions: What is the journey from conception to institutionalization and beyond for the "successful" or "effective" intervention program? Does it work especially for women, for students in a particular age range, or for our three focal disciplines of interest? Is there anything typical or universal that can be identified as essential, indeed indispensable?

Based on our survey of several ongoing programs around the world, and a more detailed analysis of four promising but disparate programs, we conclude the following:

- Multiple interventions are a kind of organizational strategy, but the more dispersed the resources and focus, the less we can tell about the impact of S&E career production. Funding constraints dictate scope and limit evaluation to *either* educational preparation or subsequent stage(s) of the career.
- Length of operation indicates sustained commitment by a sponsor or performer, but does not guarantee accountability for outcomes. On what are sponsors basing their funding decisions?
- Outcome evidence is scarce, either because it is not produced or not shared publicly. In this era of evaluation and continued improvement, this seems indefensible but common.
- Generalizing is a risky undertaking. Based on available evidence, the likelihood that similar programs and populations in different cultural contexts would benefit from adapting what the program-in-question has learned is premature.

Arguably, any intervention program geared to increasing the number and improving the experience of science participants, especially those known to be underrepresented by discipline or sector, may be better than none. The effort, however, does not assure the outcome. And some of that is due entirely to factors beyond the program's control in the larger sociopolitical environment.

9.5.2 The Link to Public Policy

A truism of public policy is that without enforcement a policy is no more than words on a page. The saga of applying Title IX in the United States to the participation of women in science, both in the educational and employment domains, is a reminder of the gap between governmental intention and action for change (Redden 2007). Shifting to other political systems, populations, and opportunity structures underscores how culture can promote or inhibit what even a national government seeks to accomplish in educating its citizens and preparing them for the workforce.

From a policy perspective, what makes a program “promising”? We have explored that question in this chapter from the two angles of sponsor and performer. With policy as an “enabler,” research would be welcome on:

- How to leverage resources from one sponsor to build and sustain support for the program after initial funding has dissipated. Building a consortium of partners is one approach, with funding provided to bridge the education-to-workforce gap, matching skills to needs, supply to demand, in ways that capitalize on all who are trained and credentialed.
- Utilizing comparative climate data to inform policies that foster changes in organizational practices. Knowledge alone will not suffice; providing incentives for “doing the right thing” by all participants is needed.
- Identifying and funding organizations with gender-sensitive infrastructures to disseminate resources to those lacking training in populations they have seldom educated in their disciplines. Critical masses of, e.g., women and foreign-born students, will both attract and help retain them to degree completion.
- Finally, encouraging “experiments” built on programs that have a track record of propelling women into the science workforce. New programs can emulate design specifications regarding scale, target, trajectory, and time frame from intervention to first workplace entry. Evaluating and publishing outcomes will heighten accountability.

9.6 Conclusions

This chapter has asked: How do we learn what works in so-called STEM programs targeted to girls and women? Further, it has searched for and presented only evaluation data on programs that have operated for many years. Whether in the Global North or Global South, programs can be categorized by discipline, nationality, geography within a country, and the familiar intersections of gender, race, ethnicity, and social-economic status. Source information will limit what is known and explanations for observed trends. There is an indisputable data gap created by a lack of longitudinal, standard-measure, periodic information collected, analyzed, and shared across national, disciplinary, and institutional boundaries. This has created a decided “knowledge gap.” We draw conclusions, and act on some of them in the presence of little valid and reliable, systematically evaluated data. Such is the inescapable reality of educational interventions.

Disappointments aside, in our effort to move systematically from program context to description to inference, we have begun to assemble a research agenda. One goal should be a catalogue of key characteristics manifested on the education pathway en route to the workforce that *both* facilitate and impede transitions for individuals and structural change for organizations. Only with a better grasp of these characteristics and their cross-cultural variations can the scholarship in this volume inform stakeholders in government, nonprofit organizations, and the media.

We have just begun the program analysis needed if incorporating "feedback loops" into program design, implementation, evaluation, and refinement is to become a modus operandi of sponsors and program administrators alike. The road from "promising" to institutionalized, sustained, and scalable "exemplary" programs in science education and training is littered with good intentions, charismatic leaders, pragmatic partnerships, and of course, policies misguided, under-funded, and unfulfilled.

Sobered by this knowledge, we envision the global future of the science workforce (one becoming indistinguishable from the global workforce) that advocates through analysis for the aspirations of especially girls and women. To be sure, programs—the unit of analysis featured here—cannot be imposed on institutions; they must be "owned" by them, seen as culturally concordant, strategic, and evolving to advance societal missions. And programs must not favor one group over another or tilt the playing field in ways that compromise competition, devalues performance, or inflates an ascribed characteristic such as gender.

To be sure, we locally and globally can act to change the history of participation in science—and we must! A creative and productive twenty-first century labor resource hangs in the balance.

Chapter References

Brainard, S.G., and L. Carlin. 1998. A Six-Year Longitudinal Study of Undergraduate Women in Engineering and Science. *Journal of Engineering Education* 87: 369–375.

Building Engineering & Science Talent (BEST). 2004. *A Bridge for All: Higher Education Design Principles to Broaden Participation in Science, Technology, Engineering and Mathematics*. San Diego, CA: BEST, www.bestworkforce.org.

Burrelli, J. 2008. Thirty-Three Years of Women in S&E Faculty Positions. In *InfoBrief*. Arlington, VA: National Science Foundation.

CAWMSET 2000. *Land of Plenty: Diversity as America's Competitive Edge in Science, Engineering and Technology*. Report of the Congressional Commission on the Advancement of Women and Minorities in Science, Engineering and Technology Development, September, www.nsf.gov/publications/pub_summ.jsp?ods_key=cawmset0409

Chubin, D.E. 2013. *Leading and Following in Science: Gender, Symbolism, and Data*, April 8, 2013, http://membercentral.aaas.org/blogs/driving-force/leading-and-following-science-gender-symbolism-and-data

Chubin, D.E., A.L. DePass, and L. Blockus (eds.). 2010. *Understanding Interventions That Broaden Participation in Research Careers 2009: Embracing a Breadth of Purpose*, vol. III. Washington, DC: National Academy of Sciences, www.UnderstandingInterventions.org.

Chubin, D.E., and R.Y. Johnson. 2010. *Telling the Stories of the BPC Alliances: How One NSF Program Is Changing the Face of Computing*. Washington, DC: AAAS, http://php.aaas.org/programs/centers/capacity/documents/BPC%20Stories.pdf.

Chubin, D.E., and W.E. Ward. 2009. Building on the BEST Principles and Evidence: A Framework for Broadening Participation. In *Broadening Participation in Undergraduate Research: Fostering Excellence and Enhancing the Impact*, ed. M.K. Boyd and J.L. Wesemann, 21–30. Washington, DC: Council for Undergraduate Research.

Commission on Professionals in Science and Technology (CPST). 2008. *Professional Women and Minorities: A Total Human Resources Data Compendium*, 17th ed. Washington, DC: CPST.

DePass, A.L., and D.E. Chubin (eds.). 2009. *Understanding Interventions That Encourage Minorities to Pursue Research Careers*. Bethesda, MD: American Society for Cell Biology.

Etzkowitz, H., C. Kemelgor, M. Neushatz, and B. Uzzi. 1994. Barriers to Women's Participation in academic Science and Engineering (Chapter 3). In *Who Will Do Science? Educating the Next Generation*, ed. W. Pearson Jr. and A. Fechter. Baltimore: The Johns Hopkins University Press.

Fox, Mary Frank, G. Sonnert, and I. Nikiforova. 2007. Successful Program for Undergraduate Women in Science and Engineering: Adapting Versus Adopting the Institutional Environment. *Research in Higher Education* 50: 333–353.

Frehill, L. 2006. *Using Program Evaluation to Ensure the Success of Your ADVANCE Program*. ADVANCE: Institutional Transformation Working Group, May 8, http://www.cpst.org/diversity/toolkit2.pdf (accessed 26 April 2010)

Greene, Jessica, Jean Stockard, Priscilla Lewis, and Geraldine Richmond. 2010. COACh Career Development Workshops for Science Faculty: Views of the Career Impact on Women Chemists and Chemical Engineers. *J Chem Ed* 87: 386–391.

Huyer, Sophia. 2010. *Third World Organization for Women in Science (TWOWS) Postgraduate Training Fellowship: Trends, Results, and Opportunities for the Future.*

Meyerson, Debra, and Megan Tompkins. 2007. Tempered Radicals as Institutional Change Agents: The Case Advancing Gender Equity at the University of Michigan. *Harvard Journal of Law & Gender* 30: 303–322.

National Research Council. 2007. *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering*. Washington, DC: The National Academies Press.

National Science Foundation. 2001. *ADVANCE Program solicitation*. Arlington, VA. http://www.nsf.gov/pubs/2001/nsf0169/nsf0169.pdf

Pribbenow, C.M., J. Sheridan, B. Parker, J. Winchell, D. Benting, K. O'Connell, C. Ford, R. Gunter, and A. Stambach. 2007. *Summative Evaluation Report of WISELI (Pdf)*. Madison: The Women in Science and Engineering Leadership Institute.

Phipps, A. 2008. *Women in Science, Engineering and Technology: Three Decades of UK Initiatives*. Stoke on Trent: Trentham Books.

Redden, Elizabeth. 2007. Female Faculty and the Sciences. *Inside Higher Ed*, October 18, http://www.insidehighered.com/news/2007/10/18/womensci

Sandler, B.R. 2009. *The Chilly Climate: Subtle Ways in Which Women Are Often Treated Differently at Work and in Classrooms*, http://www.bernicesandler.com/id23.htm (accessed 18 April 2009)

Sheridan, Jennifer, Pribbenow, Christine, Fine, Eve, Handelsman, Jo, and Carnes, Molly. Climate Change at the University of Wisconsin-Madison: What Changed, and Did ADVANCE Have an Impact? *Women in Engineering Programs & Advocates Network (WEPAN) 2007 Conference Proceedings.*

Sturm, Susan. 2006. The Architecture of Inclusion: Advancing Workplace Equity in Higher Education. *Harvard Journal of Law & Gender* 29: 247–289.

Third World Organization for Women in Science (TWOWS), 1995. *Directory of TWOWS Members.*

Wenneras, Christine and Agnes Wold. 1997. Nepotism and Sexism in Peer Review. *Nature* 387: 341–343.

Vignette 9.1
We've Only Just Begun: What Worked and What Has Not Worked Well So Far for the Promotion of Women Scientists in Japan

Sanae M.M. Iguchi-Ariga

Japan remains at the bottom of OECD countries, to our deep regret, in regard to the percentage of women researchers. In concert with the Third Basic Plan for Science and Technology (2006–2010), in which numerical targets for female recruiting levels were shown for the first time, the Japanese government initiated multifaceted programs in 2006 to promote women's involvement in the research workforce nationwide, namely funding for institutions to create model programs (taking after the ADVANCE program of the NSF in the United States), re-entry support for women returning to research after taking family leave (special postdoctoral quota), and outreach programs to attract high school girls into science disciplines. More than 90 universities and national institutes have adopted the ADVANCE-like programs to date; Hokkaido University was one of the initial ten universities to do so.

Hokkaido University is a national flagship research university of about 2,000 faculty members with more than 11,000 undergraduate and 6,000 graduate students. The support office for Female Researchers in Hokkaido University (*FResHU*) has been managing various programs to promote representation of women in academic science and technology and to support their careers (including family support), aimed at the near-term goal of reaching 20% overall female faculty by the year 2020. To boost, but not force, appointments of qualified women scientists as faculty members, extra budgets for salaries from university overhead have been offered as incentives to the faculties recruiting women as members. Women were only 7.0% of the faculty when that unique affirmative action program started in 2006, and in 2013, after 7 years, the level had risen to 12.5% by welcoming more than 100 brilliant women researchers. The affirmative action program at Hokkaido University now has been applied to a national project to increase women in science, agriculture, and engineering fields, which show the smallest participation of women both

---

S.M.M. Iguchi-Ariga (✉)
Faculty of Agriculture, Hokkaido University, N9 W9, Kita-ku,
Sapporo 060-8589, Japan
e-mail: myan@res.agr.hokudai.ac.jp

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_9

in proportion and absolute numbers. A project has also been implemented at Hokkaido University in which 27 women, including 14 foreigners, have been recruited, increasing diversity in the research and education workforce in 5 years.

Establishing in-campus day-care centers for children and providing human support to laboratories have been successful not only for helping young "mom-scientists" to stay active, but also for improving the institutional climate by showing that women are not "risky" colleagues who would work less critically because of pregnancy and child care.

Another big issue is the two-body or dual career problem. About 10% of male researchers' partners/spouses are also researchers, while more than 50%, even 70–80% in life science fields, of female researchers have researchers as partners/spouses. Support for researcher couples is, therefore, a big concern in the promotion of women in science. Young researchers show a strong tendency to look for positions either in the Tokyo metropolitan area or in the Kyoto-Osaka area, where they might have more possibilities for finding two research posts for "two in science," given a variety of numerous universities and research institutes. Hokkaido University and others located far from the above areas and somewhat isolated from other research institutes should take this issue seriously in regard to securing qualified young researchers. Much related discussion is about fairness in having more opportunities for researcher partners, but the university would also benefit from recruiting suitable pairs of researchers. Of course, evaluation systems must be considered: both partners must be qualified individually and should fulfill faculty needs. Space for laboratories and offices is another concern. Recent developments in information technologies, such as mobile telephones, e-mail, and Skype, can provide some help to remote couples. However, while it might be less problematic as long as it remains a "two-body" problem, the situation becomes far more complicated and serious when they face a "three-body" or "four-body" situation including children or elderly parents. An entire employment system of researchers must be reconsidered in order to maximize the activities of scientists, from junior to senior and regardless of gender, as well as to cope with the declining birth rate which is marked especially among women scientists.

Also, despite programmatic efforts, the percentage of women assuming leadership positions involved in decision-making processes remains disappointingly low, as in the whole of Japan. The promotion of women in science should be far-sighted policy: it requires time and effort to normalize the long and continuous gender imbalance in the research workforce. Promotion activities as well as women's careers should be sustainable. Evaluation of promotion programs and activities, however, often lays too much weight on "numeric values" showing the increase of female researchers. Numbers are, of course, important; we need more women in the research workforce indeed, but we should never overlook working conditions and the quality of the workplace. Female junior faculty and postdoctoral researchers are thus provided various opportunities and training to become empowered and more "visible," such as seminars and workshops on leadership and presentation skills; childcare also is provided as a priority for encouraging and enabling the participation of mom-scientists. Taking pride as a front-runner, the *FResHU* office organizes such efforts and welcomes female researchers, and motivates other universities and institutes as well. In addition, it has formed a network in which women researchers help, inspire, and mentor one another, and networked women function as cores for transdisciplinary research collaboration. Also including "understanding" male colleagues, the network will help women to break through the glass ceiling.

9.7

Vignette 9.2

Initiatives Promoting Women in Science at the French National Center for Scientific Research (CNRS)

Anne Pépin

The National Center for Scientific Research abbreviated as CNRS (from the French *Centre National de la Recherche Scientifique*) is the largest public research organization in France and the largest basic research agency in Europe. CNRS covers all fields of knowledge through its ten Institutes, 33,700 employees—including 25,500 tenured researchers, engineers, technicians, and administrative staff, i.e. civil servants—and 1,000 laboratories located all over the country, and some abroad, most of them joint laboratories with universities or other national research organizations and key industrial partners. Founded in 1939, CNRS plays a central role in the design, funding, execution, and evaluation of research programs at the national level, and is a leader at the international level, boasting 20 Nobel Prizes and 12 Fields Medal Laureates, and ranking first in the world in 2012 in terms of publications (CNRS 2014).

In July 2001, shortly after two laws promoting gender equality had been passed in France[18] and in an effort to respond to European recommendations on gender equality in research and higher education,[19] CNRS spearheaded national efforts by creating its *Mission pour la place des femmes au CNRS* (MPDF-CNRS), a governance-level operational unit dedicated to the promotion of gender equality and improving the status of women within the organization. A few months later, the French Ministry in charge of research would follow and create its *Mission pour la parité* (renamed *Mission pour la parité et la lutte contre les discriminations* since 2009).

---

[18] The Law of June 6, 2000, promoting gender parity in political representation, and the Law of May 9, 2001 promoting professional equality between women and men.

[19] Awareness rose at EU level at the end of the 1990s, following the 1995 Beijing UN Conference and the 1997 paper by Wennerås and Wold (1997), leading the European Commission to launch a series of initiatives including the 2000 ETAN report.

A. Pépin (✉)
Centre National de la Recherche Scientifique (CNRS), Mission pour la place des
femmes au CNRS, 3 Rue Michel-Ange, Paris 75794, Cedex 16, France
e-mail: anne.pepin@cnrs-dir.fr

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_9

Many actions were initiated over the years by MPDF-CNRS to foster women's advancement in science. Among key initiatives, the Mission has produced a number of qualitative studies on the factors hindering the progression of women in research careers, as well as research and educational tools promoting French women scientists as role models. These tools include, for example, a volume on the role of women in the history of CNRS, traveling exhibitions and DVDs, a mentoring forum for young female Ph.D. students in mathematics in collaboration with the *Femmes et Mathématiques* professional association) and since 2009, MPDF-CNRS yearly publishes a comprehensive, sex-disaggregated statistical booklet recognized by CNRS as a necessary complement to its annual Social Report and a tool for improving its HR management and organizational practices, which serves as a model for the national academic community (CNRS 2013a).

In 2009, CNRS officially committed to the development of a gender action plan in its "Contract of Objectives" with the French State, and a series of national actions have since been put into place, among which tailored awareness-raising and capacity-building trainings on gender equality in research, were developed since 2011 to target all levels of HR and scientific decision-making at CNRS and thus foster systemic change.

As a means to support this commitment, MPDF-CNRS—along with a focused consortium of European institutions—answered and won the first call for proposals on structural change in research institutions launched by the European Commission through its 2010 7th Framework Program Science-in-Society work program—a call strongly inspired from the US National Science Foundation (NSF) ADVANCE Program, which was renewed in the followed three EC FP7-SiS campaigns and will carry on in HORIZON 2020, the next framework program (2014–2020). Project INTEGER (for "INstitutional Transformation for Effecting Gender Equality in Research") was launched in 2011 for a 4-year duration. Coordinated by MPDF-CNRS, it involves two other gender action plan-implementing institutions—Trinity College Dublin, Ireland, and Siauliai University, Lithuania—as well as a German organization, GESIS, in charge of evaluating progress within each institution, and is supported by an international group of expert advisors among which are former ADVANCE officers and grantees (CNRS 2013c; Trinity College Dublin 2013) At CNRS, INTEGER more specifically targets the two CNRS Institutes with the lowest female representation, i.e. physics and mathematics.

MPDF-CNRS has played a leading role at the national level in the development and recognition of gender studies. Recently, it initiated a national inventory of researchers working on gender and/or women, and supported the creation in 2010 of a CNRS pluri-disciplinary thematic network (RTP) on gender studies to explore the integration of the gender dimension in fields outside the humanities and social sciences. In 2012, this successful initiative led the newly created CNRS Mission for Inter-disciplinarity to elect gender as one of CNRS's great interdisciplinary research challenges for the coming years. The Gender Challenge Program (*Défi Genre* CNRS 2013b), co-led by MPDF-CNRS, funds exploratory projects from interdisciplinary research teams developing a gender perspective in different scientific fields, e.g. biology, environmental science, engineering, and computer science.

MPDF-CNRS is also on the Management Committee of a pilot targeted network on gender, science, technology, and environment launched in 2012 and funded by the European Cooperation in Science and Technology (COST, genderSTE 2013), and a member of the Gender and Diversity Task Force (now standing Working Group) created in 2013 within Science Europe, the organization representing research-performing and research-funding organizations in Europe.

A major collaborative effort, the GENDER-NET ERA-NET (GENDER-NET 2014) project, a pioneering FP7-funded networking initiative which is led by MPDF-CNRS, was launched in October 2013 for a 3-year duration. This ERA-NET scheme seeks to coordinate national policies and programs promoting gender equality in research institutions and/or the integration of the gender dimension in research contents. Partners, among which are some of the most advanced national program owners in Europe (from e.g., Norway, Ireland, UK, Spain, Switzerland, France) as well as key North-American players such as the US National Academies and the Canadian Institutes of Health Research, are joining forces for the implementation of strategic joint activities, building on a systematic exchange of information, innovative assessment and knowledge-transfer methods, and the definition of common indicators. GENDER-NET is a pilot transnational policy initiative which will allow for a global vision of the best practices and conditions for success for fostering gender equality in research.

References

Centre National de la Recherche Scientifique (CNRS). 2013a. *La parité dans les métiers du CNRS,* http://bilansocial.dsi.cnrs.fr/page/editoparite (accessed July 2013).

_____. 2013b. Défi Genre (Gender Challenge Program), http://www.cnrs.fr/mi/spip.php?article267 (accessed July 2013).

_____. 2013c. Integer, http://www.cnrs.fr/mission-femmes/integer (accessed July 2013).

_____. 2014. *Key Figures,* http://www.cnrs.fr/en/ (accessed 29 March 2014).

ETAN (European Technology Assessment Network). 2000. *Science Policies in the European Union. Promoting Excellence Through Mainstreaming Gender Equality. A Report from the ETAN Network on Women and Science*. Brussels: European Commission, Research Directorate-General.

GENDER-NET. 2014. The GENDER-NET European Research Area Network, http://www.gender-net.eu (accessed October 2014).

genderSTE. 2013. Key Steps to Structural Change, http://www.genderste.eu/ (accessed July 2013).

Trinity College Dublin. 2013. INTEGER: Institutional Transformation for Effecting Gender Equality in Research, http://www.tcd.ie/wiser/integer/ (accessed July 2013).

Wenneräs, Christine and Wold, Agnes. 1997. Nepotism and Sexism in Peer-Review. *Nature* 387:341–343.

Vignette 9.3

Building the Mathematics Capacity in the Developing World: The United States Participation in the Volunteer Lecturer Program

Ana Ferreras

The Volunteer Lecturer Program (VLP) in mathematics is organized and sponsored by the International Mathematical Union (IMU) with the goal of building capacity in mathematics and mathematics education in developing countries. Under this program, mathematicians from developed countries deliver intensive short courses in advanced mathematics for degree programs at universities in the developing world. One of the countries from which the program draws volunteers is the United States (US), which has a large pool of mathematicians who have indicated their willingness to participate, essentially pro bono, in the VLP. The program offers 3–4 week mathematics lecture courses on topics at the advanced undergraduate level, with the idea of building capacity and increasing interaction between the US mathematical community and the vast, mostly untapped reservoir of mathematical talent in the developing world. Their participation was managed by the US National Committee for Mathematics (USNC/M) at the National Academy of Sciences, and the program was sponsored by a National Science Foundation grant (DMS-0937225).

9.8 The Experience of the First Woman Lecturer

Dr. Helene Tyler, associate professor at Manhattan College, taught Ordinary Differential Equations in 2009 at the Royal University of Phnom Penh (RUPP) in Phnom Penh, Cambodia. She became the first woman volunteer in the IMU program, and it was the first time that she had lectured in a developing country. Upon her return, Dr. Tyler said, “When I returned to the States and people asked how was it, I responded that I’ve never worked so hard in my life and I can’t wait to do it again!”

A. Ferreras (✉)
National Academy of Sciences, 500 5th Street, NW,
Washington, DC 20001, USA
e-mail: aferreras@nas.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_9

9.9 The First VLP Student in the United States: Following the Mathematics Dream

Dr. Tyler returned to RUPP in 2010 and the highlight of her second visit was meeting Ms. Kimsy Tor, a student who had recently graduated from high school and attained the highest score in the Grade 12 National Exam. While Kimsy excelled at all subjects, her particular talent was mathematics. She audited Dr. Tyler's class where she ranked 8th among the 21 students, all of whom had at least 4 more years of education than she did.

When Dr. Tyler returned to the United States, she contacted the leadership of her institution. Kimsy was admitted to Manhattan College, which provided her with a scholarship to pursue a bachelor's degree in mathematics and a minor in computer science. In 2011, Kimsy became the first VLP student pursuing her studies in the United States. In 2013, she completed her second academic year with an outstanding overall GPA of 3.97/4.0.

Kimsy Tor wearing a Manhattan College T-shirt

9.10 US Graduate Students Serving as Teaching Assistants in the Developing World

Dr. Angel Pineda, associate professor at California State University, Fullerton, taught Numerical Analysis II at RUPP in 2009 and 2010. Due to the intense volunteers' workload, Dr. Pineda proposed to the USNC/MI that he bring along one of his graduate students to assist him. As a pilot project, Emily Bice became the first US graduate student to serve as a VLP teaching assistant (TA) in 2010. She assisted with grading homework, laboratory assignments, and examinations; was able to give selected lectures; and administered several computer laboratory assignments. She also held office hours, where she assisted students with their homework and theses.

Emily led the development of laboratories using Octave, a free version of MATLAB©, which complemented the material presented during lectures. Dr. Pineda noted that “Emily’s work will be extremely useful for future lecturers covering Numerical Analysis, since it is critically important for the developing world to use open-source software such as Octave© and MiKTeX. Having a graduate student helping to teach the course significantly increases the impact of a lecturer and provides a learning opportunity for the student and a mentoring opportunity for the lecturer.” Emily stated, “I had a wonderful experience. Dr. Pineda’s mentoring was an integral part of my positive experience.”

Emily Bice lecturing on Newton’s multivariate method

After evaluating the impact of this initiative and building upon its great success, Martha Byrne, a graduate student of Dr. Michale Nakamaye at the University of New Mexico became the second VLP TA. Martha assisted Dr. Nakamaye teaching Symmetry, Calculus, and Functional Analysis at Obafemi Awolowo University in Ile-Ife, Nigeria in 2010. Dr. Nakamaye noted, “Having the chance to share the time with my graduate student Martha was a terrific experience and it helped me greatly.” Martha commented, “I love that I got to be a part of the VLP, travel to Nigeria, and had such a wonderful experience there. I’m a better teacher as a result of our time there and getting to collaborate on such a project.”

Martha Byrne assisting a student

9.11 Science Diplomacy: VLP Reception at the US Embassy in Cambodia

In 2012, the USNC/M held a reception at the US Ambassador's Residence (William E. Todd) in Phnom Penh to honor VLP's work in Cambodia promoting mathematics. At that time, the VLP has worked with Cambodia for over 6 years. Dr. Tyler gave a welcoming address at the reception, saying that "to say that my time in Cambodia has changed my life, both professionally and personally, may be trite and cliché, but it also is entirely true. I have learned so much from my interactions with the Cambodian mathematics community. The students have been the hardest working and hungriest that I have ever taught, and it is possible that I have learned even more from them. At home, my students have become almost too familiar; I am rarely asked a question that I have not been previously asked. But here my students come to the material with different sets of skills, some even stronger than my students at home. I feel more present during my lectures here than I often do in the United States. I am more sharply focused on how the students react to the material and to how I present it. I am certain that the experience has made me a better teacher, both here and at home."

Dr. Helene Tyler and Ambassador William (Bill) E. Todd

The event was attended by local policy makers, university leaders, VLP alumni, and current students. The purpose of the reception was to increase the visibility of the program and empower local leaders to take ownership in building mathematics capacity in Cambodia. As a result of this reception, RUPP leadership provided space to the Mathematics Department to build the first mathematics laboratory in the country.

The U.S. participation in the VLP is now managed by the IMU. While the NSF grant that supported this effort has ended, the U.S. VLP is now fully funded by the IMU. For more information, see the US VLP website.[20]

---

[20] www.volunteerlecturerprogram.com

Chapter 10
Advancing Women in Science: Policies for Progress

Cheryl Leggon, Connie L. McNeely, and Jungwon Yoon

Over the past few decades, policy issues about the participation of women in science, technology, engineering, and mathematics (STEM) fields have been discussed less in terms of human rights and social justice, and increasingly in terms of national development and international competitiveness. In today's ever expanding knowledge-based and innovation-driven global economy, nations must maximize the development and utilization of all of their human resources. Therefore, enhancing opportunities for STEM education and careers for all segments of the population has become a priority on many policy agendas.

Despite variations across countries and disciplines, the advancement, access, and contributions of women—and of other groups that traditionally have been disenfranchised or underrepresented in STEM fields—have become an integral component of policies concerning national progress and international competitiveness. Within this context, we examine the lessons learned and challenges of promising policies that have the potential to improve as well as to increase the participation of women in STEM fields in diverse economic, social, and national contexts. Although specifically focusing on women, such policies also hold promise to serve as a mechanism for enhancing processes of inclusion, social justice, and progress more generally. After briefly discussing conceptual issues that inform our understanding of these policies, we then use selected analytical dimensions to explore the various characteristics that determine the effectiveness, applicability, and promise of these

---

C. Leggon (✉)
Georgia Institute of Technology, 685 Cherry Street, Atlanta, GA 30332, USA
e-mail: cheryl.leggon@pubpolicy.gatech.edu

C.L. McNeely
George Mason University, Fairfax, VA, USA
e-mail: cmcneely@gmu.edu

J. Yoon
Seoul National University, Seoul, South Korea
e-mail: wonnie78@gmail.com

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_10

policies in broader terms. We draw upon examples from various countries and regions to illustrate the main points highlighted in this examination, inform our analyses, and further enhance our understanding.

10.1 Conceptual Foundation

Our examination of promising policies is based on the premise that *policy is not only reactive but also proactive. Reactive policies* address public problems and those approaches to public problems that seem not to be working well, if at all. *Proactive policies* can be conceptualized as anticipatory insofar as they identify and address issues before they become problems. Moreover, we posit that "policy" itself can be conceptualized in four major ways: as a proposal and/or plan; as a rationale; as an intervention; and as an initiative. As a *proposal/plan*, policy articulates goals and objectives, and then provides guidelines for activities and actions to achieve those goals and objectives. As a *rationale*, policy provides the underlying principles that justify, validate, rationalize, and support a course of action (or inaction). As an *intervention*, policy can be conceptualized as a correction to a policy, program, practice, and/or course of action to avoid outcomes deemed as undesirable (reactive). As an *initiative*, policy is conceptualized as a course of action that enhances the potential for outcomes deemed desirable (proactive).

As a plan, rationale, intervention, and/or initiative, policy does not occur in a vacuum. Policy is developed in a broader context shaped by political, economic, social, and cultural forces. Rather than viewed as static, policy can be more appropriately conceptualized as the product of various interconnected and interdependent dynamic factors and processes at a given point in time. Whenever change(s) occurs in one or more contexts, policy should be re-analyzed in the context of those changes.

Also, we operationalize the concept of "promise" by identifying specific factors or characteristics associated with policies that have been deemed successful in addressing the same set of issues in other contexts. Because "one size does not fit all," a policy that is promising in one context may not necessarily be promising in another. Accordingly, emphasis is placed on various aspects of policy as they relate to one another, thereby providing a means by which to understand, classify, and compare policy goals across countries and over time. Based on such comparisons, we identify a range of policies that show promise both in general and in the context of specific countries and regions.

10.2 Analytical Dimensions

Through lessons learned from considering a range of policies and relevant examples, experiences, and insights from selected countries in different parts of the world, our goal is to enhance understanding and to stimulate and facilitate systematic and analytical thinking about principles and processes for the development, implementation, and evaluation of policies aimed at increasing female STEM access, opportunities, and participation. To that end, representative policies were analyzed to identify commonalities as well as differences relative to various contexts. Based on comprehensive reviews of relevant literatures and policy approaches, six fundamental and interrelated characteristics were selected to serve as the bases for identifying and analyzing challenges and promising policies for progress in increasing women's participation in STEM fields and careers. These characteristics are problem and issue identification; policy statement; relevant data; gender mainstreaming; institutionalization and sustainability; and diffusion (Fig. 10.1).

Note too, that although we focus primarily on policies and policy processes in specific countries at the national and/or regional levels, these analytical dimensions are applicable to different levels of analysis and actors, as well as across institutional settings. Thus, for example, policy issues at local levels and within specific agencies and organizations (and types of agencies and organizations, e.g., universities) can be approached in similar ways relative to questions of horizontal and vertical policy development, integration, and implementation (Fig. 10.2).

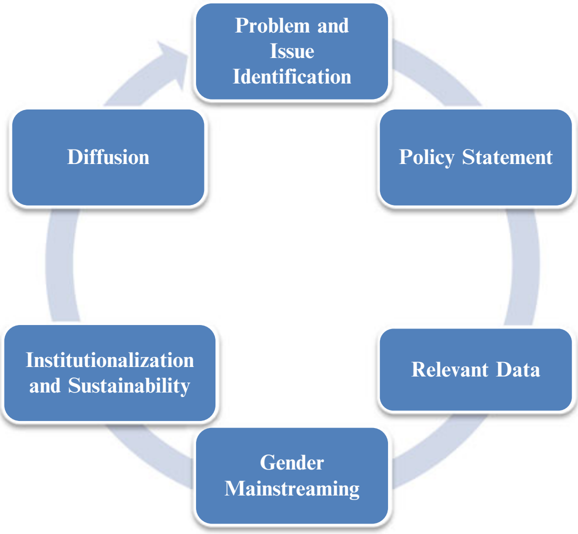


Fig. 10.1 Analytical dimensions

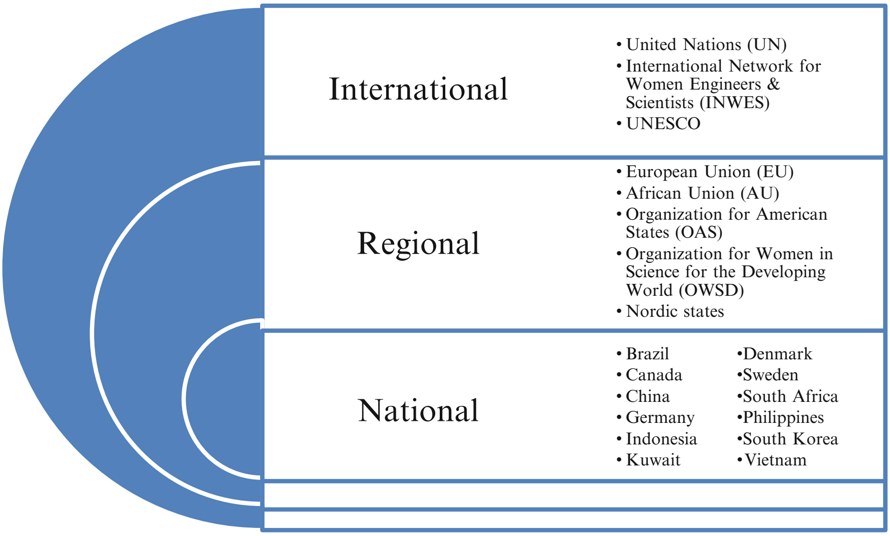


Fig. 10.2 Examples of applications of analytical dimensions

10.3 Problem and Issue Identification

As previously noted, policies can address what does, as well as what does not, work. Moreover, policies can address issues as well as problems; more specifically, all issues are not problems. Consequently, we contend that gender inequalities that depress the participation and contribution of women in STEM are ultimately harmful not only to scientific and technological advancement, but also to economic, national, and social advancement. Internationally, women comprise only a small percentage of the science and technology enterprise, signaling the crucial need for policies that encourage capacity building and bringing the development of knowledge and skills, vision and leadership, and views and aspirations to the science and technology agenda and to overall societal well-being. This situation raises questions not merely of structural adjustment, but also of legitimation and empowerment. Referring to attitudinal and cultural shifts and to access to resources, education, employment opportunities, and participation in decision making, empowerment in particular enhances women's ability to participate fully in knowledge-based activities:

> Empowerment may be understood as the ability to make strategic life choices in the context where this ability was previously denied. It involves changes in the allocation of roles, resources, and power in various aspects of society. Such changes require not only development planning or a top-down approach, but also active participation of women themselves … . Empowerment takes the form of upgrading skills, increasing employment opportunities, generating income for reinvestment and changing the gender equation. (Etzkowitz et al. 2010: 90)

Yet, in many countries, there traditionally has been little acknowledgment of women's societal or public existence, much less recognition of their critical role and capacity to engage in today's knowledge society and to be major contributors and participants in national development (Prakash et al. 2010; Berkovitch 2002). Indeed, it was not until the latter half of the twentieth century in many countries that women were accorded the right to participate in public institutions as individuals in their own right (Berkovitch 2002). The situation has been such that, especially "in the developed world, periods of shortfall in the supply of scientific personnel have prompted governments to enhance women's participation in the field." However, "given subtle biases and exclusionary practices," supply side approaches have been insufficient. Rather, wider institutional policies are required, such as "recruitment into pivotal positions and to important committees so that women can develop a network of contacts, access inside information about organizational politics, and gain visibility" (Etzkowitz et al. 2010: 87).

Effective policy making involves articulating the relevant problem or issue, specifying its scope and the magnitude of its ramifications (Kingdon 2011). Moreover, one of the most critical components of promising policy development is the clear identification of the relevant or target population(s)—that is, the group(s) or segment(s) of the population that the policy is intended to impact—and in what way(s). The Nordic countries (Finland, Iceland, Denmark, Sweden, and Norway) provide an interesting example in this regard. For the past several decades, the issue of gender balance in academia has been an especially prominent issue on their policy agendas. In these countries, 80% of professors are male, with the greatest imbalance represented in the natural sciences and technology fields. Finland, Norway, and Sweden have been identified as particularly proactive countries since the 1970s and 1980s, followed by Denmark and Iceland, with active policies promoting gender equality in research and related funding (EC 2009; Bergman 2013). In the past, initiatives in the Nordic countries tended to rely on national injunctions and legislative schemes, whereas current efforts are framed as "autonomy reforms" in which higher education and research policy is the responsibility of individual institutions. At the same time, research resources have been increasingly concentrated on large units and elite environments. Accordingly, "it is clear that there is a need for more discussion about and research on why excellence in research initiatives have become an instrument that favors male researchers over their female counterparts, and on what can be done to bring more gender balance to elite environments" (Bergman 2013: 10).

Other examples include special initiatives in Europe more generally. Aimed at increasing the proportion of women in academia, especially in the STEM fields, such initiatives have been on the forefront of the European Union (EU) agenda since the 1990s (EU 2000, 2009). Focusing on gender equality and gender mainstreaming, several EU countries have integrated policies providing funding to institutions based on their gender equity performance. Additionally, several European national research councils have instituted monitoring activities and action plans and policies for promoting gender balance and increasing the number of women researchers (EC 2008a, 2009).

Among Asian countries, South Korea, Japan, and Taiwan have launched support programs targeted to increase the presence and profile of women in STEM. For example, South Korea has relatively well institutionalized policies for encouraging female participation in STEM fields. These policies were developed over time as part of a three-phase general plan: Phase I, 1990–2000; Phase II, 2002–2008; and Phase III, 2009–2013. In particular, STEM policy concerns in South Korea beginning in the early 2000s were triggered by two phenomena—"STEM avoidance" and "brain drain"—which opened the door for policies supporting women in STEM fields (Lee 2009).[1] During Phase I in South Korea, the policy agenda for supporting women in STEM was formulated with an emphasis on gender equality in all national policy making. This emphasis is particularly noteworthy because it marks a turning point in terms of taking a gender perspective into consideration in the policy-making process—i.e., gender mainstreaming, as will be discussed below. During Phase II, the Act for Fostering and Supporting Women in Science and Technology provided both a legal and an institutional basis for policy supports for women in STEM. Phase III was aimed at making adjustments and re-establishing policy provisions and goals.

India provides another example of common issues that arise in discussions of women in STEM. "In India, the female-to-male student ratio in most scientific disciplines has been rising, but women are still grossly underrepresented in major scientific establishments in the public sector, not to speak of the upper echelons of science administration and management" (*The Hindu* 2013). Although India has many women studying and teaching science, the percentage of women actually "doing" science is not all that different from that in the rest of the world—that is, it is quite low (Godbole 2007). Moreover, studies have indicated that organizational practices and workplace discrimination cripple women's career growth. Such systemic failure has a cascading effect and serves as a major disincentive and barrier to female STEM participation (*The Hindu* 2013). Accordingly, special programs, such as those run by the Indian Department of Science and Technology and teacher fellowship programs run jointly by the three national science academies, have been established to address additional constraints faced by women teachers (Godbole 2007). Another example lies in the growing numbers of women in the Arab region of Africa and Southern Asia who are earning STEM degrees, but often cannot pursue STEM-related careers due to constraining social attitudes, as is often the case in developing countries (OWSD 2013). Across countries, even in situations where relevant STEM employment is procured, typical patterns reflect serious gender disparities in career trajectories and outcomes (EC 2004, 2008b).

Another variation on related issues can be found in Eastern and Central Europe and the Baltic states ("Enwise"—i.e., Enlarge "Women In Science" to East—countries). During the Soviet era, policies emphasizing gender equality and stressing the importance of education and access resulted in producing a considerable

---

[1] In fact, both STEM avoidance and brain drain also have been the catalysts for policy developments focused on female STEM education and workforce participation in other countries (UNESCO 2007).

proportion of highly qualified women scientists in Enwise countries. However, the post-Soviet transition saw the restructuring and decline of research systems which, while affecting both female and male scientists, left the female scientists in more vulnerable situations. Although there are higher proportions of women among researchers in Enwise countries compared to western countries, they are less well represented in the highly skilled STEM workforce. Even when there appears to be an overall gender balance among researchers, women have been squeezed out of better positions and are treated more as a backup human resource (EC 2004).

> Women scientists in every region—both developed and developing nations—face obstacles that limit their work and advancement … . Obviously, this hurts the women, but when we lose their skill, their intelligence, and their energy, the impact is felt in reduced innovation and growth across whole economies and whole cultures. In other words, when women drop out of science, everyone loses. (E.W. Lempinen, in OWSD 2013)

Problem and issue identification clearly is a first step in determining policy direction. It is an especially essential task in light of different legal and cultural contexts and applications across and within countries, which leads to some basic questions that must be considered. For instance, to what extent do policy goals and projections intended to increase the representation of women in STEM fields also include references to their increased presence as decision-makers and evaluators? Such positions are crucial to the overall issue of advancing women in science since they function as social and professional arbiters and community gatekeepers.

10.4 Policy Statement

Effective policies focus on actions that are goal oriented, and closely couple policy articulation with policy implementation. In other words, promising policies not only clearly specify goals and objectives, they also provide directives (or guidelines) for implementation. For instance, since the 1990s, the European Commission has supported special initiatives aimed at increasing the proportion of women in academia (EC 2000, 2008a, 2009). The focus has been on gender equality in academia, as well as incorporating gender perspectives in the content of research in the EU and around the world. Again taking an example from the Nordic countries, a primary policy initiative in Sweden was the Identification, Development, Advancement, and Support (IDAS 1999–2007) project for increasing the number of females in academic leadership positions; this initiative was followed by VINNMER (2007–2014) sponsored by the Agency for Innovation Systems to enhance career opportunities for women in strategically important research areas.[2] (VINNMER will be continued by the Mobility for Growth program with the objective of supporting career development for experienced researchers through mobility and international collaborations.) In 2004, the Danish Minister of Science, Technology, and Innovation

---

[2] See discussion and references for these initiatives in Bergman (2013).

in conjunction with the Minister for Gender Equality established a "think tank" to elicit institutional commitments to recruiting more women to research. Also, Norway's Ministry of Education and Research has provided short-term funding incentives for institutions to appoint qualified women to academic positions in mathematics, the natural sciences, and technology fields in which they are underrepresented. Similarly, in 2013, Iceland began a 4-year initiative, administered by the Minister of Education, Science, and Culture, in which awards are made to institutions showing substantial progress in gender balance. In Finland, all government committees, advisory boards, and other corresponding bodies, including the four national research councils, must have at least 40% women by law. In fact, all Nordic countries have adopted laws and administrative mechanisms for promoting gender equality.

Across countries, women cope with pressures of work, home, and limits on their participation in society. These pressures impact women's status in the workforce in general, and the STEM workforce in particular. Efforts from India have shown that, as steps to empower women in science, new regulations have been established to allow women with young children to work flexible hours and the country's Ministry of Science and Technology has itself invoked related policies for women scientists in all 65 of the institutes that operate under its purview (Bagla 2008). Also, the Indian National Science Academy has earmarked funds for limited research grants for some of its female members. Still, although women earned some 37% of STEM doctorates in India, the glass ceiling for promotions remains intact (Bagla 2008). As in other countries, both developed and developing, "even when obligations at home are solved and the conflict between professional and traditional roles is defeated, women still face gender disparities in terms of job satisfaction, income level, and recognition from colleagues and society at large," regardless of their professional acumen (Zubieta 2006: 192). Note, however, that India's Department of Science and Technology recently has introduced the Women Mobility Scheme for Employed Scientists, aimed at enhancing women's roles and positions in science. The stated objective is to strengthen ongoing gender initiatives and to provide a plan for seamless mobility of employed women professionals in research and development (IDST 2012).

In many instances, policy approaches begin with constitutional statements—as a case in point, the Vietnam constitution proclaims equal rights for female and male citizens and prohibits sex discrimination. Moreover, the Vietnam constitution posits that state employed women "shall enjoy paid prenatal and postnatal leaves during which they shall receive all their wage and allowances as determined by law. The State and society will create all necessary conditions for women to raise their qualifications in all fields and fully play their role in society." This is an example of government policy as a catalyst for institutional initiatives to enhance women's participation in the workforce.

Another case in point is South Korea: during the Phase I policy plan (1990–2000), issues concerning women in STEM were put on the national public agenda. This action was largely due to the efforts of the Association of Korean Women Scientists and Engineers (KWSE), the first organization for women in science and technology in South Korea. KWSE's goals were to increase the number of women in STEM and to protect their rights. KWSE lobbied for the government to adopt affirmative action in employment, promotion, training, scholarship, and policy-making processes (Lee 2009). Initially, despite strong efforts on the part of KWSE, women scientists received little positive response from government officials. However, it is critically important to note that KWSE was successful in bringing issues concerning women in STEM into the public discourse and demanding at least some acknowledgment of these problems. Consequently, during Phase 2 (2002–2008), two basic plans were implemented. The rationales for both plans were strategically framed in terms of national competitiveness and human resource development. The main focus of the First Basic Plan was to remove fundamental barriers for women's entry into STEM fields. The main focus of the Second Basic Plan was policy efficacy, with the goal of supporting and promoting relevant policies and programs. In particular, compared to the First Plan, the Second Plan provided more employment protections for women facing career interruptions due to childbearing and marriage, and sought to improve the overall working environment.

As has been noted, flexible maternity leaves and childcare assistance have been viewed as helping the family life–work balance. In Japan too, equal opportunities are enshrined in law and, at the institutional level, many universities now have responded by providing maternity pay and child care facilities (Bonetta and Clayton 2008). The University of Tokyo, for example, offers fellowships to encourage women scientists to return to work after career breaks. Changes in India have included the launch of a new government fellowship program for women scientists whose careers have been interrupted by their husbands' job transfers or by child-bearing, and women have been seizing the opportunity to resume their science careers (Bonetta and Clayton 2008). Typical strategies in some universities and companies have included adopting policies such as recruitment targets, mentoring programs, and women-only awards.

As mentioned, a critical component of the policy statement is the policy goal. However, while promising policies are goal oriented, it is important to recognize that goal achievement can be defined (and assessed) in terms of targets and quotas.

10.4.1 Promising Policies Include Targets and Quotas

Promising policies clearly define goals, establish a plan to meet those goals, and provide metrics to aid in assessing the degree of progress made toward achieving those goals in a specified amount of time. Some related policy discussions of gender equality use notions of "targets" and "quotas" interchangeably. Both targets and quotas are specific objectives that are measurable at multiple points in time. However, there are distinctions between them that have significant ramifications for both policy and practice.[3]

---

[3] This discussion draws on information from the Australian government's Workplace Gender Equality Agency (WGEA 2013).

10.4.1.1 Targets

Much of the research literature on the efficacy of targets and quotas in addressing gender diversity tends to focus on private sector companies. This literature defines "targets" as voluntary goals set by individual companies for themselves (WGEA 2013). In this context, setting targets is voluntary, which can be a disadvantage insofar as not all organizations will set them, or those that do will set them at levels that are ineffective. By setting their own goals, companies increase "buy-in" from their employees which, in turn, increases the probability of successfully achieving those targets. A company can tailor targets to its organizational structure and the environment in which it operates, and can make whatever adjustments are warranted in real time. In addition, a company can set targets at various organizational levels. Businesses are familiar with the concept of targets, and view them as an effective tool to improve performance in general.

10.4.1.2 Quotas

Quotas are imposed on an organization by an external body that has authority to enforce them—for example, government—with the ability to set and implement penalties for non-compliance. Moreover, individual companies cannot negotiate quotas with the government. Compared to targets, quotas work faster in terms of putting issues (such as gender equality) at the top of an organization's agenda. However, one problematic aspect of quotas is that organizations, even within the same industry, vary in terms of certain characteristics such as size and structure. Consequently, setting the same quota across firms in a given industry does not impact all firms to the same extent and/or in the same way.

Some countries, such as Denmark, Finland, and Iceland, never employ quotas or earmarks to address gender imbalances. By contrast, Norway and Sweden previously implemented earmarking schemes that proved highly controversial. In fact, in Sweden, earmarking was used primarily to increase the proportions of men in female-dominated academic fields; this policy was discontinued in 2011 (Bergman 2013).

10.4.2 Promising Policies Delineate Benchmarks to Assess Progress

Promising policies not only set goals but also provide guidelines for using established standards or benchmarks defining success to assess progress over time relative to short-, medium-, and long-term goals. Moreover, promising policies address issues of accountability in terms of related policy implementation and evaluation. Several countries have operationalized accountability in terms of integrated policies aimed at increased institutional funding based on performance in gender equity (e.g., Germany, Netherlands, and Ireland).

Some promising policies encompass specific national gender equality structures in active support of policy goals. For example, in South Korea, the 5-year Basic Plan not only set mid- and long-term goals for supporting women in STEM fields, but also facilitated the evaluation of supporting programs by delineating factors for monitoring and indicating their achievement. In 2004, the First Basic Plan for Fostering and Supporting Women in Science and Technology was initially built around five institutes—four regional and one national. The Institute for Supporting Women in Science and Technology monitors the outcomes of policy programs, such as the recruitment target system (RTS) and promotion target system (PTS), and reports results to the National Science and Technology Council (NSTC). Indeed, the RTS has been lauded as a systemic mechanism that facilitates the attainment of policy goals.

In many cases, policy strategies focus on the local institutional level in order to infuse gender equity throughout an organization; this is a type of bottom-up approach. Some institutions adopt strategies such as mentoring initiatives and/or special incentive funding for recruitment and retention of women in fields in which they are underrepresented. Thus, some institutions, including the Norwegian University of Science and Technology, have used start-up funding to support female appointees in highly male-dominated departments (Bergman 2013). Even when such initiatives are open to both genders, women are much more likely than men to participate in them.

At the national level, influential policies promoting gender balance in research have been found in various organizational entities, most notably national research councils. Examples include the Austrian Science Fund; Academy of Finland; German Research Foundation; Science Foundation in Ireland; Netherlands Research Council; Norwegian Research Council; Swedish Research Council; Swiss National Science Foundation; and the UK Research Councils. Also, the efficacy of such policies is enhanced by bottom-up engagement of the scientific community itself, such as the funding mechanisms put forth by the Czech Republic Contact Center on Women and Science (EC 2009). Moreover, regardless of level of analysis, policies to promote women in research typically are coupled with monitoring activities and action (Bergman 2013; EC 2009).

10.5 Relevant Data

Evidence is crucial to effecting promising policies in terms of plan, rationale, intervention, and initiative. Data that are accurate, credible, reliable and valid both drive and inform promising policies. This point underscores the criticality of the systematic collection over time of data that are relevant to and inform the specification of the policy issue or problem. Such data are used to enhance understanding of the impact of a given or proposed policy on various stakeholders and policy actors from governmental and nongovernmental organizations, institutions, and disciplinary and cross-disciplinary groups. In addition, these data provide a basis for benchmarking and evaluation insofar as they facilitate the ability to identify and assess appropriate indicators of policy efficacy at various points in time.

Data collection efforts, such as the administration of censuses and surveys, are fundamental to the policy process. For example, China's first large-scale time-use survey in 2008 has been used by policy makers to better delineate and address trends that limit female access to employment and mobility. Another example comes from the Act for Fostering and Supporting Woman in Science and Technology in South Korea which mandates that the Institute for Supporting Women in Science and Technology conduct an annual survey on the status of women scientists and engineers; survey responses contribute to a statistical database used for policy evaluation and development. Still another example is the data-driven strategy of the European Union (EU) for enhancing women's participation in science. Every 3 years since 2003, the EU publishes *She Figures*, a publication that consists of human resource statistics and indicators on gender equality in science and in the research and technological development sector. *She Figures* has been praised as a model for collecting, organizing, and disseminating data and information to inform decisions concerning policy design, development, implementation, and assessment.

Note especially that it is crucial to collect and employ appropriate data—that is, data that are collected, categorized, aggregated, and disaggregated in ways congruent with policy statements. For policies aimed at increasing the participation of women in STEM careers, it is essential that data are disaggregated not only by gender, but also by race, ethnicity, field, and other relevant sociocultural, political, and economic categories (Huyer and Westholm 2007). This stipulation applies to data collected in countries in the "developed" world as well as those in the "developing" world. It is important to be aware that collecting relevant data on women—especially in some nations in the developing world—can be challenging for at least two reasons: (1) because women often are not even registered in any citizenship database and (2) there is little acknowledgment of their contributions and/or ability to participate in a meaningful way in STEM (or other) development efforts (Prakash et al. 2010). Policies that (directly or indirectly) combat socio-structural and cultural barriers to the broader societal participation of women have yet to be embraced universally, although some countervailing trends and efforts have been identified (Drori et al. 2002; Berkovitch 2002; UNESCO 2004, 2007). Also, the types of data and measures that are used in policy planning and evaluation can themselves be limiting or problematic if they do not actually capture or reflect the intended goal and related factors identified in the policy problem or issue.

Valid metrics and expanded relevant data collection are crucial for the effective planning, implementation, monitoring, and evaluation of policy initiatives. Reliable data are essential to determine development strategies based on policies seeking to promote gender equity and eliminate STEM gender disparities. Thus, noting that "the presence of certain equality measures is linked with the rates of participation of women in science" (EC 2008a: 8), the European Commission has gone a long way in developing metrics to assess gender equality and participation in STEM education and the STEM workforce, and to assess the impact of specific policy efforts (EC 2008a, 2012). Along with efforts by other researchers and organizations, these activities have served as lessons and provided direction for related data collection around the world.

Although the systematic collection of credible, reliable, and valid data is time consuming, labor intensive, and expensive—the return on this investment is more than worth the time, labor, and cost in terms of the contributions that such data make to the entire policy process: refining the implementation, enriching the assessment, and expanding understanding of the impact of policies on various stakeholders. In sum, these data enable us to identify what is working well, what is not working well, and why.

10.6 Gender Mainstreaming

Despite some efforts to remove gender disparities, women remain underrepresented in STEM in educational attainment, careers, research and development, and decision-making positions (UNESCO 2003, 2004). As a result, a more comprehensive approach—gender mainstreaming—has been introduced across levels of analysis to address related problems and issues. Gender mainstreaming refers to the treatment of gender and gender perspectives as integral to the design, implementation, monitoring, and evaluation of policies and programs in all political, economic, and social spheres (UN 1997). Achieving gender equity necessitates a comprehensive strategy for assessing the ramifications and implications of policies and programs for men as well as for women.

In particular, an objective of gender mainstreaming in scientific research has been the inclusion of women at all levels of seniority in the STEM job market, emphasizing an expanded capacity for full participation in knowledge production and research (EC 2009). With the Beijing Declaration of the Fourth World Conference on Women in 1995 paving the way for the institutionalization of policies for advancing gender equality, gender mainstreaming, especially in regard to STEM education and workforce issues, has been an explicit item on the global policy agenda for the past several years and has influenced national level policy in turn. For example, in 2000 the Indonesian government directed all government agencies to integrate gender mainstreaming in their planning, formulation, implementation, monitoring, and evaluation of policies and development programs.[4] Initial gender mainstreaming strategies were also adopted in South Korea by the Dae-Jung Kim administration (1998–2002). Efforts to take gender equity perspectives into national policies were initiated with the establishment of the Ministry of Gender Equality and implementation of legislation such as the Framework Act on Women's Development, which emphasized the formulation of the policy strategies for promoting women. Furthermore, this trend toward gender mainstreaming helped to create a more favorable environment conducive to advocating policies for

---

[4] Republic of Indonesia (2000).

advancing, expanding, enhancing, and institutionalizing the participation of women in science and technology.

Although a number of countries and organizations previously had policies focused on female recruitment,[5] explicitly engaging the language and institutionalizing the approach of gender mainstreaming have become a strategy for integrating gender equity considerations in the standard operating procedures and activities of governments and other organizations. One example can be taken from the Nordic countries where objectives have shifted to emphasize "a gender equality perspective in all decision making in academia and in policy development in general" (Bergman 2013: 9). It also is noteworthy that countries with the largest underrepresentation of women in research in Europe—Austria, Germany, Switzerland, the Netherlands, and Belgium—now are adopting proactive policy approaches at national and institutional levels (Bergman 2013).

Mainstreaming female participation in all aspects of careers in STEM fields requires continuous and systematic monitoring over time. Although monitoring is a critical determinant of policy impact, its effectiveness depends on implementation parameters and goals. The role of South Korea's Institute for Supporting Women in Science and Technology, which was responsible for monitoring the outcomes of policy programs, is a case in point. In 2012, the Institute's "reorganization" abolished all regional institutes, which thereby reduced its main responsibilities from policy planning and development to training and education only. Moreover, this reorganization limited the role of monitoring to the small national institute, thus raising concerns about the overall policy process, implementation, and effectiveness.

Promoting gender equity in public and private research spheres necessitates systematic monitoring of women's participation in STEM careers not only in terms of quantity (e.g., numbers), but also in terms of quality (e.g., status as indicated by presence in decision-making positions). The lack of consistent and appropriate data disaggregated by field on gender distributions and statuses in science and, in some countries, a general dearth of research on women in STEM have been identified as a hindrance to gender mainstreaming in some areas, such as the Enwise countries (EC 2004).

10.7 Institutionalization and Sustainability

Institutionalization and sustainability are key attributes of promising policies. In this case, "institutionalization" refers to the degree to which a policy (program and/or practice) is integrated into the standard operating procedures of an organization. The concept "sustainability" refers to continuation of a policy over time. Institutionalization can be conceptualized as one indicator of sustainability—the greater the extent to which a policy is integrated into the standard operational

---

[5] These were typically individual-oriented approaches.

procedures of an organization, the greater the likelihood that the policy will be sustainable. Sustainability cannot be precisely defined; rather, sustainability is context specific. However, across contexts, sustainability has become an important criterion in the decision to accept or reject a given policy, practice, or program.

Regardless of the level of application, promising policies share the following characteristics:

- Statements that explicitly link gender mainstreaming to social and economic development
- Direct and indirect support for implementation
- Demonstrable relevant and practical commitment

Thus, for example, rather than a general statement about the importance of educating all citizens for the national good, promising policies for gender mainstreaming clearly and unequivocally delineate women as a specific policy category, and assert that women must be educated—especially in STEM—to enhance national growth and international competitiveness. In addition, as promising policies, they include directives for action. Accordingly, in the context of advancing women in STEM, institutionalization can be defined as the extent to which gender mainstreaming policies are coupled with national policies for development; that is, the degree to which gender mainstreaming policies are integral components of national policy—rather than peripheral add-ons. In this same context, sustainability can be operationally defined as the extent to which policies, programs, and practices are likely to persist over time.

Policies that show promise for effecting change are sustainable insofar as they can be maintained and supported over time in terms of goals, implementation and outcome. Measures for enhancing the participation of women in science might include improvements in the following areas:

- Science education and access at all levels
- Recruitment and retention initiatives
- Antidiscrimination legislation

Sustainable policies—especially in the context of development—meet the needs of the present without compromising the ability of future generations to meet their own needs (UN 1987). Gender mainstreaming policies that focus on improving education for all, as well as enhancing women's participation in STEM, are strategies for more sustainable development (Cohen 2006). This point is consistent with the conceptualization of sustainability in higher education in the UN Decade of Education for Sustainable Development (UN DESD).

Both effective and promising policies are sufficiently flexible to adjust to economic, legal, social, and political changes in the policy environment. Consequently, these policies require action that cuts across government, institutional, and disciplinary contexts. In STEM fields in particular, successful policies depend on both top-down and bottom-up strategies to address barriers to women's full participation. It is important to note that these barriers include—but are not limited to—"neutral" policies and practices that differentially impact women. Examples can be found in the regional contexts of the Nordic states and the European Union, and in the national context of South Korea. For example, since the 1980s, the Finnish government has worked with universities to ensure the implementation of gender equality legislation and, since 2010, has formally approved the idea of integrating gender equality issues in academic and STEM policy overall. In South Korea, the 2002 Act for Fostering and Supporting Women in Science and Technology provided both a legal and an institutional basis for policies that support women in STEM (Lee 2009). However, in the absence of the institutional commitments, sustainability can be compromised. Supporting programs can be unexpectedly abolished or reduced. Even with ostensibly supportive policies, implementation can be diverted and programs abolished or merged, resulting in weakened effects of affirmative action, as was the case for South Korea's RTS and PTS. Sustainability and institutionalization are synergistic; both are necessary for policy to fulfill its promise.

To address issues of gender mainstreaming, the Philippines' Department of Science and Technology established a women's association to provide funding for research and training. Similarly, India's Department of Science and Technology has supported gender initiatives within its budget commitments over time, positing objectives of encouraging and empowering women and of gaining gender parity in the science sector (IDST 2012). For example, in 2009, the Department initiated the Consolidation of University Research for Innovation and Excellence in Women Universities (CURIE) program to enhance the research infrastructure in these institutions. Also, special scholarships were established to motivate women to make contributions to national development through technology research, development, and adaptation. Other plans have included schemes for providing opportunities for women of 35–50 years of age in STEM fields who had breaks in their careers for pursuing research; special efforts were made to identify and encourage women in small cities and remote areas. Thus far, approximately 30% of the women awarded fellowships have been employed in universities and national laboratories, and have been acclaimed as a significant addition to the country's STEM workforce (IDST 2012).

10.8 Diffusion

Policies and policy approaches also can provide general models for goals and actions framed as plans, rationales, interventions, and initiatives. With both developed and developing countries asserting the need for STEM expertise, policies cannot be viewed as applicable only at the national level (cf. Blättel-Mink 2009). Promising policies are those with rationales, principles, and processes that can be adapted and applied on different levels across organizations and in various contexts. From this perspective, our understanding of policy can be enhanced through analyses of relational processes and interactions at and across different levels of an organization.

Certainly, women in STEM can benefit from a range of targeted policy efforts, such as gender mainstreaming in line with well-established conventions and directives (e.g., the Convention on the Elimination of all Discrimination Against Women); frameworks governing women's workplace rights; and systematic data collection on women and their experiences in STEM, work, and family life (OWSD 2013). The international context is strategically significant for regional and national governments and organizations operating as policy actors and sources of policy ideas, policy agenda setting, and policy formulation, implementation, and evaluation. Indeed, the international context can provide leverage for and lend credibility to policies being proposed in individual or groups of countries. Frequently, initiatives begun by some component of the United Nations are adopted by individual member states and/or consortia of countries (McNeely 1995). Similarly, regional organizations also serve as sources of policy ideas and models for individual members. For example, as a condition of membership in the EU, a country must agree to participate in and adopt certain policies, programs, and platforms. Also, local, national, and regional level policies and issues can inform and drive policies in other countries and regions around the world (Drori et al. 2002).

National and international networks are critical mechanisms for policy institutionalization and diffusion. While acknowledging differences among countries and regions in regard to gender participation in society more generally and in STEM in particular, international and regional groups act to promote the formulation of STEM development policies encompassing gender considerations. Consequently, both governmental and nongovernmental international organizations play especially significant roles in networking and policy diffusion. For instance, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) has long been committed to promoting equal access to education and to increasing the participation of women in STEM fields and encouraging their access to scientific and decision-making bodies. Thus, for example, while many Latin American countries lack specific policies to promote a more significant incorporation of women in STEM (Zubieta 2006), UNESCO has been consulting with various nongovernmental organizations and member states since 2011 to establish a regional plan including gender relevant science, technology, and innovation policy for Latin America and the Caribbean.

Recognizing that women's talents have been under-recognized and under-utilized in most countries and that they can provide vital contributions to development, UNESCO has promoted the establishment of national committees on gender, science, and technology for assessing and promoting gender mainstreaming in STEM-related policies. While member states ostensibly have signed on to pursue related policies, their capacity to follow through, and their political and institutional will to do so, can vary widely. However, the fact that related issues are incorporated in the policy dialogue is critical to the policy process and to opening doors for policy diffusion.

The International Labor Organization (ILO) also promotes gender equity in numerous resolutions and conventions. For example, the ILO Policy on Gender Equality and Mainstreaming calls for systematically analyzing and addressing the specific needs of both women and men in all initiatives, and for targeted interventions to enable both women and men to participate in and benefit from development efforts. Such measures are meant to provide guidance to member states. Thus, for example, as have other countries, Jordan has followed ILO recommendations to establish a comprehensive system of relevant sex-disaggregated data collection allowing for directed and flexible responses to labor market concerns and supporting transparency in policy formulation, monitoring, and evaluation has allowed for on-going policy transformation (Goulding 2013: 134). In fact, Jordan has taken female participation seriously in terms of development and rights and has led its region in the adoption of UN, UNESCO, and ILO informed policies for gender sensitive employment services and targets for women. Jordan's policy agenda also has reflected gendered social protections, including childcare assistance and maternity insurance, which arguably are helping to overcome cultural and economic barriers to women's labor market participation (Goulding 2013).

In many countries, international organization priorities in policy formulation can be highly influential in terms of their effects on national legislation promoting gender equality and antidiscrimination. However, while their activities are necessary to facilitate a more gender sensitive policy environment, they may not be sufficient to guarantee that countries adopt and implement effective policies. Thus, we find situations in which, for example, the Iranian government barred women from careers in nuclear physics and electrical engineering; Chinese institutions expected women to obtain higher entry grades for science courses than their male counterparts; and women in developed countries obtain more than half of all university degrees but their share of qualifications in science and technology is a mere 30% (*The Hindu* 2013). In general, women remain more constrained by unequal access to productive resources and forms of employment discrimination—intentional and/or unintentional, direct and/or indirect. That is,

> … there are many challenges, misconceptions, and obstacles that prevent policy makers from designing effective gender sensitive employment policies and strategies … . Globally, there is a habitual separation of economic and social policies, with gender issues often relegated to under-resourced and under-prioritized social policy. (Goulding 2013: 132)

10.9 Conclusion

Women remain the least integrated into the STEM workforce in countries around the world. Beyond questions of social justice and rights, women's underrepresentation in STEM translates into a significant loss of scientific human capital for development and progress (UNESCO 2007). It is generally recognized that "the difficulties encountered by women, constituting over half of the world's population, in entering, pursuing, and advancing in a career in the sciences and in participating in decision making in science and technology should be addressed urgently" as fundamental issues of national development and progress.[6] Nevertheless, despite recommendations against gender bias especially in the context of promoting development, it is not unusual for females to be disadvantaged at many stages in STEM career pathways. Social and cultural barriers represent some of the greatest impediments to gender equality in the sciences. Indeed,

> In many countries, the problem is not merely to attract women to STEM fields, but, even more to the point, to transform male (and female) attitudes and to remove other societal barriers and constraints to their participation in STEM. Because politics sets the context for policy action, the interests of different stakeholders may not be aligned and may even be antithetical to one another. Consequently, successful policy making often must be treated as a balancing-act. (Leggon and McNeely 2012: 114)

To inform and enhance understanding of what works and what does not work to achieve gender equity in STEM, through systematic analyses of relevant policies, we identified characteristics of policies that are promising in terms of planning, development, implementation, and evaluation. Various conceptualizations of policy as plan, rationale, intervention, and initiative reflect both reactive and proactive policy approaches. Consequently, we conclude that, to develop, nurture, and fully engage the STEM potential of all segments of society, what is needed are changes that will enhance effective policy development and implementation, such as the following (cf. EC 2008b):

- From *inertia to awareness and sincere commitment* to the goal of gender equity
- From *gender imbalance to gender balance* in representation in career and decision-making positions and roles
- From *opacity to transparency* in funding, recruitment, and promotion procedures
- From *inequality to quality* in science, a critical component of which is equality
- From *ignorance to knowledge* based on appropriate (accurate, credible, reliable, and valid) evidence
- From *complacency to urgency* in fulfilling the STEM potential of all segments of society

In sum, women's participation in STEM varies by factors such as discipline, sector, and nation. When allowed the opportunity, girls and women perform at increasingly high levels in STEM fields (EC 2000). Even in countries and fields in which more women are earning advanced STEM degrees, these increases typically are not reflected in the STEM workforce (cf. Blättel-Mink 2009). Despite—or perhaps because of—advances in women's participation and representation in STEM, extreme variations and policy challenges remain. Therefore, enhanced understanding of lessons learned from effective and promising policies designed to advance women in science is critical for success in meeting these challenges.

---

[6] From UNESCO's Declaration on Science and the Use of Scientific Knowledge (in Cetto 2000: 466).

Chapter References

Bagla, P. 2008. Indian Government Offers Helping Hand to Women Scientists. *Science* 319: 1470.

Bergman, Solveig. 2013. *The Nordic Region—A Step Closer to Gender Balance in Research? Joint Nordic Strategies and Measures to Promote Gender Balance Among Researchers in Academia*, TemaNord 2013, vol. 544. Copenhagen: Nordic Council of Ministers, http://www.norden.org/en/publications/publikationer/2013-544.

Berkovitch, N. 2002. *From Motherhood to Citizenship: Women's Rights and International Organizations*. Baltimore: Johns Hopkins University Press.

Blättel-Mink, Birgit. 2009. MINT: The German National Initiative for More Women in SET. *Equal Opportunities International* 28(1): 104–109.

Bonetta, L., and J.P. Clayton. 2008. *Beating the Odds: Remarkable Women in Science*. Washington, DC: American Association for the Advancement of Science, http://sciencecareers.sciencemag.org/sites/default/files/media/loreal_booklet_copyright.pdf.

Cetto, A.M. (ed.). 2000. *World Conference on Science: Science for the Twenty-First Century, A New Commitment*. France: UNESCO.

Cohen, J.E. 2006. Human Population: The Next Half Century. In *Science Magazine's State of the Planet 2006–7*, ed. D. Kennedy, 13–21. London: Island Press.

Drori, G., J.W. Meyer, F.O. Ramirez, and E. Schofer. 2002. *Science in the Modern World Polity*. Stanford: Stanford University Press.

Etzkowitz, Henry, Namrata Gupta, and Carol Kemelgor. 2010. The Gender Revolution in Science and Technology. *Journal of International Affairs* 64(1): 83–100.

European Commission (EC). 2000. *Science Policies in the European Union: Promoting Excellence Through Mainstreaming Gender Equality*. Brussels: EC.

______. 2004. *Waste of Talents: Turning Private Struggles into a Public Issue—Women and Science in the Enwise Countries*, Report of the Enwise Expert Group on Women Scientists in the Central and Eastern European countries and in the Baltic States. Brussels: EC.

______. 2008a. *Benchmarking Policy Measures for Gender Equality in Science*. Brussels: EC.

______. 2008b. *Mapping the Maze: Getting More Women to the Top in Research*. Brussels: EC.

______. 2009. *The Challenge in Research Funding: Assessing the European National Scenes*, EUR-23721-EN. Brussels: EC.

______. 2012. *She Figures 2012: Gender in Research and Innovation*. Brussels: EC.

Godbole, Rohini. 2007. Editorial. *Resonance* 12(12): 1–3.

Goulding, K. 2013. *Gender Dimensions of National Employment Policies*. GED Working Paper 2/2013, International Labor Organization.

Huyer, S., and G. Westholm. 2007. *Gender Indicators in Science, Engineering, and Technology: An Information Toolkit*. Paris: UNESCO.

Indian Department of Science and Technology (IDST). 2012. *Annual Report 2011–12*. New Delhi: Indian Ministry of Science and Technology.

Kingdon, J. 2011. *Agendas, Alternatives, and Public Policies*. Boston: Longman.

Lee, Eun Kyoung. 2009. Boundary Agenda Between Gender Equality and Human Resource: The Establishment of Policy for Women in Science and Technology in Korea. *Asian Women* 25(2): 29–47.

Leggon, C., and C.L. McNeely. 2012. Promising Policies. In *Blueprint for the Future: Framing the Issues of Women in Science in a Global Context*, ed. W. Pearson Jr., L. Frehill, and K. Didion, 109–116. Washington, DC: National Academies Press.

McNeely, C.L. 1995. *Constructing the Nation-State: International Organization and Prescriptive Action*. Westport, CT: Greenwood Press.

Organization for Women in Science for the Developing World (OWSD). 2013. *Kuwait Amir Welcomes Women Scientists*, International Conference on Women in Science and Technology in the Arab Countries, 21–23 April, http://owsd.ictp.it/news/kuwait-amir-welcomes-women-scientists

Prakash, Nirupama, Betty McLellan, and Barbara Wejnert. 2010. *Empowerment of Women Through Science and Technology Interventions*. New Delhi: Regency.

Republic of Indonesia. 2000. Indonesian Gender Mainstreaming Presidential Declaration, Presidential Instruction No. 9/2000. State Ministry for Women's Empowerment, Republic of Indonesia.

The Hindu. 2013. The Science of Missing Women. Opinion editorial (28 January), http://www.thehindu.com/opinion/editorial/the-science-of-missing-women/article4351064.ece

United Nations (UN). 1987. Report of the World Commission on Environment and Development: Our Common Future, Brundtland Commission Report, Annex to General Assembly Document A/42/427, *Development and International Co-operation: Environment* (2 August 1987), http://www.un-documents.net/ocf-02.htm

______. 1997. *Report of the Economic and Social Council for 1997* (A/52/3, ECOSOC 1997/2), http://www.un.org/womenwatch/osagi/pdf/ECOSOCAC1997.2.pdf

United Nations Educational, Scientific, and Cultural Organization (UNESCO). 2003. *Assessment of Resources, Best Practices, and Gaps in Gender, Science, and Technology in the Asia-Pacific Region*. Jakarta: UNESCO.

______. 2004. Comparative Study on Gender Dimension of Policies Related to the Development and Application of Science and Technology for Sustainable Development. In *Regional Secretariat for Gender Equity in Science and Technology*. Jakarta: UNESCO.

______. 2007. *Science, Technology, and Gender: An International Report*. Paris: UNESCO.

Workplace Gender Equality Agency (WGEA), Australian Government. 2013. *Targets and Quotas: Perspective Paper*, https://www.wgea.gov.au/sites/default/files/2014-03-04_PP_targetsquotas.pdf

Zubieta, J. 2006. Women in Latin American Science and Technology: A Window of Opportunity. In *Women in Scientific Careers: Unleashing the Potential*, 187–202. Paris: Organization for Economic Cooperation and Development.

Vignette 10.1
A Comprehensive National Approach to Promote Gender Equality in Science: The Case of Norway

Liisa Husu

The Nordic countries—Finland, Denmark, Iceland, Norway, and Sweden—can be characterized as global gender leaders when it comes to overall gender equality in society (WEF 2012). In all five Nordic countries, gender equality promotion in science and in academia more generally has been actively on national policy agendas since the 1980s, especially in Finland, Norway, and Sweden (Bergman 2013). Yet, if the proportion of women among full professors is used as an indicator of gender equality in academia and science, Norway and Sweden do not excel in a European comparison, reflecting the same level as European (EU-27) countries on average. In 2010 in the EU-27 and Sweden 20% and in Norway 21% of all professors were women; Finland and Iceland did slightly better with 24%; and Denmark had clearly lower figures with 15% (EC 2013).

However, the area in which Nordic countries do excel is gender balance in scientific and academic leadership and decision making. For example, while nine out of ten European universities are still led by men, the Nordic universities, nearly all of which are public institutions, clearly show a more gender balanced pattern: 43% of Swedish, 31% of Finnish, and 25% of Norwegian universities had female Rectors (the highest leadership position) in 2010 (EC 2013). When it comes to high level scientific boards and committees, recently monitored by European Women and Science Statistics, Nordic countries again show near gender balanced patterns, with Sweden at 49%, Norway at 46%, and Finland at 45% of women in contrast to the EU-27 country average of 36% in 2010 (EC 2013). Notably this development is not anything new in the Nordic region; the boards have been gender balanced since the early 2000s and even earlier (see EC 2003, 2009). Nordic women have thus reached significant representation among gatekeepers who shape the scientific agenda.

Of the Nordic countries, Norway has shown the most comprehensive approach to addressing gender inequalities in science and academia, effectively involving key

---

L. Husu (✉)
Centre for Feminist Social Studies, Örebro University, Örebro, Sweden
e-mail: Liisa.husu@oru.se

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_10

stakeholders, adopting innovative measures, and systematic and long-term backing by political will at the highest levels. Norway is not a member of the European Union but, rather, is an EC-associated country, participating fully in European research activities. The most radical measure allowed by Norwegian legislation was an attempt to earmark academic positions for the underrepresented gender. However, this measure was disallowed by the EFTA Court (the Court of Justice of the European Free Trade Association States) on 24 January 2003 as discriminatory against men (see Lismoen 2013). This EFTA ruling forced Norway to develop other types of measures.

The political will to promote gender equality in universities and research has been notably evidenced by the high-level Committee set up by The Ministry of Education and Research. The Ministry appointed in 2004 the *Committee for Mainstreaming Women in Science*, later changed to the *Committee for Gender Balance in Research*. The Committee has completed three terms. It is a national level Committee with comprehensive expertise in gender issues, supporting gender equality developments and providing recommendations on institutional measures in universities, colleges, and research institutes, engaging in awareness-raising activities and providing advice to various stakeholders in the academic and research sector (Gender Balance in Research 2013).

The committee is funded from the state budget, and the Chair and members are appointed by the Ministry of Education and Research. The funds cover a secretariat and support relevant activities. The committee cooperates closely with the Research Council of Norway and KILDEN, the Norwegian state funded information center on gender. It reports regularly to the Ministry of Education and Research and other relevant entities.

The committee members are representatives of key stakeholders, e.g., universities, research institutes, students, and funding bodies, holding high positions in their institutions and demonstrating personal engagement in their institution's work for gender equality. The appointment principles for members thus take into account not only formal representation but also individual commitment and potential for high institutional impact.

The Committee can be characterized as an active national level think tank and information hub for gender actions in academic and scientific research in Norway. It also has high regional visibility and impact, in the Nordic countries and Europe more broadly, as well as further international presence. Its information portal, *Gender Balance in Research—Norway* (in both Norwegian and English) is primarily a collection of relevant Norwegian resources. The portal was developed by KILDEN Information Centre for Gender Research in Norway, another important national information hub, at the assignment of the Committee.

Inspiration and encouragement through university information and advice are complemented by a substantial monetary incentive. In 2007, Norway's Ministry of Education and Research established a Gender Equality Award of two million Norwegian kroner, presented annually to reward the research community's gender equality efforts. In practice, the Committee has been commissioned by the Ministry to assess the nominees and announce the award.

The establishment of the Gender Equality Award was a concrete and visible ministerial measure to encourage and mobilize institutions to actively engage in gender equality planning, and to give an extra boost to their activities. The award purpose is to increase the proportion of women in academic positions and thereby promote a better gender balance in academia, along with resources that institutions themselves have reserved for gender equality efforts. Universities, colleges, and research institutes are invited to submit their existing action plans and gender equality measures to the Committee. They also must document financial resources set aside for implementation. The Committee assesses the submitted action plans and measures and gives its recommendation to the Ministry for award to one or more institutions.

Institutions that have been granted Gender Equality Awards have included the University of Life Sciences (2012), the Norwegian School of Sport Sciences (2009), the Norwegian School of Economics and Business Administration (2008), and the Norwegian University of Science and Technology (2007), in addition to traditional multi-faculty universities. However, in late 2014, the Ministry decided to discontinue the national award, news which was critically received by many in the Norwegian scientific community (Mesna 2014) The awards increased the accountability and visibility of gender equality promotion in the competing institutions, since detailed evaluations of all candidates are published on the Committee website. Discussions about whether similar awards should be established have been undertaken in at least Sweden and Iceland.

References

Bergman, Solveig. 2013. *The Nordic Region—A Step Closer to Gender Balance in Research? Joint Nordic Strategies and Measures to Promote Gender Balance Among Researchers in Academia*, TemaNord 2013, vol. 544. Copenhagen: Nordic Council of Ministers, http://www.norden.org/en/publications/publikationer/2013-544

European Commission (EC). 2003. *She Figures 2003 Statistics and Indicators on Gender Equality in Science*. Luxembourg: Official Publications of the European Communities.

______. 2009. *The Gender Challenge in Research Funding. Mapping the European National Scenes*. Luxembourg: Official Publications of the European Communities.

______. 2013. *She Figures 2012. Statistics and Indicators on Gender Equality in Science*. Luxembourg: Official Publications of the European Communities.

Gender Balance in Research—Norway, http://eng.kifinfo.no/ (accessed 1 September 2013).

Lismoen, Harald. 2003. EFTA Court prohibits affirmative action practices. *EIRO European Industrial Relations Observatory Online,* http://www.eurofound.europa.eu/eiro/2003/02/inbrief/no0302102n.htm (accessed 1 March 2014).

Mesna, Marte. 2014. *Over and Out for the Gender Equality Award*, http://eng.kifinfo.no/nyhet/vis.html?tid=8959 (accessed November 18, 2014).

World Economic Forum (WEF). 2012. *Global Gender Gap Report 2012,* http://www3.weforum.org/docs/WEF_GenderGap_Report_2012.pdf (accessed August 19, 2013).

Vignette 10.2

Women's Advancement in Science and Engineering in South Africa

Cheryl de la Rey

Before the advent of democracy, the South African higher education system enrolled more men than women. Within a decade of 1994, when the first democratic elections took place South Africa, the gender profile in higher education was at a level that many other countries took decades to achieve. By 2000, the number of women in universities exceeded men; women were 53% of university students. There have been changes in university staffing too, although not as rapid compared to student enrolments and graduations. Up until 2005, universities employed more men than women. In 2006 women outnumbered men for the first time, and by 2007, women comprised 51% of all university employees at all levels.

Two provisions in the South African Constitution have been instrumental in improving the status of women. Firstly, a commitment to gender equality eliminated all discriminatory legislation, policies and regulations. Secondly, there is the provision for redress of past discrimination, which is somewhat unique, differentiating South Africa from many other countries. This provision opened up space for equity legislation compared to equality alone. All employers who employ more than 50 staff must comply with employment equity legislation, one of the key legal instruments, which requires each institution to:

- Set targets for race, gender and disability recruitment and retention
- Report annually on progress in meeting these targets
- Provide reasons when targets have not been met

C. de la Rey (✉)
University of Pretoria, Lynnwood & Roper Str Administration Building,
Room 4-33, Hatfield, Pretoria 0002, South Africa
e-mail: rector@up.ac.za

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_10

Given the relatively rapid upward trend in the participation of women, for some time it was assumed that all was on track to achieve full gender equality in higher education within a definite time span. This optimism has since given way to a reality that shows that below the high level of aggregated data, several continuing and persistent gender disparities are discernible.

10.10 Looking into the Data

Although the total number of women enrolling in and graduating from universities has increased to a level which appears to be equivalent to that of men, closer examination of the data reveals that a pattern of decreasing percentages as the level of study moves upward from undergraduate to doctoral levels. When enrolments are examined by field of study, men continue to dominate in science, engineering and technology (SET). In 2010 women comprised only 38% of enrolments in SET disciplines and women were severely underrepresented in engineering, physics and computer science (ASSAf 2011).

While there is no doubt that women have made meaningful inroads into higher education, it is evident that the path to gender equality is not a straightforward matter of a linear, continued progression. Although South Africa showed dramatic increases in enrolments and graduation of women after formal obstacles were removed and equity legislation was introduced, there continues to be underrepresentation of women in certain areas. The key lesson from the South African experience is that the removal of formal discriminatory policies and procedures even when accompanied by redress measures is necessary to advance the status of women, but insufficient to achieve true equality.

10.11 Culture and Society

Although in South Africa there is no overall inequality in the number of girls in schooling, gender biases in teaching practices and in the curriculum militate against equality in science and mathematics, subjects that are necessary for access and success in SET disciplines. Research has identified multiple factors that inhibit women's participation in the SET sector. The biases include pressure to conform to traditional gender roles in schools; science and mathematics curricula skewed in favor of traditional boys' interests; sexual harassment; the masculine image of science; and the lack of positive role models for girls in SET (Moletsane and Reddy 2011).

Some years ago, while conducting a series of interviews with academics, I realized that a critical examination of the concept of career is crucial, if we hope to gain a clearer understanding of the problem of gender bias (De la Rey 2010). Due to childbearing, childrearing, and other family responsibilities most women are not likely to follow the anticipated pattern of uninterrupted service that contributes to career advancement. For women late beginnings and interruptions to the development of the career trajectory are typical. Unlike male scientists, women's careers are affected by the life events of others, typically their husbands and their children. For some disciplines, such as computer and electronic engineering, the fast pace of change makes re-entry difficult (ASSAf 2011).

Scientific careers, in particular, require large, early stage investments of time and energy. By the time careers are being established, many women confront decisions about relationships and family. Even though career goals have assumed more significance in the lives of women as their participation in all sectors of the paid labor force has increased, women's responsibilities in the family and household domain have not diminished concomitantly.

Beyond the career trajectory itself, we also need to examine the gender implications of the ways in which scientific careers are crafted. Scientific careers are built through building up a reputation. Reputations are not simple translations of research productivity as there is no necessary direct relationship between research productivity and reputational capital. The processes of reputation and career building are affected by feedback mechanisms which ensure that past performance brings fresh rewards that promote even further activity that enhances greater reputation. Although reputation is closely linked to research performance, it is also affected by other factors such as access to networks, mentors, and seniority. Reputations are made through informal networks that involve colleagues, friends, critics, and competitors. It works like a narrative, story-telling process through which the characters of science are created.

The competition inherent in scientific careers (e.g., for grants and promotions) also presents a challenge. For many women engaging directly and actively in competition is experienced as difficult because in doing so they risk a perception of themselves as ambitious; a character trait that is inimical to traditional constructions of femininity.

For the few women who succeed, they discover that they not only have to deal with the challenges of the career itself, but they have to overcome organizational cultures and practices that have been shaped in ways that favor men and masculinity. As long as the obstacles remain, the number of women will remain small.

10.12 The Future

What we learn from South Africa and many other countries is that in order to achieve meaningful gender equality in science and engineering we need a multi-pronged approach, incorporating a portfolio of strategies or interventions that address the many facets of gender bias. These interventions include stereotype reduction via media and communication campaigns, mentorship programs, enhanced access to funding and better gender representation in decision-making committees. What Aisenberg and Harrington (1988) called "the rules of the game" were created by men and privilege masculine traditions and behaviors. By identifying many of the unsaid rules and informal practices, we can begin a process of change to open access to more women.

Human capital development is one of the biggest obstacles to African social and economic development, therefore increasing the participation of women in science and engineering is not optional; it is essential.

References

Aisenberg, N. and M. Harrington. 1988. *Women of Academe*: *Outsiders in the Sacred Grove*. Amherst, MA: University of Massachusetts Press.

ASSAf. 2011. *Participation of Women and Girls in the National STI System in South Africa Based on the Gender Equality-Knowledge Society Framework*, WISAT-OWSD.

De la Rey C. 2010. *Empowerment of Women and Gender Equality*: *Lessons from South African Higher Education*, Association of Commonwealth Universities Conference, Cape Town, 25–27 April.

Moletsane, R. and V. Reddy. 2011. *Women*'*s participation in industrial science*, *engineering and technology*. Human Sciences Research Council Policy Brief.

Vignette 10.3

Enabling Policies: Capacity Building in Science and Technology in Brazil

Alice Abreu

Brazil, like many other countries in Latin America, has seen the number of women as university students increase substantially in the last decades (OEI 2004). There are now more women than men enrolled at universities and they are also the majority of those completing their courses. In fact, Brazil is an especially interesting case to consider because women constitute, since early 2000, the majority of M.Sc. and Ph.D. graduates. Moreover, although women are less present in engineering, mathematics, physics, and computer science, their participation in these disciplines is larger than in many developed countries. What are the policies that have enabled this exceptional situation?

The Brazilian system of science and technology (S&T) was established in the last 60 years and, since its beginning, has had a strong focus on capacity building. The creation in 1951 of CNPq (National Council for Scientific and Technological Development) and of CAPES (Coordinating Agency for Training of Higher Education Personnel) was crucial to this process. The former aimed at financing research and supporting individual researchers, and the latter sought to promote and enhance capacity among university teachers. The late 1970s saw the establishment of the first graduate level courses in the country, and CAPES also assumed an important function related to the evaluation and quality control of the postgraduate system.

The Brazilian S&T system grew significantly throughout the 1980s and, in 1985, the Ministry of Science and Technology was created. Today, it sponsors the highest national body for science and technology, the National Council for Science and Technology, an advisory consultative board presided over by the President of Brazil. Also, a related Special Secretary for Policy for Women was created with Ministerial status in 2003, replacing the National Council for the Rights of Women, which

A. Abreu (✉)
Federal University of Rio de Janeiro, Rua Anibal de Mendonça 28 Apto 501,
22410-050 Rio de Janeiro, Brazil
e-mail: alicepabreu@gmail.com

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_10

existed since 1985. The S&T system today is quite strong (Abreu 2010; Cruz and Chaimovich 2010), with the highest investment to gross domestic product ratio in Latin America, a well-funded Ministry of Science Technology and Innovation, and a significant presence on the international scene, ranking 13th worldwide in refereed publications.

Brazil currently has 3,343 graduate programs across scientific areas, of which 1,664 are Ph.D. programs. In 2012 alone, M.Sc. graduates numbered 42,000 and Ph.D. graduates numbered 12,000. Moreover, since 1998, women have represented the majority of M.Sc. graduates and the majority of Ph.D.s since 2004.[7] Available figures show that, in 2008, women accounted for 54% of M.Sc. and 51% of Ph.D. degree attainment.[8] Note that education in federal and state universities in Brazil is free of charges, at both undergraduate and graduate levels. These universities represent approximately 35% of higher education institutions, but incorporate almost the whole research community of Brazil.

The Brazilian capacity building effort has increased and diversified substantially from its starting point in the early 1950s. Between CNPq and CAPES at the federal level and agencies at the state level, several different support mechanisms have been put in place. They have ranged from research funding granted through competitive calls for projects, to a wide range of scholarships and fellowships supporting students and researchers at different points in their careers.

For example, the *Scientific Initiation* scholarships are granted to provide support for undergraduate students to work on projects under the supervision of researchers. The scholarships actually are awarded to the researchers, who then select students to enroll in their projects. Also, masters and doctoral scholarship awards are made through graduate programs; in those programs that have been deemed *centers of excellence*, scholarships are available for all accepted students. Postdoctoral scholarships are granted at the national level. Finally, as a crowning support for the best scientists in the country, CNPq awards Senior Research Fellowships on a highly competitive basis.

The numbers supported by these policy instruments are impressive. Together, CNPq and CAPES granted almost 62,000 scholarships in 2002 and almost 142,000 in 2012, as shown in the table. More impressive, however, is the fact that women have steadily increased their participation. Women were the majority in all award categories in 2012, with the exception of the Senior Researcher Fellowships. (Although still significant, women have never exceeded 35% of fellows at that level over the last 15 years.)

---

[7] In 2004 only Italy, Portugal, and Brazil had a majority of women as Ph.D. graduates (<InternalRef RefID="Par130" >CGEE 2010: 43).

[8] See Box 1 in Frehill et al. (2015).

Brazil scholarships granted by CNPq and CAPES (2002, 2012)

	2002		2012	
Categories	Numbers	% Women	Numbers	% Women
CNPq				
Undergraduate (IC)	18,843	54	36,391	56
M.Sc. (GM)	5,602	52	9,865	53
Ph.D. (GD)	5,743	49	9,362	51
Post doc (PD)	88	39	1,548	57
Senior researcher (PQ)	7,765	32	9,940	35
CAPES				
M.Sc. (GM)	13,054	NA	43,591	NA
Ph.D. (GD)	10,180	NA	27,598	NA
Post Doc (PD)	179	NA	3,663	NA
Total	61,454		141,958	

Sources: CNPq/AEI (2.9.3-sexo_GA_paisext_0112) and CAPES (geocapes 4.10), accessed 2 September 2013

It is clear that the last decade has seen a very significant growth of the S&T system in Brazil, and women have profited from it. The system is now complex and robust, with a steady source of funding involving different types of institutions and organizations. Systematic efforts for capacity building have effectively included women, who are now the majority of university students at all levels. This strong presence of women in university enrollments and in scientific research arguably is related to the fact that the public sector offers free education and that governmental agency scholarship programs are based on a transparent decentralized and merit-based system. Women can compete on an equal basis and have been very successful in doing so.

However, in regard to scientific careers in both education and research areas, it is important to understand the mechanisms of advancement, which keep women as a minority at the higher levels. It is true that the massive entry of women into university and graduate programs is recent, and a few more years are required to determine how this generation of women will fare. The Full Professors of today typically would have had at a minimum 15–20 years of career progression before reaching that position. This would mean looking back to the 1990s, when the participation of women was not as strong as in recent years.

Sex-disaggregated data in S&T databases reveal interesting aspects of the place of women in the Brazilian science and technological system. However, further research is needed to fully understand the social processes that are behind related statistics and to follow the current generation of women scientists to determine whether they will be able to effectively influence the Brazilian scientific structure and to participate fully and occupy the highest positions in the system.

References

Abreu, Alice. 2010. Women for Science in Brazil. *ISA E-Bulletin* 16 (June): 64–89.

CGEE. 2010. *Doutores 2010: estudos da demografia da base técnico-científica brasileira* (Ph.D.s 2010: Study of the Demography of the Brazilian Techno-Scientific Base). Brasilia: Centro de Gestão e Estudos Estratégicos.

Cruz, Carlos Henrique de Brito, and Hernan Chaimovich. 2010. Brazil. In *UNESCO Science Report 2010. The Current Status of Science Around the World*, 103–121. UNESCO, http://www.unesco.org/new/en/natural-sciences/science-technology/prospective-studies/unesco-science-report.

Frehill, Lisa M., Alice Abreu, and Kathrin K. Zippel. 2015. Gender, Science, and Occupational Sex Segregation (Chapter 3). In *Advancing Women in Science*: *An International Perspective*, ed. W. Pearson, Jr., L.M. Frehill, and C.L. McNeely. New York: Springer.

OEI—Organización de los Estados Iberoamericanos y UNESCO SAP. 2004. *Proyecto Iberoamericano de Ciencia*, *Tecnología y Género—GENTEC—UNESCO. Informe comparativo regional e informes nacionales de Argentina*, *Brasil*, *Costa Rica*, *España*, *México*, *Paraguay*, *Uruguay y Venezuela*. OEI and UNESCO SAP, http://api.ning.com/files/3wIypPzztSduT4Q6g5O8DZkdNgudKlow6TrCnNeQq-F-B5AwrJ42Jdwu3rT8RlkhkY5vbmuBO-EZK0Pu0qVZ6cDwbV180bSf/Reporte_FinalGENTEC.pdf

Chapter 11
Postscript

Connie L. McNeely, Lisa M. Frehill, and Willie Pearson, Jr.

This volume is a first step in expanding the dialogue on women in science and technology (S&T) as an international issue, noting that critical challenges remain for understanding the professional lives and contributions of women scientists around the world. Even with expanded degree attainment in some fields, gender disparities in S&T workforce participation and status remain significant and the underrepresentation of women in science has been recognized as a major social, political, and economic issue. While some gains have been made in advancing women in related fields, a great deal of work remains to be done to understand and address fundamental issues attending scientific participation, status, and productivity in terms of gender dynamics and representation. Indeed, the examination of selected disciplines in this volume has helped to underscore the importance of attending to the varied mechanics of scientific workforce capabilities and conditions contingent on the field-specific production of knowledge.

Gender disparities, marked by significant variation in the participation and advancement of women in S&T and related fields, are associated with a range of disciplinary, institutional, and professional environments, in addition to broader social, political, economic, and cultural contextual determinants. Noting such factors, insights from the works in this volume have been considered relative to the

---

C.L. McNeely (✉)
George Mason University, Fairfax, VA, USA
e-mail: cmcneely@gmu.edu

L.M. Frehill
Energetics Technology Center, 10400 O'Donnell Place, Ste 202,
St. Charles, MD 20603, USA
e-mail: lfrehill@etcmd.com; lisa.frehill@gmail.com

W. Pearson, Jr.
Georgia Institute of Technology, Atlanta, GA, USA
e-mail: willie.pearson@hts.gatech.edu

W. Pearson, Jr., et al. (eds.), *Advancing Women in Science: An International Perspective*, DOI 10.1007/978-3-319-08629-3_11

three related analytical strands discussed in the Introduction—*globalization, the social organization of science, and gendered societal relations* reflected in education and occupational sex segregation. Taken together, these strands offer a systemic approach and framework for addressing women as a crucial resource for the development of an innovative and productive S&T workforce. Accordingly, while providing a wide ranging, yet in-depth discussion of pertinent issues, the contributions in the volume can be considered within this analytical framework to identify and examine questions regarding women in science relative to different individual, national, and international conditions. That is, they lead to calls for further research that actively incorporates gender as a dynamic and defining feature of S&T academic and workforce representation and productivity, providing deeper direction on how social, institutional, and cultural contexts affect the participation and advancement of women scientists.

While the focus of much related research has been on outcomes, *understanding and affecting the gender disparities noted here require attention to process, i.e., to the ways in which science is organized, how it is conducted, and where it is located.* Analysis of complex gender processes requires recognition of changing relationships and patterns of interaction over time and place, and addressing such issues in relation to observed disparities requires examination of both internal and external processes and effects, turning on a variety of basic questions. For example, what are comparative trends and causal dynamics in hiring women scientists and in their career trajectories? How does the globalization of science labor markets impact women's participation in science? What kinds of educational and professional outcomes might be expected in light of different socio-cultural and organizational contexts? What kinds of processes and outcomes might be expected given different cultural and institutional identities and organizational, economic, and social contexts? To address such questions, detailed delineations of differentially available opportunities based on societal structures and relations are required, and analyses of societal relations and interaction patterns over time and place are needed to provide a clearer understanding of the processes affecting the advancement of women in science. Moreover, they will help to fill the lacunae in knowledge needed to provide better information and approaches for addressing the underrepresentation and career disparities of women in related fields.

Also, *the development of research networks and collaborative relationships of women with other researchers (in academia, government, and industry) is an important step for fostering female advancement in scientific fields* (as it is for males), with the potential for building professional influence and creating career opportunities. Increasingly, such networks and collaborations include individuals from multiple national and international locations. Thus, various straightforward questions arise. For example, what are the motivations for building, maintaining, or ending collaborative network relations? What impacts do spatial and temporal factors have on such relations? What determines collaboration partner identities? How do scientists access and maintain non-geographically bounded relationships? Collaboration and network construction are iterative processes dependent on the ways in which science is organized. In that vein, questions of network participation, access, and equity also are central concerns relative to the gendered nature of scientific practice and representation. Building scientific capacity depends on increased participation in S&T networks and communities, and further research is needed on how to effect that participation. Such networks and collaborative relationships also can reflect the diffusion and engagement of S&T talent in different parts of the world. Various factors must be considered in delineating such relationships, e.g., societal and institutional cultures, research team capabilities, institutional supports, funding, and location. This means taking gender equality as an integral concern in network and collaboration processes. Accordingly, the social and organizational features of scientific participation and productivity represent important sites for studying conditions for advancing women in related fields and must be considered to determine means for exploring opportunities for female S&T representation and contribution.

Another important issue in practice, policy, and research on women in S&T education and careers is gender mainstreaming. *Gender mainstreaming, especially in terms of research initiatives, assessment programs, and data collection efforts, means prioritizing and integrating gender equity as a central concern on broader political and economic agendas*. Thus, strengthening analytical tools to incorporate gender considerations is fundamental to effecting related practices. In particular, the development and engagement of gender-specific metrics at different levels of aggregation and their broader incorporation in research and policy analysis are crucial for effectively addressing inequities and problems that inhibit the advancement of women scientists. In addition, augmenting data to allow more comprehensive analyses will help to determine and better understand related effects and changes in policies and societal impacts on the participation of women in S&T fields.

In practical terms, a number of tasks arise for further research. These include, for example, exploring and developing varieties of (qualitative and quantitative) indicators for accurate depictions of gender effects on scientific capacities and participation; developing longitudinal datasets for characterizing disciplinary, professional, and contextual dynamics; constructing detailed profiles of networked properties for assessing relevant processes and outcomes and determining educational and professional impacts; determining key spatial and temporal indicators to explore representational distributions and relationships and to conduct comparative analyses of factors conditioned by gender and location over time; and developing gender delineated S&T labor market trends and projections.

Further investigation is clearly needed in terms of contextual dynamics, disciplinary and professional cultures and relations, and other conditions of S&T production. Such issues speak not only of conditions of inclusion and representation more broadly, and not only in terms of resources, but also of rights and societal well-being. In addition, the issues delineated here can be modified for use within and across disciplinary structures and cultural settings for a finer grained understanding of determinant processes, and comparative analyses can be conducted to better understand when, where, why, and how some initiatives and policy efforts have similar or different outcomes and effects for different groups and individuals. Due to varying social dynamics attending relevant processes in different countries and cultural contexts, other dimensions of social identity and stratification (e.g., race, ethnicity, age, and disability) also are critical considerations for understanding intersectional determinants and effects on scientific participation by marginalized groups.

Gender equity is a fundamental requisite for building scientific capacity in the world today, and growing demands for S&T researchers means looking for ways to develop, incorporate, and/or modify policies and programs supporting broader participation in these fields, with much of the emphasis on women as a large yet often marginalized group. To that end, *increasing the participation and status of women in science requires an action orientation*. That is, S&T gender imbalances and inequalities are here framed as actionable issues, with policies and programs aimed at effecting change across academia, government, and industry. A wide range of issues have been invoked in the discussions in this volume, suggesting a varied research agenda encompassing matters such as professional opportunities and trajectories, disciplinary fields and access, institutional affiliations and structures, and socio-cultural relations and practices, all of which affect the position of women in science. Even in fields with high representations of women, gender is still an important social force that shapes the productive relations within science, with implications for innovative processes. Unpacking the complex dimensions and layers associated with different stakeholders and interests, here defined particularly in gendered terms, is key to understanding social interactions and structures both within and across science fields and the larger role of science in society today and in the future.