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Mathematical Institutions and the "In" of the Association for Women in Mathematics

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Abstract
From its founding, the Association for Women in Mathematics paid special attention to the difference made by specific prepositions, and the associated nouns and verbs they bring into play. This chapter focuses on the AWM's second preposition, and what it means to be "in" mathematics. Women have been doing mathematics—learning, teaching, creating, enjoying, applying, and more—for as long as there has been mathematics. Yet they have only sometimes in this history been doing so from *within*, as recognized and validated participants in mathematics as an organized collective endeavor. This chapter examines some of the history of women in mathematics and of women being tacitly or explicitly kept out of mathematics, mostly from before the AWM's founding. It shows the importance of the institutional history of mathematics for understanding the history of women's participation in and exclusion from the discipline and the significance of the AWM in light of this history.

Key words: institutions, organizations, gatekeepers, publishing, gender, training, recognition, Fields Medal

Introduction

To understand the connections between the people, institutions, and ideas of the history of mathematics, subtle differences in wording can make all the difference. From its founding, the Association for Women in Mathematics paid special attention to the difference made by specific prepositions, and the associated nouns and verbs they bring into play. An important early decision was to adopt the preposition "for" in the association's name, marking the AWM's mission as advocating for women, as opposed to the emphasis with "of" on the identities of the association's members (see Gray 1971b, p. 1).

This article focuses on the AWM's second preposition, and what it means to be "in" mathematics. As the AWM's founders recognized, there is a great difference between *doing* mathematics and *being in* mathematics. Women have been doing mathematics—learning, teaching, creating, enjoying, applying, and more—for as long as there has been mathematics. Yet they have only sometimes in this history been doing so from *within*, as recognized and validated participants in mathematics as an organized collective endeavor. Understanding the history and implications of the "in" of the AWM sheds light as well on the "for" in its name, and the significance of advocacy and recognition in mathematical institutions.

While doing mathematics can in principle be a rather solitary pursuit, being in mathematics is a thoroughly shared condition, dependent on the combined work and initiative of many. From its start, the AWM has focused on training, career opportunities, representation, recognition, and related aspects of mathematics as an organized profession. This is because, in its modern incarnation, these institutional matters have defined the boundaries of mathematics as something *to be in* and not just something *to do*.

The margins of institutional mathematics have historically been capacious places for women's participation. Women have produced and shared mathematics as theorists, translators, educators, students, posers and solvers of puzzles, reckoners, calculators, and more. They have contributed non-mathematically to others' doing mathematics as advocates, funders, organizers, administrators, publishers, communicators, supporters, and more. Ruling these activities as outside of mathematics, maintaining their marginalization, has required constant renegotiations of mathematics and its institutions. Being *in* mathematics is a function of what one does, where one does it, how others regard that work, and how that work relates to the identity of the person doing it. Being out of mathematics can involve any of these aspects, and the history of mathematics' margins reflects negotiation and contestation over each of them.

This article examines some of the history of women in mathematics and of women being tacitly or explicitly kept out of mathematics, moving from the European origins of modern mathematical institutions to the American contexts that more immediately set the stage for the AWM. This account shows the importance of the institutional history of mathematics for understanding the history of women's participation in and exclusion from the discipline. Institutions and institution-making have central places in the history and sociology of science and scholarship as forces determining who can participate in knowledge work (e.g. Berman 2012, Shapin 2008). These same institutions and records of institution-making are vital sources of evidence for understanding this history and sociology (Barany 2020). Feminist histories of science and scholarship have paid special attention to how institutions define legitimate producers of knowledge and the kind of knowledge they can produce (Niskanen and Barany 2021, Pereira 2017). To understand the conditions and importance of the AWM, famous individuals from the history of women and mathematics must be considered alongside the structures, cultures, assumptions, and social relations of modern mathematics that determined who would be in and who would be out.

Making and Breaking the Margins

Certain kinds of mathematical training and activity have been means of social division and exclusion for most of the known history of mathematics, as well as the history of social division. Prehistoric artifacts contain evidence of numeracy in the form of tallies, but few indications about either mathematical or social organization. In the earliest cities and multi-city societies, numbers and accounts were among the first purposes for systematic writing and record-keeping. Though mathematics may not have been identifiable as a coherent and separate kind of knowledge in the oldest historical sources, these clearly show numeracy and geometry as activities connected to social ordering in ancient societies (Robson 2008, ch. 2). From marketplaces and households to temples, courthouses, and other settings, early mathematical practices were sources of economic, political, religious, judicial, and other forms of authority. These settings and practices were often reserved for men, but Robson (2008) identifies several examples of evidence of women wielding numerical and metrological expertise in ancient Mesopotamia between 2500 and 4000 years ago.

For most of its history, mathematics has been a part of social groups, places, and activities that have excluded and divided. As a form of technical and philosophical expertise learned from and shared among others, mathematics has contributed to such divisions and distinctions. For tradespeople who shared calculation tricks or philosophical elites who exchanged puzzles and proofs, mathematics helped to define specific spheres of social, economic, and cultural interaction. Here, doing mathematics was one of many things that a community of people did together as a distinct community. Sometimes mathematics has been an explicit criterion of entry or participation, though examples like Plato's legendary requirement that pupils know geometry seem more the exception than the rule. Sometimes particular mathematical activities have required access to places and resources—royal courts, libraries, printing apparatus—conventionally limited by criteria that had little intrinsically to do with mathematics and much to do with identity and privilege.

Barriers and opportunities defined by the social contexts of doing mathematics set the terms for a relatively late development in the history of mathematics, the possibility of being *in* mathematics as an institution in its own right.[1] Being in mathematics required mathematics to be organized as a distinct sphere of social and intellectual activity, such that doing mathematics could underwrite its own recognizable social role and identity. This possibility emerged gradually in the early modern period, as identities such as geometer or mathematician grew out of older ones like philosopher, astrologer, and scholar. These identities solidified in spaces for mathematics carved from associated social formations concentrated especially around publishing, patronage, and elite realms of governance and culture. Importantly, these roles represented a small fraction of all the walks of life that involved doing mathematics, marking off particular areas where doing mathematics and recognizing others doing mathematics could in themselves be a source of money and prestige.

The intersection of publishing and elite culture created both limitations and opportunities for women's participation in emerging mathematical institutions. Three prominent examples from the first half of the eighteenth century illustrate some of the institutional stakes of women's contributions to textbooks, treatises, translations, and periodicals that established common culture, consensus, and spaces of mathematical debate and identity formation. They also show that women's presumptive exclusion from later mathematical institutions was in important respects a departure from some relevant antecedents.

Established in England in 1704, the *Ladies' Diary* quickly became a leading venue for mathematics ranging from clever puzzles to challenging subjects of current debate and research. While in many respects reinforcing contemporary gendered status distinctions, the periodical embedded mathematics in a space marked for women where both women and men could engage in mathematical conversation (Costa 2002). Italian *filosofessa* Maria Gaetana Agnesi honed her mathematics as an element of cultural attainment among Milan's social elite. She presented her 1748 calculus book, enthusiastically embraced across Europe, as an index of women's potential contributions "to the sublimities of a science" and "the glory of their sex" (Mazzotti 2007, 2018). Also in 1748, in France, Émilie du Châtelet completed her translation and commentary of Newton's *Principia*. Published posthumously in 1759, this significant mathematical and philosophical work derived from Châtelet's extended immersion in exclusive social and scientific settings in Enlightenment Paris (Terrall 1995).

In each of these examples, women from privileged social contexts participated as women in the kinds of activities of creating, sharing, and evaluating mathematics that made up new mathematical identities and institutions. Each did so, however, on terms set by male gatekeepers: editors, publishers, and academicians who retained the privilege of adjudicating participation in mathematics through their control of economic and social institutions with more rigid gendered barriers to participation. These gatekeepers facilitated or denied opportunities within broader contexts of norms and expectations that defined how women could participate in scholarship. Where women were more often seen as legitimate spectators or appreciators rather than originators of knowledge, they found room within expository and didactic genres to frame new ideas in suitably modest and receptive terms (see Terrall 1995, p. 293). When interlocutors praised or criticized these women's mathematics, they did so in gendered terms, making their work stand for the virtues or limitations of all women (see Terrall 1995, pp. 294-296; Mazzotti 2018). This marked their contributions and identities as exceptional or marginal and exposed them to reevaluation amidst shifting social understandings and prejudices.

[1] Robson and Stedall's (2009) handbook puts these social contexts and conditions in the center of approaches to the history of mathematics, including the presence of mathematics in and beyond formal institutions. A distinctive recent discussion from a mathematician's perspective is Harris (2015, pt. 1).

Such social shifts in elite cultural and intellectual spaces across Europe in the latter half of the eighteenth century changed the status of both women and mathematics. Scientific academies developed over that century into rarefied manifestations of the prestige and power of their official patrons. The men who drew stipends, adjudicated prizes, and filled these academies' official functions rallied to the methods of rational mechanics, the technically demanding application of infinitesimal calculus to physical phenomena. For the savants of the French Académie des Sciences, rational mechanics marked the intellectual boundary between sober, serious, masculine science and the naive, speculative, metaphysical, feminine reasoning of the unlettered masses (Terrall 1999). Partial exceptions to this pattern, such as the elite mathematical activity of Mary Somerville, reflected their own highly gendered conditions of possibility and perception (Stenhouse 2021). Where Châtelet could occupy a boundary position involving substantial engagement with and contribution to elite scientific debates, later women were systematically shut out or hemmed in by suppositions about fundamental differences between masculine and feminine thought (Terrall 1999, 257-260), a pattern repeated in elite scientific spaces across Europe.

Training and Constraining

At the turn of the nineteenth century, the prolonged military conflict of the Napoleonic wars and new approaches to government and civil service that centered the expertise of engineers expanded the field of mathematical professionals in exclusively male domains. Mathematics became the foundation of training and work in engineering professions whose professionals occupied social roles and functions of power and prestige reserved to men. In the context of world history, Western Europe was relatively late to technically intensive training and examinations for civil service as a gendered and classed means of creating civil elites that reinforced social biases and inequalities. These were, for example, defining features of Chinese imperial governance for centuries, dating back at least as far as the early Tang dynasty (618-907 CE) and being continually revised and debated in view of changing social, economic, and institutional contexts (Elman 2013).

The French apotheosis of this model was the École Polytechnique, founded in the wake of the French Revolution. Its professors came from the Paris scientific elite and its students, all cadets of the French military, were trained in a rigorous mathematical regime that seeded subsequent generations of scientists and engineers in service to the French state (Belhoste et al. 1994). Using technologies new to advanced scientific education, most notably the blackboard, the École Polytechnique massively expanded the number of technically adept practitioners of modern mathematical methods, training them in male military settings and launching them to careers in male realms of state employment. Many institutions, notably the United States Military Academy at West Point (Phillips 2015), followed suit, making elite engineering education the province of particular men in particular positions of national and military service in many parts of the world.

In England, an intensified mathematical training for an expanded technical elite took place largely outside of explicitly military contexts, in the nearly-as-exclusively male walled-in colleges of Cambridge University (Warwick 2003). Prejudiced suppositions about women's minds and bodies and the connections between the rigors of mental and physical exertion justified regimes of training that shut women out and lavished on vigorous young men the attention and opportunities necessary to master and make a career from intricate technical mathematics (Warwick 1998, Winter 1998). Across these settings, the place of mathematics as a component of or outgrowth of other institutions of socialization, training, certification, and endeavor meant that those other institutions set the basic terms for participation in mathematics. An all-male military academy or an all-male Cambridge college was not just a place to do mathematics with an arbitrary gender barrier attached: the cultures, practices, and infrastructures of each space were built around certain assumed homogeneities and created distinct obstacles for those who did not fit their assumptions.

Consequently, when women engaged the masculinized institutions of nineteenth century mathematics, they had to do so almost always as outsiders and exceptions. In the early years of the École Polytechnique, Sophie Germain learned mathematics in the private spaces of her family library and then deployed a pseudonym and the veil of postal correspondence to access lessons and correspondence from the military institution's decorated instructors. As she built a mathematical reputation she was eventually able to set the pseudonym aside and engage openly in mathematical discussions with famous interlocutors, but as a woman she continued to be denied the kind of systematic training and access to privileged scholarly settings that would allow more than peripheral participation in most aspects of organized mathematics in and beyond France. Where she was able to participate, she was dependent on the discretion and exceptions of conventionally empowered men.

Half a century later, the career of Sofia Kovalevskaya recapitulated many aspects of Germain's. She developed an interest and proved her talent for mathematics in domestic settings. Winning the support of established mathematical men, she was able to pursue studies and research from the margins of the German university system, navigating repeated formal barriers to ordinary channels of participation. Sustained accomplishments in the limited areas of professional mathematics open to her helped overcome formal opposition and tacit barriers to her eventual appointment to a more conventional professional mathematical role in Stockholm, as part of a new academic institution whose gatekeepers—including mathematician Gösta Mittag-Leffler—could sidestep the many traditional barriers to women's formal professional attainment.

In the latter part of the nineteenth century, the first Cambridge women's colleges created settings for women students to attempt the university's demanding mathematics training. Compensating for limited training opportunities prior to university and at the university itself, women students at Cambridge proved themselves just as capable as men in competitive mathematics examinations but continued to be accorded marginal status in the systems to which those examinations were meant to be a gateway (Jones 2009).[2] The men who set the examinations, adjudicated regulations, ran Cambridge's interconnected network of social and academic organizations, shaped perceptions through media and public debate, and otherwise held the institutional center at and around the university made space for including and even celebrating exceptional women while reinforcing a norm of women as marginal. Their influence was felt in the cultural expectations and value systems surrounding mathematical training and examinations. When women began to succeed according to previously valorized standards, such as skill and speed at complex technical calculation, those values shifted perceptibly to preserve male primacy, emphasizing other aspects of achievement where women's achievements could be more easily minimized or set aside (Rankin 2016).

On the Continent, the education and career of Emmy Noether reflected women's continued marginalization at the end of the nineteenth century in expanded systems of training and advancement built for and designed around men and their traditional institutions. Noether had privileged access to mathematics and to academic training from her family, and excelled in a number of fields in school. She was able to specialize in mathematics within the German university system, though not without complication. Her meteoric accomplishments as a mathematician, collaborator, and mentor led to significant recognition but did not obviate numerous barriers and restrictions on women's careers in mathematical academia, importantly including limitations on Noether's ability to earn a living from her mathematical vocation. Intellectual contributions of indubitable importance offered partial ground for Noether to be an exception within male institutions, and her exceptional status followed her throughout her career.

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[2] Jones (2009) focuses her study of women and mathematics in late nineteenth and early twentieth century Cambridge on Grace Chisholm Young (1868-1944), a formidable mathematician whose granddaughter Sylvia Wiegand became the AWM's thirteenth president. See Wiegand's article in this volume.

Exceptions and Expectations

The story of women mathematicians through the nineteenth century is often told through exceptional figures like those discussed above, in part because the predominant institutions of mathematics made exceptions of any visible women. Expanded and diversified settings for mathematical training and careers from the late nineteenth century into the twentieth made space for women to be in mathematics without necessarily being repeatedly defined and marked as exceptions, as their forebears had been. Green and LaDuke's (2009) prosopography of American women mathematics PhD holders from before 1940 underscores the variety of training and career paths, some exceptional and some normal (if often peripheral), that came with new opportunities for women in higher education. These, in turn, responded to changing social expectations for women, including possibilities for employment in professions associated with advanced training—mainly teaching but also publishing, administration, and technical fields (Green and LaDuke 2009, ch. 6).

Such prosopographical approaches—studying women mathematicians, scientists, and engineers by assembling bits and pieces of information available about many individuals to develop a picture of their common experiences and contexts—have offered a crucial counterpoint to historical understandings based on the exceptional figures who found fame and left a deeper paper trail. They complement, as well, statistical and demographic analyses and comparisons that give an aggregated view of participation in mathematics and science (e.g. Chipman and Thomas 1987). Because the documents and records historians typically use to write histories are typically created, collected, and preserved in the very institutions that have made women marginal and exceptional, finding the normal and common experiences of women connected to these institutions can demand meticulous and resourceful efforts to unearth and reconsider the available evidence. Margaret Rossiter's groundbreaking studies of women scientists in America, published between 1982 and 2012, have been a vital model and foundation for work situating women mathematicians in broader institutional, social, and other conditions that were designed around particular sorts of men. More recently, Margot Lee Shetterly (2016) used related methods of group biography to surface a generally overlooked community of Black mathematical professionals in the United States space program.

The flipside to methods that compile the often subtle or indirect traces of women's experiences in mathematical institutions is to use those masses of records to examine how institutions set expectations and created obstacles or opportunities for all, to understand how these produced different conditions for different would-be mathematicians. As formal rules explicitly limiting women's training and employment in mathematics faded in the twentieth century, other rules and expectations maintained entrenched inequalities. Some of these operated (and continue to operate) comparatively directly. For example, the AWM has consistently pointed to the unequal effects of anti-nepotism policies on women married to fellow academics, with obstacles deriving from how a superficially gender-neutral policy sits within the heavily gendered conditions of family relationships, mobility, and career advancement. Julia Robinson famously achieved many milestones of a decorated mathematical career, including election to the National Academy of Sciences, before holding a mainline faculty appointment (see Lamb 2019).

Other rules enforcing gender bias could be just as explicit without being officially formalized. Hilda Geiringer was an accomplished applied mathematician by the time she arrived in the United States as a refugee of World War II, and like her near-contemporary Emmy Noether found that she would only be seriously considered for employment in women's colleges, rather than research institutes or universities that would readily hire men of comparable research attainments (McNeill 2019). When Geiringer proposed in 1950 to bring her successful general education course in mathematics to Harvard, the Mathematics Department there found it inconceivable that a woman could be an appropriate teacher for a class of male freshmen.[3] While women could in principle teach in colleges and universities with predominantly- or all-male student bodies, in practice those who would hire them had to be able to picture them in such a role.

For those seeking to establish themselves in the mathematics profession, gendered expectations about career prospects became self-fulfilling, justifying channeling funding and opportunities to privileged and mobile young men (Barany 2021). Philanthropic organizations that took an interest in mathematics starting in the 1920s saw the field as a venue for international cooperation and common culture. Employing a logic of investment borrowed from the industries whose wealth funded new large-scale philanthropies, funders sought to direct resources to future leaders who would extend the value of a fellowship or project grant beyond the period of initial funding. Looking for future leaders often amounted to looking for younger versions of current leaders, entrenching standards and biases by channeling advantages to the already-advantaged.

Reflecting a set of principles developed over the preceding decades, a mid-century Rockefeller Foundation guide to identifying fellowship recipients advised setting a higher bar for women candidates due to the risk of their marrying and leaving the field, which would limit the long-term impact of the fellowship (see Barany 2018b, 2019). Such suppositions and the guidelines they enforced were not based in empirical reviews of scientific careers or any systematic attempt to understand the factors that made for successful investments, even by the funders' own standards. Foundation officers took for granted that women would be poor investments and were not challenged in these assumptions by the men surrounding them.

This kind of thinking meant that a broader increase in educational and career opportunities for aspiring mathematicians did not necessarily translate into more opportunities for women, especially in elite sections of the discipline being remolded around new funding for travel, publication, electronic computing, and other resource-intensive activity. Wider pipelines came with more direct competition for funding, admission, and advancement. Military and government funders that joined philanthropies as major non-academic mathematics sponsors after World War 2 adopted many of the values and expectations that philanthropies and universities used to identify good investments (Barany 2016). These assumptions extended from elites to support for rank-and-file mathematical training that linked government funding to national defense using terms like the "manpower problem" to define the financial and institutional needs of postwar mathematical sciences. The typically male decision-makers directing resources had strong incentives to support those poised to thrive in a sexist world, whether or not their own personal biases supported that state of affairs.

Filed Away

When women did play major roles in mathematical institutions, their gender affected how they and others understood their contributions. One of the most important shapers of mid-twentieth century mathematics was Mina Rees, who held a 1931 PhD from the University of Chicago and made full use of her mathematical training and experience to allocate resources and match projects to experts in support of mathematical research on the wartime Applied Mathematics Panel and through the postwar Office of Naval Research (see Shell-Gellasch 2011, Barany 2017). Formally, however, her role was as an administrator rather than a mathematician, so the considerable mathematical knowledge and skill she brought to her work were not credited as mathematical. Despite having a greater effect on mathematical research than most card-carrying mathematicians of the time she came not to see herself as a research mathematician (e.g. Rees 1979, p. 16).

[3] Geiringer-Ahlfors-Birkhoff correspondence, April-May 1950, Harvard University Mathematics Department Archives, box 15, folder "G". Co-educational arrangements between Harvard and Radcliffe meant that in practice Geiringer's prospective classroom may not have been exclusively male, despite Harvard's gender exclusivity.

The experience of Rees, herself also a significant player in the history of computing, reflects what historians of computing have examined and explained in detail (e.g. Abbate 2012). With some significant exceptions, women have been vital contributors to technically and intellectually challenging mathematical work insofar as their contributions could be seen as essentially secretarial or administrative. In settings where programming and engineering computers were seen as more prestigious and demanding, and compensated accordingly, employers replaced women with men, paying the men more and according them higher status for comparable work. Racism and sexism have historically worked together to devalue and obscure mathematical work by devalued and obscured members of society (see e.g. Hottinger 2016, Shetterly 2016; cf. Hersh and John-Steiner 2010).

Seeing women's work as essentially secretarial and, conversely, seeing secretarial work as essentially women's, were both early-twentieth century developments in corporate settings with lasting effects on mid-century and later mathematics (see Strom 1992, Kwolek-Folland 1994). In academic organizations, "secretary" remained a prestigious institutional role associated with august academic societies (often male-dominated—the American Mathematical Society did not have a woman as secretary until 2013) while acquiring new associations with lower-status functional and infrastructural work by women. These dual associations complicated what it meant for women mathematicians to take on positions as secretary in mathematical organizations, even in the more prestigious traditionally male form that would be seen as respectable if held by a man. As Mary Gray quipped in the second *AWM Newsletter,* in 1971, "One easy thing for women to do to improve their image is to refuse to serve as secretary of anything" (Gray 1971b, p. 2).

The devalued title of secretary when held by women was of a piece with the gendered bifurcation of labor in mathematics departments over the twentieth century, a split that remains visible in many departments today. The letters, reports, and other communications essential to the operations of both research and organizational activities in twentieth-century mathematical institutions depended on the complex skilled labor of uncounted women who were not mathematicians like Rees, but without whom mathematical work could not take place (cf. Webster 1996). As secretary for the mathematics faculty at the Institute for Advanced Study from 1933 to 1950, to take one especially accomplished example, Gwen Blake worked in multiple languages to manage mathematical and professional activities for a highly active group of full-time faculty and a large number of visitors. Her work included managing visa and housing arrangements, dealing with public inquiries, and producing and organizing high volumes of correspondence for committees of the American Mathematical Society and the 1950 International Congress of Mathematicians (along with its would-be 1940 predecessor, canceled due to war) on which IAS mathematicians served.[4] Because much of Blake's work circulated under the signatures of the famous mathematicians for whom she worked, her crucial contributions to the transformations of American and international mathematical institutions before and after World War II were not widely recognized in her time, nor have they been broadly credited since.

Blake did not have advanced mathematical training, though the expertise her job required can be seen in the training of her successor, Caroline Underwood, who came to the post with a masters degree in library science.[5] Many who worked to make mathematical institutions possible from roles that hid their contributions did so with substantial background in the field. Mina Rees wielded an unusual degree of institutional authority, even as the importance of her mathematical acumen was minimized. Women with undergraduate, masters, or sometimes higher training in mathematics filled

[4] Blake's work must typically be read between the lines of correspondence in the IAS Archives and the personal papers of mathematicians with whom she worked. See also Records of the Comptroller, Institute for Advanced Study Archives, box 1, folder 17.
[5] "Underwood, Caroline May 27, 2010," interview by Linda Arntzenius, Oral History Project files and recordings, Box 10, IAS Archives.

technically challenging roles for scientific presses and associated organizations, who needed employees with the mathematical skill to compose and correct technical and scholarly publications and reaped a substantial hidden subsidy from the career barriers that kept women with such training out of more prestigious and better paid positions in other industries. Caroline Seely, a familiar name to historians who work with the American Mathematical Society archives, held a PhD in mathematics and was the first full-time mathematician employee of the AMS, working in a secretarial and editorial role while remaining active as a researcher (Green and LaDuke 2009, pp. 73, 286).

From 1971 to 1972, a short-lived Berkeley mathematics department newsletter, *Mother Functor*, mixed discussions of women's hiring in faculty positions with reports from secretaries on the department's work environment and an anonymous note on the alienating experience of women graduate students.[6] The newsletter, with its deliberately provocative title (issue 3 included a note suggesting that the title exhibited male chauvinism), reflected a precipitous political moment in and beyond mathematics that also gave rise to the AWM. While the AWM has focused primarily on the women in mathematics as students, researchers, and professionals, the connections between working conditions, sexism, and women's careers in and around mathematics more broadly have remained a perennial concern. Viewed through the history of mathematical institutions, women—often with advanced mathematical expertise—have been essential participants in the work of mathematics in much greater numbers and to much greater effect than one might conclude by focusing solely on those professionally regarded as mathematicians. Persistent inequities in status, resources, and much else have made this participation a complex consideration in the history of women *in* mathematics, affecting the perception and opportunities for women in many different roles.

A Near Miss

If administrative and infrastructural workers represent the easily-overlooked supporting stratum of scientific institutions, their opposite in the history of scientific institutions are the celebrated recipients of major prizes. The former hold the institutions together and make their operations possible, while the latter represent the institutions' values and aspirations both internally and to the wider world. The Fields Medal began in 1936 as a way for mathematicians to promote an international consensus around promising contributors to the discipline (Barany 2018a). The medal's profile got a rapid boost from a confluence of events in 1966 that resulted in its comparison to the Nobel Prize, initially as political cover for an activist mathematician who drew criticism for dodging a U.S. House Un-American Activities Committee subpoena to accept an award in Moscow, the site of that year's International Congress of Mathematicians (Barany 2015). The medal eventually became one of the most recognizable markers of excellence in mathematics both within and beyond the world of mathematicians. It was until 2014 an exclusively male award, awarded before 2006 by exclusively male committees.[7]

In the inaugural *AWM Newsletter*, Mary Gray (1971a, p. 6) signaled the importance of "great women mathematicians" as role models and standard-bearers to counter mistaken beliefs about women's relative potential and contributions. "Young women in mathematics," Gray urged, "need to be encouraged to think of themselves as potential Fields medal winners." Historians and sociologists of science are familiar with the tendency of recognition to build on recognition, with those thriving in systems built for them able to convert initial successes into further accomplishments and credit, while those disadvantaged by prevailing systems miss out on

[6] I accessed *Mother Functor* in carton 3, folders 5-6 of the Stephen Smale papers, BANC Mss 99/373, The Bancroft Library, University of California, Berkeley. Copies are also archived separately in the Bancroft and Mathematics/Statistics libraries at Berkeley.
[7] A list of winners and committee members is available at the International Mathematical Union's website.

recognition and the further opportunities that come with it (Rossiter 1993). This makes prizes a precarious target for addressing bias in a discipline: while awards tend to reaffirm and reinforce the privilege of those already privileged, they can also be powerful means of redirecting values, attention, and resources in new directions.

Post-1966 views of the Fields Medal grew out of perceptions of the small number of pre-1966 recipients, comparatively young men with tight connections to elite mathematical institutions. A majority had close links to prominent centers in Paris or Princeton. They rose through those connections, with the help of prizes like the Fields Medal, to prominent positions in the discipline. When the prize suddenly became more prominent in and beyond mathematics in 1966, it was easy to look backward and see a trail of accomplished men who set a pattern for the award's future status and expectations. So it is important to understand the contingency of that initial group and the factors that made those specific men into the Fields Medal's and in some respects the mathematics discipline's models. Because the early career pathways for mid-twentieth century mathematics were designed around a certain profile of young male mathematicians (Barany 2021), there was plenty of room for variation and accommodation in the lives of those who fit the mold for them to nonetheless receive recognitions that in retrospect can look like predestination. For those outside the institutional core, near misses can reverberate with lasting consequences. It was overdetermined but not at all inevitable that the early mold for the Fields Medal would be cast exclusively around men.

In 1958, the history of the Fields Medal and of expectations of and institutional support for women in mathematics almost changed decisively, but for a small number of near misses. That year, Soviet mathematician Olga Ladyzhenskaya was nominated for a Fields Medal by Kurt Friedrichs and advanced to the shortlist on the forceful advocacy of Andrey Kolmogoroff.[8] Ladyzhenskaya was already becoming internationally known among leading researchers in partial differential equations, and would be part of the Soviet delegation that made a standout impression at the 1958 International Congress of Mathematicians in Edinburgh (Friedlander et al 2004). Navigating obstacles of gender and social position to work on the forefront of Soviet mathematical analysis, by 1957 she had published striking and significant results. However, delays and limits on communication across the Iron Curtain meant that Kolmogoroff's intervention arrived after the committee had started to narrow its consideration around other candidates. Though Ladyzhenskaya was placed on the shortlist, committee members lacked easy access to the publications that excited her advocates. Her candidacy stalled because, as the committee chair Heinz Hopf put it, "important as her achievements may be, only very few of us know enough about them and now very little time is left to form a judgment" (Hopf to committee, 5 March 1958).

Ladyzhenskaya's near miss is, in one sense, a story about a rising star of mathematics whose recognition as such was delayed and diminished by accidents of circumstance. The fact of her gender did not appear explicitly in the committee's discussions. Her gender is nonetheless vital to understanding how her personal circumstances resulted in a near miss, producing just enough effect on the timing of her career, her recognition in and beyond the Soviet Union, the capacity of those who did not know her to extend the benefit of doubt, and other factors that in the decisive moment left her just outside the committee's final selection. Just a little extra advantage, whether being on the other side of the Iron Curtain, being able to publish earlier in Western journals, being able to advance more rapidly through training and career opportunities in the Soviet Union, or even having an advocate in Kolmogoroff able to communicate just a little more rapidly with the rest of the committee, could have turned the tide. Not all of these disadvantages came from her gender, but her gender made all of these disadvantages potentially decisive.

[8] My account of Ladyzhenskaya's candidacy is based on the "Fields Medal Committee 1958" folder in box 3 of the Oscar Zariski Correspondence, Papers of Oscar Zariski, Harvard University Archives HUGFP 69.10, Cambridge, MA. See Barany 2018a.

In another sense, Ladyzhenskaya's near miss is a story of missed chances for generations of women to see themselves in the Fields Medal template. Mary Gray's charge in the early years of the AWM could have looked very different with even one woman Fields Medalist to whom to point. In yet another sense, this is a story about how norms and assumptions about male mathematical careers keep opportunities open for some men while demanding formidable feats of skill and fortune for all others. Each of these views of Ladyzhenskaya's story reflects part of what it means for women to be in mathematics, and how that belonging can be contingent, conditional, and precarious.

Seeing Women in Mathematics

Institutions work by coordinating and compounding. They turn people learning and doing mathematics into members of a discipline that sustains and supports mathematical training and careers. They define what success means and channel resources to help those bound for success to attain it. They make visible people and models and ideals and values, and convert that visibility into patterns and pathways for the institution's future. From among all the people involved in producing and sharing mathematics, organized mathematical institutions determine who gets to be *in* mathematics and on what terms, who can thrive in systems designed to create particular kinds of mathematicians and particular kinds of mathematics.

An important thread in the activities of the Association for Women in Mathematics has been using the AWM's institutional wherewithal and partnering with others to convert the visibility of individuals into new opportunities and expectations for participation in mathematics. Anchored to famous individual names from the past, recurring events including the Noether Lectures (since 1980) and Kovalevsky Days (since 1987) shift emphases of who and what mattered in the past while building the kinds of institutional networks and pathways that can change norms and experiences for new and old participants in the discipline. Recurring and stand-alone events and initiatives linked to famous names alike reflect the fundamental connection between ideals and expectations in mathematics and the personal and organizational relationships and infrastructures that bring those ideals and expectations into the world.

In some respects Maryam Mirzakhani's 2014 Fields Medal is a counterpoint to Ladyzhenskaya's experience. By 2014, enough women were sufficiently integrated into the major institutions of mathematics that although major prizes and opportunities still went (and continue to go) predominantly to men there were multiple women who were plausible medalists, numerous women at later career stages to prove women could thrive in the discipline's elite, and even a woman as chair of the committee to select the medalists. These changes, the result of persistent advocacy and action around mathematical institutions, meant that yet another possible near miss in one iconic corner of the discipline was not missed after all.

Following her Fields Medal, and again with renewed vigor after her death in 2017, Mirzakhani's story became a major rallying point for promoting and celebrating women in mathematics. Commemorations of her life and ideas were a centerpiece and a focus of external messaging in the first World Meeting for Women in Mathematics in Rio de Janeiro in 2018. Participants in that meeting launched the annual May12 Initiative, now coordinated by a number of organizations for women in mathematics (including the AWM), to celebrate women in mathematics on Mirzakhani's birthday. The 2018 $(WM)^2$ meeting coincided with an International Congress of Mathematicians that returned to an all-male slate of Fields Medalists, where men continued to occupy the bulk of the most visible positions across the program. The institutional conditions of participation and visibility determine both what is normal and what is exceptional, and both norms and exceptions can be obstinately durable.

Mirzakhani broke through as an exceptional mathematician winning a famous prize. Her story reframes how we understand the complex dynamics of both exceptional and less exceptional participation in the discipline. Mirzakhani's biography reflects both how conventional pathways toward elite mathematical careers have become vastly more open to women and how those same pathways continue to place unequal demands on mathematicians on the basis of gender. In these respects, Mirzakhani was perhaps more an echo than a counterpoint to Ladyzhenskaya. Both thrived in settings that accommodated them but were not built with them in mind, both could be normal participants at some times but had to be exceptions at others.

Individuals like Ladyzhenskaya and Mirzakhani do not make norms, expectations, and exceptions; institutions do. The history of the Association for Women in Mathematics, with its focus on women's visibility, representation, and opportunities across many institutional spaces in mathematics, reflects the enduring significance and persistent challenges of institutional awareness and transformation. So long as mathematics persists as an institutionalized discipline, its history will depend on how institutions define who is within, and how they learn to see the meanings and consequences of different conditions of belonging.

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