Cambridge University Press
978-0-521-82605-1 - Gender Differences in Mathematics: An Integrative Psychological Approach
Edited by Ann M. Gallagher and James C. Kaufman
Excerpt
More information

1

Research on the Women and Mathematics Issue

A Personal Case History

Susan F. Chipman

The history of research on the issue of women's participation in mathematics provides an interesting case study of the psychology and sociology of research in the social sciences. Although there had been prior research on the topic, two key works of the early and mid-1970s sparked a major burst of interest. They were Lucy Sell's unpublished study of women at the University of California at Berkeley (Sells, 1973), "High school mathematics as the critical factor in the job market," and Sheila Tobias's publications on math anxiety (Tobias, 1976, 1978), the first of them an article in *MS* magazine in 1976. The study of mathematics, or the failure to study mathematics, came to be seen as a critical barrier to women's participation in a wide range of high-status and remunerative occupations during those surging years of the women's movement. Based on a random sample of freshmen entering Berkeley in 1972, Sells (1973) reported that only 8% of the females had taken four years of high school mathematics, whereas 57% of the men had. This report received a lot of attention.

The U.S. National Institute of Education (NIE) responded with plans for a special grants competition addressing this perceived problem. Background preparations for this competition were exceptionally thorough. Three review papers were commissioned to examine existing research results and opinions concerning major classes of possible influences on women's choices to study mathematics or to select occupations requiring mathematical competence: Fennema (1977) reviewed cognitive, affective, and educational influences; Fox (1977) reviewed social influences; and Sherman (1977) reviewed possible biological explanations. These papers were presented at a large, 2-day-long working conference in Washington, DC, that brought together many people concerned with the mathematics education of women, in February 1977. A grants announcement was issued (NIE, 1977). The research grants were intended to provide "a better knowledge base for designing effective educational programs to encourage women to enroll in mathematics beyond the minimal school requirements." An important underlying assumption was expressed in the opening statement describing the research requested by the announcement, "Women's lower enrollment in the study of advanced mathematics precludes them from entering a variety of occupations requiring mathematical competence."

The grants competition was sponsored by an organizational unit called the Career Awareness Division of the Education and Work Group of the NIE. By the time the research projects were completed, there had been a major reorganization of the NIE. I found myself responsible for this research program, and for a planned publication to pull the research results together, because they had been grouped with all other research on mathematics learning, in a division on Learning and Development that I was chosen to direct. The planned summary publication for the research program was to include chapters by each supported researcher as well as a research synthesis. Although my earlier involvement in the grants competition had been somewhat peripheral – I had attended the working conference and had served as a reviewer of grant proposals – I chose to take on the job of synthesizing the research myself, rather than contracting it out, as originally planned (Chipman, Brush, & Wilson, 1985; Chipman & Thomas, 1985; Chipman & Wilson, 1985). At the NIE, we were continuing to receive more grants proposals on the topic of women (or girls) and mathematics than on all other topics in mathematics education combined. This seemed disproportionate. Mathematics education was not, and still is not, a well-researched area. Many problems concerning more effective ways to teach mathematics had not been addressed. It was part of my job responsibility to define and set research priorities.

In this chapter, I discuss how I have come to understand the women and mathematics issue since the late 1970s, in all its many dimensions. I have revisited the issue many times (Chipman, 1994; Chipman, 1996a, 1996b), sometimes also considering related issues such as participation in fields of science and technology and the participation of minorities, with separate consideration of minority women (Chipman & Thomas, 1987). In addition to these review efforts, I have pursued some research into specific aspects of the issue: possible test bias (Chipman, 1988b; Chipman, Marshall, & Scott, 1991) and the impact of mathematics anxiety on choice of major field and career (Chipman, Krantz, & Silver, 1992, 1995).

As I began the task of synthesizing the set of research grants on women and mathematics, it seemed logical to first define the problem. It was then that I noticed a significant omission in the preparation for the grants competition – there had been no commissioned paper on the demographic facts of the problem. As the language of the grants announcement made clear, everyone involved was thoroughly convinced that the problem existed and that it was serious.

Very quickly, my planned research synthesis chapter turned into two chapters, a first chapter that outlined the demographic facts of the problem

(Chipman & Thomas, 1985) and a chapter attempting to synthesize the findings of the research grants (Chipman & Wilson, 1985). I soon uncovered a major surprise: mathematics has been the least sex-typed of college majors! By that, I mean that the representation of women among math majors has been as close to their representation among all recipients of Bachelor of Arts (BA) degrees as one can find for any field of study. This fact immediately casts doubt on the idea that mathematics is a particularly problematic field for women. It was revealed by a readily available and complete data set, the statistics on earned degrees conferred in the United States that have been maintained by the National Center for Education Statistics (NCES) since at least the 1949–1950 academic year. In that academic year, 24% of all BA degrees went to women and nearly 23% of BA degrees in mathematics went to women. In the 1976–1977 academic year, the last year for which statistics were available when I did these analyses, 46% of BA degrees were awarded to women and 42% of the BA degrees in mathematics. In publications over the years, I have periodically updated these figures. My latest update appears in Table 1.1. Note that women's share of the degrees awarded remains high at the BA level (although lagging their recent majority status among BA recipients) and has continued to climb at the level of graduate degrees. In the early 1980s, I concluded that if there was any problem concerning women's participation in the study of mathematics, it seemed to be at the level of continuation to the doctoral degree and that some self-examination of university math departments might be warranted. Despite some improvement, this conclusion still seems valid. Women's level of participation in the study of mathematics itself has been much higher than their level of participation in other fields that are seen as math-related, requiring mathematical competence, such as engineering, computer science, and physics. Thus, it hardly seems plausible that

TABLE 1.1. *Percent of Degrees Awarded to Women*

	BA – All	**Math BA**	**MA – All**	**Math MA**	**PhD – All**	**Math PhD**
1950	24	23				
1960	35	27				
1970	43	37				
1975	45	42	45	33	22	10
1980	49	42	49	36	30	13
1985	51	46	50	35	34	15
1990	53	46	53	40	36	18
2000	57	47	58	45	44	25

Source: The primary source of these data is the Series of Earned Degrees Conferred, National Center for Education Statistics. Data 1950–1970, as cited in Chipman & Thomas (1985). Data 1975–1990, as cited in National Science Board, *Science and Engineering Indicators – 1993*, Appendix Tables 2-19, 2-25, and 2-27, pp. 272–285. Data for 2000 from *Digest of Education Statistics* (2001), http://nces.ed.gov/pubs2002/digest2001/tables/.

aversion to mathematics is or was functioning as an important barrier to women's participation in those fields. Perhaps the explanation should be sought elsewhere.

No such complete data were maintained concerning the study of mathematics at the high school level. However, at the time of my synthesis effort, I was able to find a number of large representative data sets. One of the grants had been to Armstrong (1985) for a National Assessment of Educational Progress (NAEP) survey of women and mathematics that was conducted in 1978, taking a nationally representative sample of 1,700 twelfth-grade students. Thirty-one percent of the males and 27% of the females had taken some variant of the usual 4-year high school mathematics sequence. Similarly, the 1979 report of the College Entrance Examination Board (CEEB; Educational Testing Service [ETS], 1979) stated that 64% of males and 45% of females expected to have completed four years or more of high school mathematics. Of course, individuals taking the SAT are not a random sample of all students, but they constitute a large fraction of students going on to college. More than 900,000 individuals were covered by that 1979 report.

These data did indicate a sex difference in the study of high school mathematics, especially in the study of advanced courses such as calculus or optional courses beyond the standard college preparatory track: those courses tended to be about 60% male in participation. However, these differences were not nearly so extreme as most people believed or as Sells (1973) had reported. About 40% of those who were approaching college with 4 years of mathematics preparation were women and about 40% of women were entering college well prepared in mathematics, having taken the standard 4 years of high school mathematics. (For more details, see Chipman & Thomas, 1985.)

There were also older data sets that could have better informed the research planning. The National Longitudinal Sample of persons who were twelfth graders in 1972 showed that about 39% of the males and 22% of the females had taken 4 years of high school mathematics. Farther back, the 1960 Project TALENT sample showed that 33% of the boys and only 9% of the girls were taking four years of mathematics. Even so, it would have been difficult to argue that mathematics was functioning as a barrier to entry into math-related careers because only 3% of the girls were planning to go into math-related careers. Clearly, too, a significant change had occurred between 1960 and 1972: the percentage of girls studying 4 years of high school mathematics had more than doubled. The successive CEEB reports from 1973 to 1979 also showed a slow increase in female participation in the study of advanced high school mathematics. It seems that a process of change was well underway by the time the grants competition was initiated. One wonders how the research would have been different if these facts had been recognized at the time. Why weren't these facts recognized? Why weren't such analyses done in preparation for the grants competition?

Perhaps it was that the decision-makers and the lobbyists for the research harkened back to their own school experience in the 1960s, 1950s, and before and remembered that few girls had been studying advanced mathematics in those days or perhaps remembered that they themselves had not chosen to study mathematics. Although an analysis of the dimensions of the "problem" seemed like a mundane, standard thing to do when starting the research synthesis effort, perhaps I asked the question because I myself had majored in mathematics in college and had attended a high school in suburban Chicago where many girls had studied advanced mathematics in the early 1960s. A large social change in expectations for women's lives occurred during those years; undoubtedly some women found themselves hampered by the educational choices they had made when expecting to lead very different lives. Analyses of the Project TALENT data (Wise, 1985) showed that the choice to study advanced mathematics in high school in 1960 was predicted by a girl's expectation of going on to college and pursuing a career of some sort. In later years, many more girls would have such expectations. Correspondingly, it seems that by the time the 1998 High School Transcript Study was done, sex differences in high school math course participation had disappeared, or even shifted to favor females. Even calculus was shown as being taken by 11.2% of males and 10.6% of females; Advanced Placement (AP) calculus by 7.3% of males and 6.4% of females (NCES, 2001).

In summary, by the time the brouhaha concerning the mathematics preparation of young women was raised, the "problem" had already diminished significantly, and that trend has continued until the present time. Sells's highly publicized and influential data were unrepresentative of the national situation at the time; perhaps her sample size was too small or perhaps the University of California was atypical. Furthermore, the bare facts, as well as some of the analyses done in the studies that provided the facts, cast doubt on the assumptions that were held about the causal relations between the study of high school mathematics and entry into fields seen as "math-related." It might be that the intention to go into a math-related field, or even the mere intention to attend college, "causes" the study of advanced high school mathematics, rather than vice versa.

Despite what these facts show, it is obvious that the belief that there is a large "women and mathematics problem" persists today. One constantly reads of efforts to "solve" it by offering single-sex math classes and the like.

INVESTIGATING THE DETERMINANTS OF MATH COURSE ENROLLMENT AND ACHIEVEMENT

The primary focus of the research grants that NIE awarded was on understanding the factors determining enrollments and achievement in advanced high school mathematics. Beyond that, the emphasis was on examining variables that might plausibly explain sex differences in math course enrollments. A consequence of that concern was a relative neglect of cognitive variables in the research that was done. Despite the widespread belief that there are sex differences in some inherent ability to learn and do mathematics, a topic to be discussed later in this section, it was already known in 1977 that sex differences in mathematical ability and/or achievement at the beginning of high school were negligible and, therefore, had little promise of explaining the differences in enrollment or choice of occupational field. Measures of spatial ability were well represented in the research, but measures of general intellectual ability, or prior mathematics ability and/or achievement, were not. Affective measures of attitudes related to mathematics, mathematics study, mathematics teachers, and so on, were well represented. As with demographic facts, the effort to synthesize the results of the research studies brought out shortcomings in the way the research studies had been designed to address the question of determinants of course enrollment. The grant to analyze previously collected, nationally representative Project TALENT data (Wise, 1985) revealed that the strongest correlates or predictors of individual differences in advanced mathematics course enrollment were measures of cognitive ability, mathematics ability, or even verbal ability at the beginning of high school, although these measures did not serve to explain the sex differences in enrollment that were still large at that time. The sex differences in enrollment then present did, however, tend to account for the sex differences in mathematics achievement that were measured at the end of high school. This agreed with Fennema's (1974) earlier report that sex differences in math course-taking had an important role in explaining what had tended to be interpreted as sex differences in inherent mathematical ability. Project TALENT was not designed to examine decisions to enroll in advanced mathematics and science or the sex differences in those decisions. Consequently, it did not include measures of attitudes toward mathematics, and did not provide an opportunity to assess the relative explanatory contributions of cognitive and affective variables. This proved to be a problem for the research program as a whole.

The nature of this problem was evident even within the cognitive realm. As mentioned above, the best-represented cognitive variables in this research were various measures of spatial ability. It was believed that there were sex differences in spatial ability and that spatial ability was important to mathematics. Intuitively, the capacity to mentally rotate, translate, and transform objects appears to be important in mathematical thinking, at least in geometry. Fennema (1977) reported on opinions from the mathematical community that support this point of view.

There is a tendency to think that measures of ability have a stronger theoretical, scientific basis than they actually do. Ability testing and the definition of abilities has been a pragmatic and empirical technology.

Performance is sampled within a domain of tasks or situations, in a way limited by the practical constraints on testing. Statistical techniques, usually factor analysis, are used to identify tasks that "go together," have something in common, and those that seem to be independent of each other. The hypothetical "something" in common is called a factor, and may sometimes be labeled an ability, although the technical psychometric use of the term *ability* does not always carry with it all the implications of the popular meaning of *ability*. For instance, a psychometric *ability* sometimes consists entirely of learned knowledge. In the history of cognitive testing, it has been found that all intellectual performances have something in common: that is, persons who do well or poorly on one intellectual task also tend to do well or poorly on other, quite different intellectual tasks. This common factor has been called general intelligence or "g." Some relatively recent research is beginning to show the way to a deeper theory about the nature of general ability. For example, Carpenter, Just, and Shell (1990) showed, by constructing computational models of cognitive processes in solving Raven Progressive Matrices items, and by converging evidence from another task, that individual differences in performance on this well-accepted measure of general intelligence are largely accounted for by individual differences in the number of problem-solving goals that can be managed in working memory. Intuitively, this characterization of general intelligence also sounds much like the essence of mathematical ability, as distinct from learned mathematical knowledge.

Many different tasks, which can be performed with diverse mental strategies, have been called tests of spatial abilities. Various tests of so-called spatial abilities do not necessarily have high correlations with each other, as contrasted with their correlations with other kinds of tasks (Lohman, 1979; McGee, 1979). There is no single, unitary spatial ability that these tests are measuring. Lohman (1979, 1988, 1996) concluded that a considerable proportion of performance on spatial tests, especially complex spatial tests, is explained by variation in measures of general intelligence, what all tests of intellectual performance have in common. One of the surprises of the effort to synthesize the results of the NIE grants (Chipman & Wilson, 1985) was that the studies including measures of spatial ability did not provide any strong evidence for sex differences in spatial abilities, despite a previous review concluding that this was a reliable cognitive sex difference (Maccoby & Jacklin, 1974). The nationally representative and relatively large Armstrong (1979) study even reported a statistically significant advantage for 13-year-old females on 15 items taken from the Paper Form Board test. These unexpected results might be due to the tests used (most often the DAT Spatial Relations test, which requires the examinee to select the three-dimensional (3-D) shape that will be formed by folding a two-dimensional (2-D) shape along indicated fold lines), or due to changes over time affecting the experiential influence on "ability" measures, or due to relatively small sample sizes in many of the studies. Psychometric studies have often had huge sample sizes that make almost any observed difference statistically significant, even though it may be too small to be considered practically significant. At the time, the research studies that had shown substantial sex differences in a spatial ability (Sanders, Soares, & D'Aquila, 1982; Vandenberg & Kuse, 1979) used a test involving the rotation of objects in three-dimensional space. Indeed, a formal and thorough meta-analysis of the research on sex differences in spatial abilities done independently at about the same time (Linn & Petersen, 1985) concluded that sex differences are found primarily on that type of measure and not on the other types of measures of spatial ability. Although that review has been cited more than 400 times in the intervening years, none of the citing articles is a later review or meta-analysis that would change this picture.

Despite these results undermining the notion that putative sex differences in spatial ability might explain putative sex differences in math enrollments or achievement, it is probably worth mentioning that the evidence for a specific contribution of spatial ability to mathematics performance, distinct from the contribution of general intelligence, is surprisingly weak. Smith (1964) and Werdelin (1961) are two of the most frequently cited references on this point, but neither of them actually provides strong evidence for a relationship between spatial ability and mathematics performance. Several reviewers of the literature have concluded that no such relationship has been shown (Fruchter, 1954; Very, 1967; even for geometry: Werdelin, 1961; Lim, 1963). Fennema & Sherman (1977, 1978) and Sherman (1980) did report that the DAT Spatial Relations test shows a correlation of about 0.50 between the DAT score and general tests of mathematical achievement in a high school population enrolled in college preparatory mathematics courses. However, the DAT is the type of spatial ability test that Lohman (1979) characterized as being similar to measures of general intelligence, and Fennema and Sherman do not provide any evidence for a specific unique contribution of spatial ability either. In the larger and more broadly representative Project TALENT sample, there were two measures of spatial ability, Visualization in 2-D and Visualization in 3-D, but they were not among the variables having a correlation of 0.20 or higher with mathematics achievement (Wise, Steel, & MacDonald, 1979). One of the NIE studies that emphasized spatial ability provided an intriguing pattern of results. Stallings (1985) used the DAT and course-specific tests of mathematics. The pattern of correlations she found for the different types of mathematics is quite consistent with what one might expect: algebra I (0.49), geometry (0.53), algebra II (0.15), trigonometry (0.38), analytic geometry (0.68), and calculus (0.20). Unfortunately, the design of her study did not include a measure of general intelligence or even one of verbal ability, so it, too, cannot provide evidence of a unique contribution of spatial ability to performance in any of these mathematical fields, despite a suggestion of some promise for analytic geometry and geometry. This seems to have been an opportunity missed because of the intense focus on possible explanations for sex differences. In contrast to the general lack of evidence of a contribution of specifically spatial abilities to mathematics performance, there is such evidence for predictions of success in courses such as mechanical drawing and shop (McGee, 1979).

Within the mathematical community, there is a long-standing distinction between algebraists and geometers. Perhaps this is grounded in a difference in their reliance on spatial thinking, but both types are counted as mathematicians. There is more than one way to do mathematics. The need to do mental rotation in depth (apparently the primary locus of sex differences in spatial ability) probably does not arise all that often. Furthermore, very advanced mathematics often deals with N dimensions, not just 3. Heavy reliance on spatial thinking can prove a barrier in moving on to N dimensions.

affective variables

In addition to spatial ability, the NIE studies emphasized the possible role of affective variables in determining course enrollments and mathematics achievement. Fennema and Sherman (1976) developed a thorough and extensive set of attitude scales, but two variables have received the most extensive exploration: liking for mathematics and mathematics anxiety/confidence. Although these variables seem closely related conceptually and have a strong correlation with each other (0.60–0.65), they behave rather differently with respect to sex differences (Chipman & Wilson, 1985). Consistently, there is no sex difference in liking for mathematics. Thus, it may not be surprising, after all, that women have been so well represented among math majors. In contrast, there is an equally consistent sex difference in mathematics anxiety/confidence (Hyde, Fennema, Ryan, Frost, & Hopp, 1990). Although Fennema and Sherman (1977) attempted to construct separate scales for anxiety and for confidence, the two scales were found to have a correlation of −0.89 with each other, so they can be considered to have been measuring the same thing. It is not entirely clear what to make of the small mean sex differences that are observed. Because no one seems to have published the full *distributions* of male and female scores, it is not clear, for example, whether serious mathematics anxiety is more common among females than among males. It might be that, for social reasons, females are less willing to express high confidence in themselves as learners of mathematics, even if they in fact have such high confidence. The interpretation of these attitudinal variables is not entirely straightforward. The questionnaires that measure these variables are fallible yardsticks. Some people will use extreme values on the scales; others will not. The expression of true opinions may be tempered by the person's impression of what is a socially acceptable answer. Expressions of very high confidence in mathematical ability may be more socially acceptable in males than in females. Admissions of weakness, anxiety, or distress may be less socially acceptable for males. We can never be certain that the apparent sex differences in these subjective variables reflect genuine differences in the characteristic the scale purports to measure. Nevertheless, sex differences in mathematics anxiety/confidence showed some potential to explain sex differences in enrollment.

Another important affective variable is the perceived utility of mathematics study and of the resulting mathematical knowledge. Looking over the historical changes in girls' and women's study of high school mathematics, participation in higher education, and participation in the workforce over the past 50 years, it seems likely that the primary driver of change lay in this area. Among the NIE grant studies (see Chipman & Wilson, 1985, for details), the general perceived usefulness of mathematics was moderately related to enrollments, while more specific perceptions of mathematical requirements for a planned job or career or aspirations for higher education had a somewhat stronger relationship to enrollments or enrollment intentions. Wise (1985) reported that sex differences in career interests in the Project TALENT sample from the early 1960s predicted math course enrollments, preceded differences in achievement, and probably could explain the sex differences in enrollment and achievement that then prevailed. As discussed earlier, by 1998–2000, sex differences in high school mathematics enrollment had virtually disappeared and women had become the majority among BA recipients. Yet, sex differences in participation in the so-called math-related fields, engineering (23% female in 2000), physics (22% female in 2000), and computer science (28% female in 2000) remain substantial (NCES, 2001). Other sciences such as biology (58% female in 2000) and chemistry (46% female in 2000) now have an excellent representation of women. The once male-dominated fields of medicine (6% female in 1960; 43% in 2000) and law (2.5% female in 1960; 46% in 2000) changed radically between 1960, the year that Project TALENT began, and 2000. For many women, the primary utility of math study in high school may be in meeting the requirements for admission to the college of their choice rather than the inherent requirements of their occupational choice.

Thus, the historical evidence strongly suggests that the utility of mathematics study for girls and women was an important factor in changing rates of participation in advanced high school mathematics courses. However, one of the frustrations in summing up the results of the NIE math grants and similar research done at that time was the difficulty in performing analyses that would shed light on the relative importance of various cognitive, affective, and other variables in predicting mathematics enrollments, intentions to enroll, and mathematics achievement. Not surprisingly, earlier mathematics achievement, confidence in oneself as a learner of mathematics, and