Women's Participation in Physics Higher Education: The Leaky Pipeline Revisited*

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Abstract

This paper provides quantitative evidence that the 'pipeline' model for increasing women's participation in physics is flawed. Using NSF data on Bachelor and PhD award rates for men and women for the years 1973-1998, cohorts are simulated to allow for comparison of male and female retention rates in physics and several comparable disciplines. We find that although women now enter and stay in physics at higher rates than in the past, their retention rates consistently lag behind men's. We see similar patterns of retention in the physical sciences, mathematics, and computer science even as retention to the doctorate improves, it improves more for men than it does for women. This pattern means that gender parity will be unlikely because greater numbers of women than men would need to receive the Bachelor's degree, or more women than men would need to enter the pipeline from other disciplines in order to have equal numbers of women and men receive the PhD in physics.

Introduction

Physics stands out among the physical sciences for failing to attract a substantial proportion of women into its academic ranks. Indeed, physics lags behind most scientific and professional fields in terms of participation by women.

> "[L]arge numbers of women receive M.D.'s, law degrees, and engineering degrees. These male-dominated fields require (to varying degrees) familiarity with technical equipment, commitment to long hours, mathematical and analytical skills, just as physics does. Yet, physics picked up only a handful of women compared to these fields" (Ivie and Stowe 2000: 5-6).

Despite having requirements similar to other fields, physics has not shown similarly large increases in women's participation, especially at the top levels of the profession. The first International Conference on Women in Physics held in 2002 by the International Union of Pure and Applied Physics (IUPAP) sought to address this issue and "to understand the severe under-representation of women worldwide and to develop strategies to increase their participation in physics," (Hartline 2002). More than 300 physicists from 65 countries participated and produced eight resolutions for an organized effort to fully include women as equal partners in leadership roles and in policy making.

In this paper, we explore the pipeline model for increasing women's representation in physics. The pipeline model predicts that women will reach the highest levels of the physics profession in due course, as their increased numbers at the entry to the 'pipeline' in primary school and secondary school progress through the profession. However, we will show that leaks in the pipeline affect outcomes.

The Pipeline Model

Many efforts have been dedicated to improving women's employment in the academy following changes in the civil rights laws in the early 1970's (Kellough 1990). Intervention programs have been designed based on the Pipeline Model (Schiebinger 1999), which proposes to increase the number of women interested in science by building a steady supply of young women "flowing" into the pipeline. The expectation is that filling the entrance of the pipeline will eventually improve the overall number of women in the academy as a substantial number of women "propagate" all the way up to the top echelons of the academic career.

Support for the effectiveness of this reasonably impermeable pipeline comes from the Statistical Research Center of the American Institute of Physics. Their study, "Women in Physics, 2000" (Ivie and Stowe, 2000), identifies many positive changes in women's participation in physics. Among these changes:

1. By 1997, almost half of all high school physics students were female
2. 20 of the physics departments in the United States (excluding women's colleges) that responded to AIP surveys had more than 40% women among their bachelor's degree recipients in the 1994-1998 period
3. Salary differences between males and females at equivalent levels of physics are largely non-existent (see, however, discussion in Valian 1998).
4. Most importantly, women's participation in all levels of physics has increased significantly since the early 1970's.

Although the AIP study also finds that women's proportional participation decreases at each increasing level of academic rank (see Figure 1 and Table 1) and at each increasing level of institution (see Table 1), Ivie and Stowe argue that time must be taken into account when measuring the achievement of professional status by women.

> "Considering the number of women receiving their PhDs in the past, women are not underrepresented on physics faculty. This conclusion is based on a 1998 survey of male and female members of AIP's Member Societies. Full professors who identified themselves as physicists received their PhDs an average of 29 years before the survey date. At that time, just 3% of PhDs in physics were awarded to women. Therefore, women's representation among full professors of physics is about what we would expect. When we look at other ranks, women's representation is better than we might expect," (Ivie and Stowe 2000: 9).

Allowing sufficient time lag for achieving the professional level suggests that there are no major leaks in the pipeline once students have earned their undergraduate degree. From this perspective, efforts to improve female representation should be focused at the entry point. Little, if anything, more needs to be done at the university level; the field of physics need only wait until the new influx of women has made its way through the pipeline and female representation will improve.

Figure 1 about here

Table 1 about here

However, the rate of increase of women at the top echelons of the academic science career is still very slow, or almost static, especially in physics (Valian 1998). Despite 30 years of effective early intervention programs, there is still a tremendous disproportion of women to men in physics. In 1998, women held only 17% of assistant professor positions, 10% of associate professor positions, and 3% of full professor positions (Ivie and Stowe 1999). Figure 1 illustrates this continuous drop in the number of women at almost every level of the academic ladder in physics.

The research that we report here shows that tertiary education is still a major leakage point for women in the physics pipeline. The leakage becomes apparent when observing that retention of undergraduate physics majors into graduate school has improved more for men than it has for women. Current graduation rates at the bachelor's and doctoral levels demonstrate that retention rates for female physicists continue to lag behind those of men, and behind retention rates of women in other scientific disciplines.

Our findings have important implications for collegiate and graduate physics education. Preserving the increase in female participation achieved by efforts at earlier points in the progression toward a career in physics requires that universities act to stem the flow of women out of physics.

Methods

This project examines the leaky pipeline thesis, which asserts that women leave the field of physics at higher rates than men at several points along the professional path. To explore the validity of this claim, we analyze and compare retention rates from the bachelor's to the doctoral level for men and women. Data from the National Science Foundation's (NSF) WebCASPAR dataset[1] provide the number of bachelor's and doctoral degrees given in specific fields, including physics, for each year. We use these data to compare physics to other fields, particularly in terms of the proportion of women at each educational level. Of particular interest is the comparison to other physical science disciplines, such as astronomy and chemistry, as well as the comparison to the fields of mathematics and computer science. All of these fields have historically had little formal participation by women, and all of them have made deliberate efforts in recent decades to increase women's participation. Mathematics is included because it serves as a gateway for other scientific and technical disciplines—students with inadequate mathematical backgrounds are not able to succeed in Physics. Computer science is included because like physics, it requires a strong math foundation, and like many areas of physics, it involves working with a machine. In fact, when computer science was establishing itself as a discipline, many professionals crossed over from physics into CS.

The data are also used to study changes in the retention rates of women over time. We estimate retention rates by comparing a particular class of bachelor's degree recipients to the doctoral recipients seven years later. Seven years is the average time-to-degree for doctoral students in physics[2], so the proportion of women receiving a bachelor's degree in 1973 is compared to the proportion receiving a PhD in 1980. These data approximate retention rates for each class. In the absence of true cohort information—data that follow a specific group of students through the bachelor's and doctoral levels—this estimation is an effective method for studying gendered retention in physics education. The retention rates obtained from these snapshots can then be compared with snapshots from other years, to identify and compare improvements in retention for men and women.

Results

We observed a number of findings about the discipline of physics in general, and about women's participation in physics education specifically. These findings are discussed below. Major findings are listed in bold and explained using observations from the data analysis.

The number of students in the field of physics remained relatively constant from 1973 through 1998. The field of physics has not grown during the period of study, at either the undergraduate or graduate levels. The number of students receiving bachelor's degrees in physics varied from just under 3500 to just under 4500 (Figure 2). The number dropped in the late 70s, then began to increase and reached a peak in the late 80s that was comparable to its position in 1973, and then began another decline through the 90s. Overall, the number of bachelor's recipients averaged in the high 3000s. This stability is also true for the physical sciences[3] generally, where the number of bachelor's degree recipients remained around 15,000 per year.

Figure 2 about here

Figure 3 about here

For recipients of the PhD, the pattern is similar, but with less pronounced rises and falls (Figure 3). In detail, the number of PhD recipients overall averaged in the low 1000s; it declined in the late 70s and early 80s, reaching as low as 830 in 1980, and then rose as high as 1465 in 1994, before becoming rather stable at around 1400.

Figure 4 about here

Figure 5 about here

The gender composition of physics students is increasingly female. Women received only 7.33% of bachelor's degrees in physics in 1973. That number rose steadily to 19.28% in 1998 (see Figure 4). At the doctoral level, women's representation grew from only 3.81% of PhD recipients in 1973, to 13.64% in 1998 (see Figure 5). This is a growth of 163% at the bachelor's level and 258% at the doctoral level. The increase in the proportion of women in physics is likely due, at least in part, to very deliberate efforts by the educational system to increase the exposure of young girls to the sciences, and additional efforts to keep women interested in physics through high school and college. According to Neuschatz and McFarling (1999; see also Ivie and Stowe 2000), the proportion of women among those enrolled in high school physics increased from 39% in 1987, to 47% in 1997. This change at the high school level is important because women's participation in physics at later stages is significantly influenced by their early exposure to the field. According the American Institute of Physics report "Women Physicists Speak" (Ivie et al. 2002) nearly a third of the practicing female physicists who were interviewed indicated that their teachers encouraged and influenced their choice of physics as a career.

Figure 6 about here

Figure 7 about here

Women participate in physics education at lower rates than in comparable disciplines—including not only the other disciplines of the physical sciences (chemistry, astronomy, 'other physical science'), but also computer science and mathematics. However, participation in physics has grown at higher rates than in CS or math. Although women make up a higher proportion of the field of physics than they did in the past, their representation is significantly less in physics than in the other disciplines of the physical sciences (see Figures 6 and 7). The proportion of women receiving the bachelor's degree in physics in 1998 lagged behind that of astronomy by 15 percentage points, behind the category 'other physical sciences' by nearly 20 percentage points, and behind chemistry by over 25 percentage points. At the PhD level, women's proportion of degree recipients in physics lags behind that of astronomy by nearly ten percentage points, and behind both chemistry and 'other physical sciences' by nearly 20 percentage points. The proportional discrepancy between physics and the other disciplines of the physical sciences, at both the bachelor's and the doctoral levels, actually increases during the years of this analysis, even as women's proportional representation has increased in all of these disciplines.

Figure 8 about here

Figure 9 about here

Comparing physics to fields outside of the physical sciences, such as computer science and math, also reveals that physics lags in its recruitment of women in tertiary education (see Figures 8 and 9). At the bachelor's level in 1998, women's proportional representation lagged behind that of CS by nearly 8 percentage points, and behind that of math by nearly 28 percentage points. The difference between women's representation in math and physics is consistent throughout the period of study (1973-1998), while the difference between CS and physics varies during the period due to a large fluctuation in the field of CS.

Table 2 about here

Despite lagging behind CS and math in terms of the proportion of women's representation, physics has shown more *growth* in women's proportion of degree recipients than either computer science or math (see Table 2). Women constituted 13.64% of the doctoral physics class in 1998—a growth of 258% since 1973. In contrast, the proportion of women in computer science grew by 113%, and in math by 170%. However, to put these numbers in context, keep in mind that the proportion of women in physics in 1973 was much lower than in the other disciplines: just 3.81% in physics, compared to 7.65% in computer science and 9.55% in math.

Figure 10 about here

Retention of physics students through graduate school has increased. Retention in physics is defined as continuation from the bachelor's degree through the PhD. The data set used for this report does not permit tracking the same cohort. Instead, we simulate a cohort by comparing snapshots of graduation numbers at two points in time, lagged to allow for the normal progression from one degree to another. Because only a small minority of American citizens attends graduate school, retention rates are low in all fields (see Lovitts 2000). Figure 10 shows the retention rates for physics, astronomy, chemistry, and 'other physical sciences' for the period 1973-1998. The retention rate for physics rose steadily during this period, although it flattened out in the late 1990s.

Figure 11 about here

Female retention still lags behind male retention. Figure 11 compares male and female retention rates to the overall rate for the discipline. At the start of the period —for the cohort receiving a bachelor's degree in 1973 and a PhD in 1980—male and female retention rates were roughly equal. But the retention rates diverged thereafter, as retention improved more for men than for women. After the gap of nearly 5 percentage points was attained for the 1981 PhD cohort, the gap fluctuated but showed no overall increasing or decreasing trend. This divergence is striking when one considers that during this period many educational policy makers were specifically focusing on improving women's representation in academic disciplines. For the cohort receiving their PhD's in 1998, women's retention lagged behind men's by just over 5 percentage points.

The difference may seem small, but it has important consequences for the gender composition of the field of physics. Because the retention of women lags behind the retention of men, the already small proportion of women preparing for careers in physics decreases between the bachelor's and doctoral levels. An insufficient retention rate for women in physics leads to a large, persistent gap between the numbers of men and women Ph.D. recipients.

Figure 12 about here

Figure 13 about here

As long as retention rates remain higher for men than for women, the physics pipeline has a gendered leak. That is, women leave physics after the bachelor's degree at higher rates than men. When we formulate the ratio of female retention in physics to male retention in physics, and then compare this ratio to those of the other disciplines in the physical sciences (Figure 12), two patterns emerge. First, we find that in chemistry, like physics, the ratio actually went down near the start of the period of analysis and has since shown no consistent trend towards improvement. Second, we find that astronomy and 'other physical sciences' have erratic patterns, where the ratio surpasses 100% at some times, and drops below 40% at others, with no consistent trend whatsoever.

Turning from the physical sciences to compare physics to mathematics and computer science—again using the ratio of female retention to male retention—we find that physics consistently retains more of its female students than either of these other disciplines (Figure 13). The pattern over time for CS is, however, similar to that for physics. As in physics, the ratio for CS dropped swiftly from a rather high percentage at the start of the period (over 70%, as compared to over 100% for physics), and then never showed signs of increasing again. In contrast, the ratio for math began quite low (just over 20%) and has shown only a slight upward trend, approaching 30% by the end of the period.

Discussion

We find that while the number of students has remained relatively constant during the period of analysis, the female proportion of these students has increased significantly. However, In comparison to the other fields of the physical sciences, and to computer science and mathematics, women participate at lower rates. The growth rate of women's proportion in physics is large and, if held constant, may eventually make physics comparable to these other fields. But equity in physics will be difficult to achieve so long as the retention of women from the bachelor's to the PhD lags behind that of men.

Great strides have been made to increase women's participation in physics. The consequence of these efforts is that women received 13.64% of PhDs in 1998, as compared to only 3.81% in 1973. That is a significant improvement that reflects efforts to increase women's access to physics education at the earliest levels. The data suggest that women's participation at the educational and professional levels will continue to rise in the coming years.

Despite this finding, the research presented here suggests that, based on the current workings of the physics pipeline, women's proportion of bachelor's degree recipients would have to exceed that of men in order for their proportion of PhD recipients to be equal. The pipeline leaks for men and women, but for women more than men. If the pipeline in physics had no disproportionate leak for women, then there would be no discrepancy between male and female retention rates, regardless of each gender's proportion of the field. The proportion of bachelor's recipients is an issue of recruitment into the pipeline, whereas the proportion of PhD recipients is an issue of retention through the pipeline. If the leaky pipeline was under repair-that is, if the attrition of women was decreasing-then the discrepancy in retention would decrease over time. Instead, the discrepancy is consistent for all cohorts finishing a PhD in 1981 or later. So long as the retention of women lags behind that of men, female representation will not be equitable because female bachelor's recipients in physics will always be less likely than their male colleagues to continue on for the PhD.

What does the comparison to other disciplines show us? First, we must examine the particularly inconsistent patterns found in both astronomy and 'other physical sciences'. These erratic patterns are likely explained the relatively low number of students in these disciplines. Astronomy awarded only 97 PhD's in 1973 and just 117 in 1998. 'Other physical sciences' awarded 209 PhD's in 1973 and a mere 46 in 1998. By comparison, the numbers in physics are much higher. Physics awarded 1338 PhD's in 1973 and 1393 in 1998. The numbers in chemistry and math are similar to those for physics. In computer science, the numbers were low at the start of the period—196 PhD's awarded in 1973—but comparable to physics at the end of the period—858 PhD's awarded in 1998.

Once we eliminate the disciplines with consistently low numbers of students from the analysis, an important pattern emerges. Generally, the gap between male and female retention does not improve. When the gap does change, it usually grows. In other words, when retention improves, it improves more for men than for women. So we have a pattern across at least four disciplines—physics, chemistry, mathematics, and computer science—in which the retention gap either grows or stays level in a period that saw much attention given to the under-representation of women. As a result, we have to recognize that efforts to improve women's participation in these disciplines have focused too heavily on recruitment, and not paid enough attention to the issue of retaining women from the bachelor's to the PhD. Meanwhile, efforts to improve retention in physics overall have had greater success with men than with women.

Alternative Recruitment Models

To demonstrate whether alternative models could speed up the process towards a more equitable representation of men and women in physics, we have envisaged a few scenarios where women's retention is improved. These scenarios are summarized in Figures 14 and 15. Figure 14 considers a female retention level of 100% between the bachelor's and doctoral levels. This assumes that the total retention rate is fixed by a number of external factors. The percentage of PhDs that would be awarded to women is then determined by the ratio of the percentage of bachelor's degrees awarded to women in a given year over the retention rate of those women to the PhD seven years later. With a retention rate of 100%, the percentage of female PhD recipients clearly improves dramatically (triangles in Figure 14a) and it almost reaches equity in 1998. Figure 14 also shows a more realistic model in which both male and female retention rates are kept equal to the total values shown. In this case, the number of female PhD recipients (open circles in Figure 14) is equivalent to the total retention rate. Figure 14 also shows two distinct possible ways of obtaining the PhD percentages corresponding to the 100% female retention rate in Figure 14a: 1) we calculate the increase in the total retention rate which is necessary to make space for an enlarged number of women, keeping the men's retention rate fixed; 2) we calculate the decrease in the men's retention rate, keeping the total rate fixed.

Figure 14 about here

Figure 15 about here

The two projections correspond to the dashed and dot-dashed curves, respectively, in Figure 14b. In order to obtain an equivalent improvement towards equity, as shown by the triangles in Figure 14a, by following the pipeline model and maintaining the same retention rates for women as we found in the existing data, one would have had to increase the number of female bachelor's degrees by a factor of 5 in 1973, and by a factor of 3.5 in 1991. Similarly, following the projections in Figure 15a, one would obtain an increase by a factor of 3.5 in 1973 and by a factor of 2.5 in 1991.

We also considered a smaller retention rate value of 70%. This is shown in Figure 15, which should be read following the same guidelines as for Figure 14. Based on this analysis, a realistic plan can be constructed where both factors—increase in overall retention and decrease in the retention of men are properly weighted according to external variables.

Once men and women are earning PhD's at comparable rates, parity in the field of physics will still be difficult to achieve at the professional level due to factors that produce "demographic inertia" amongst academic departments. Using data from sociology departments, Lowell Hargens and J. Scott Long (2002) offer an excellent model for analyzing the faculty portion of the academic pipeline. Their model accounts for such important effects as the age-sex composition of the department, changes in the size of the department, the sex composition of PhD recipients, as well as attrition patterns from the field. As a consequence of these factors, moderate changes in the gender composition of PhD recipients have almost no effect on the gender composition of academic departments. This point highlights the need to move swiftly towards gender parity at the PhD level.

Future Work

More information is needed in order to understand and repair this leaky pipeline in physics. Why are women less likely than men to continue on to the PhD? Possible answers include overt and covert sexism, institutional discrimination, job market constraints, or some combination thereof. It is possible that the culture of undergraduate physics education is, in a variety of ways, discouraging of women's continued participation. To investigate these possibilities, it is important to investigate this undergraduate culture through interviews and ethnography. Additionally, the issue of prestige needs to be taken into account. For instance, many undergraduate physics departments offer both the bachelor of art and the bachelor of science degrees, but the bachelor of science is more likely to prepare a student for graduate education. If women are disproportionately enrolling in the bachelor of art programs, this may explain why their attrition levels are higher than men's.

It is also important to ask more questions of practicing female physicists about their experience in physics education and the professional practice of physics. Further, women who have left the field of physics at all levels—undergraduate, graduate, and postgraduate—should be interviewed to discover their reasons for leaving, and the perspectives of practicing male physicists should be considered to determine how their perceptions of the field compare to their female colleagues. Finally, the pipeline investigation needs to be extended to the professional level. This should begin with an application of Hargens and Long's model (discussed above) to the field of physics.

Conclusion

This research concludes that a more careful intervention plan for retention of women in physics can substantially improve the present gender disparity in physics and contribute to a future of continued movement towards equity. An enormous investment of resources has increased women's participation at the earliest stages of the pipeline. However, many of the women recruited into the discipline of physics are lost at later stages due to the leaky character of the pipeline. Improving the retention of women in physics would allow those efforts to have a greater impact on women's participation at the highest levels by repairing the current wasteful process.

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Notes

1. WebCASPAR is available online at http://caspar.nsf.gov/.

2. The seven-year interval was selected after reviewing WebCASPAR data on time-to-degree. The average time-to-degree varies by discipline, and changes over time for all disciplines, but seven years is roughly the average for physics, and is comparable to other disciplines cited in this paper. Ivie and Stowe prefer a five-year interval, based on data collected by the American Institute of Physics. The authors have analyzed the patterns using both interval sizes and find them comparable.

3. The broad category 'physical sciences' includes physics, chemistry, astronomy, and 'other physical sciences'. The data does not specify which research areas are listed under 'other physical sciences'.

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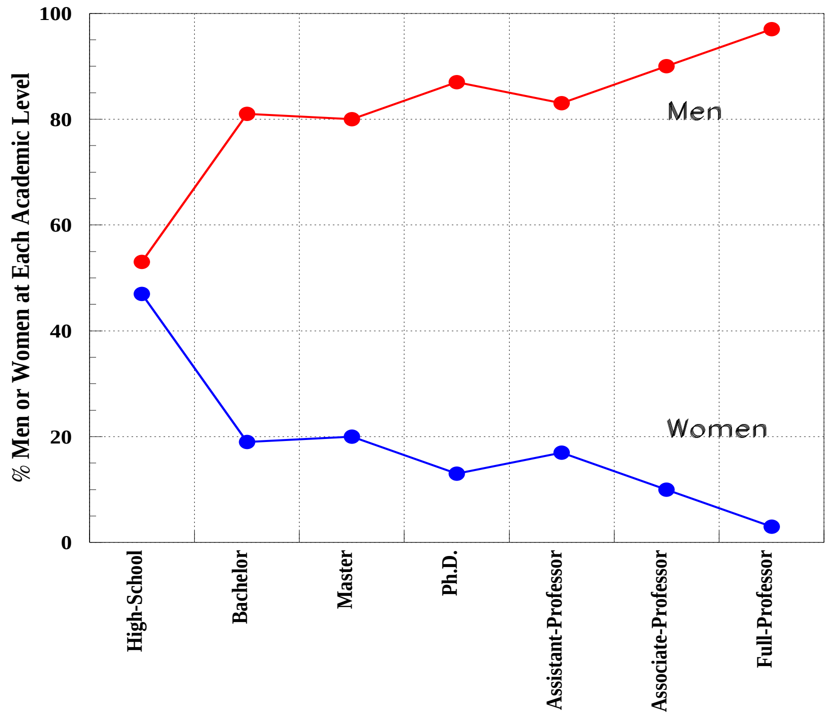


Figure 1: Percentage of men and women in the US academy. Data source for all figures is the NSF WebCASPAR database.

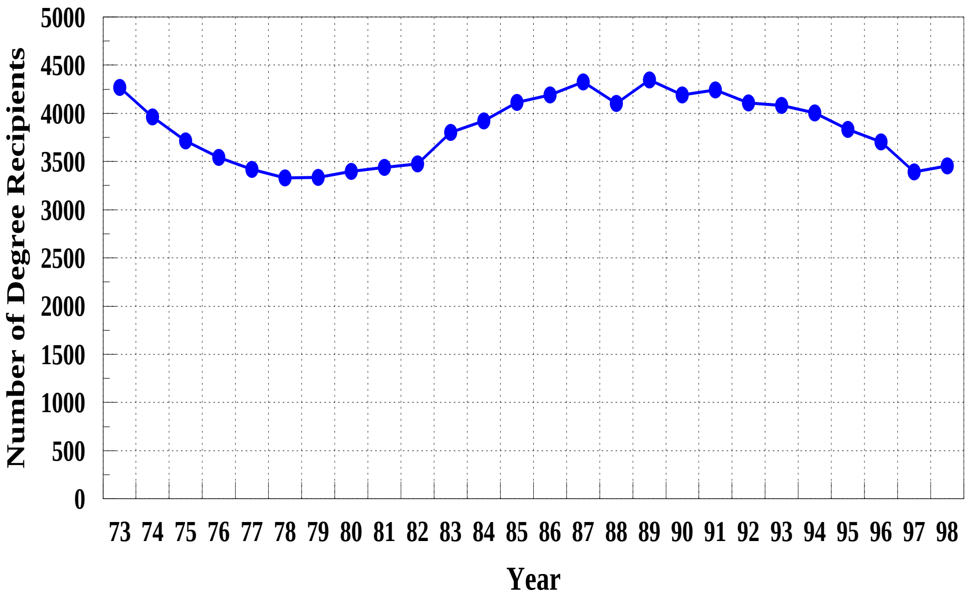


Figure 2: Number of bachelor recipients in physics, 1973-1998.

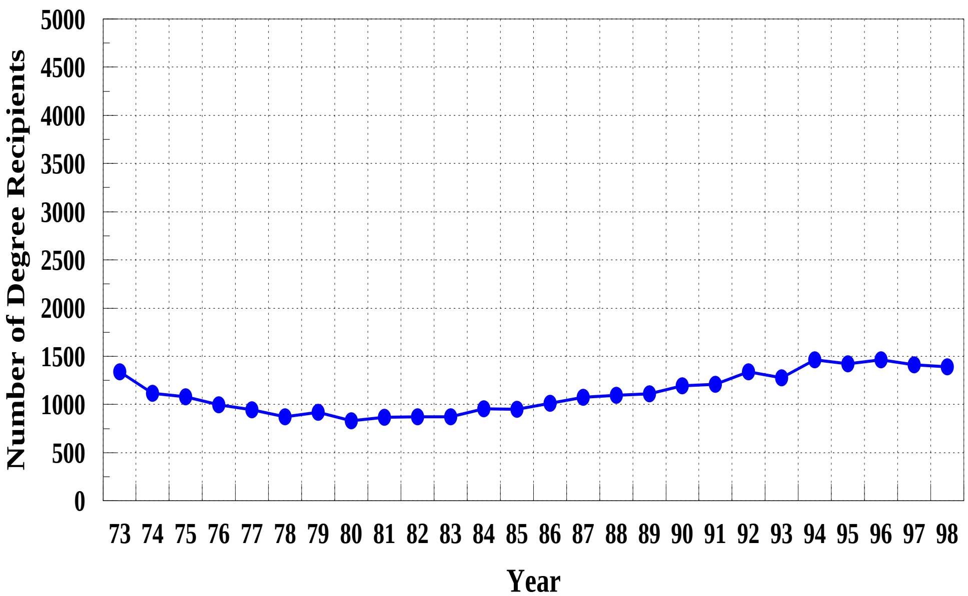


Figure 3: Number of PhD recipients in physics, 1973-1998.

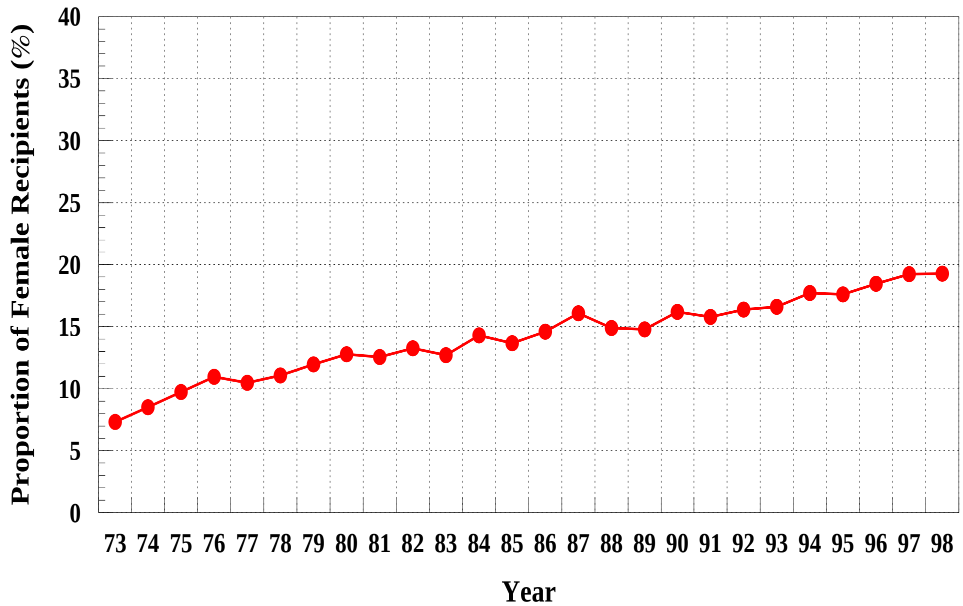


Figure 4: Proportion of women receiving the bachelor's degree in physics.

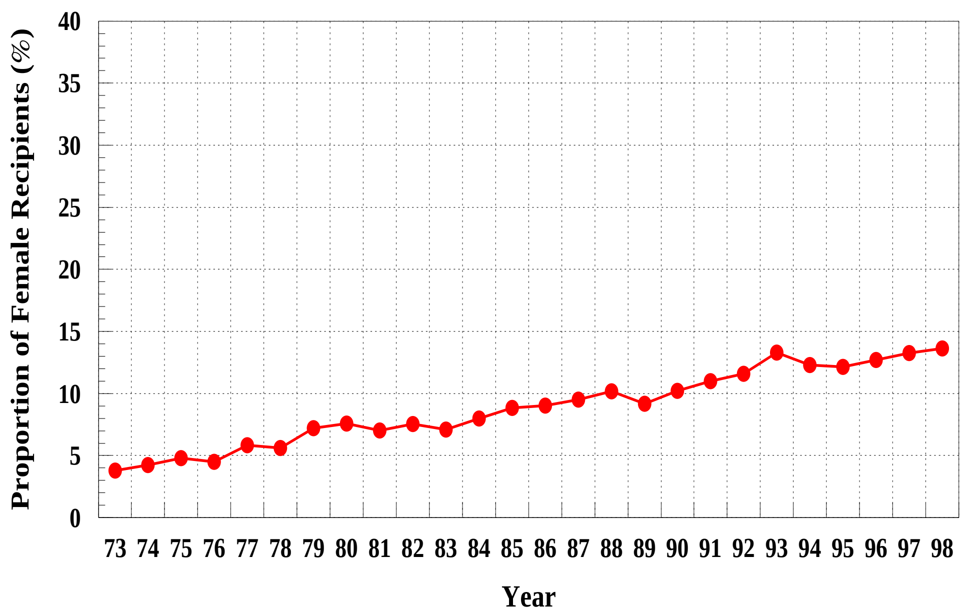


Figure 5: Proportion of women receiving the PhD in physics.

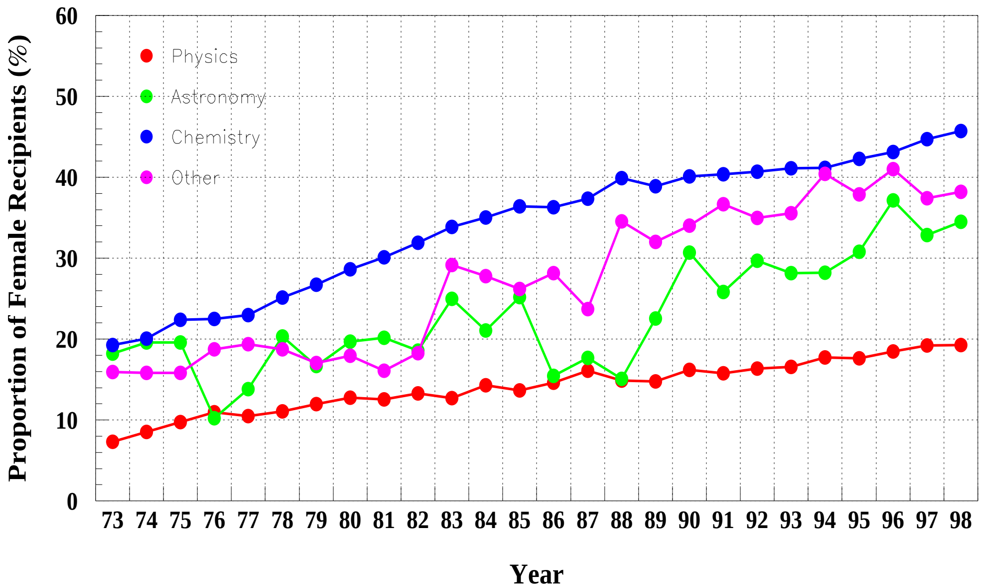


Figure 6: Proportion of women receiving the bachelor's degree in physical science disciplines.

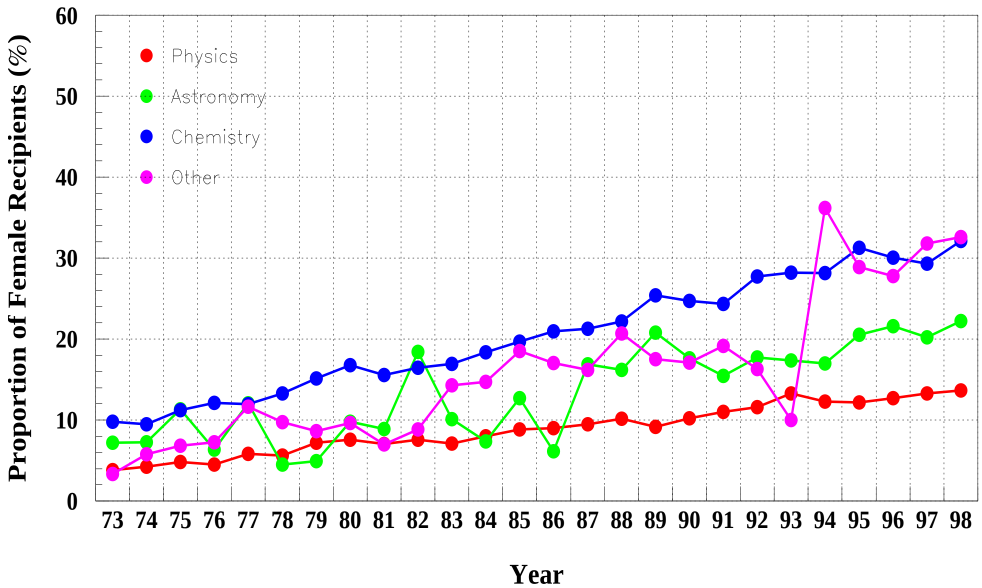


Figure 7: Proportion of women receiving the PhD in physical science disciplines.

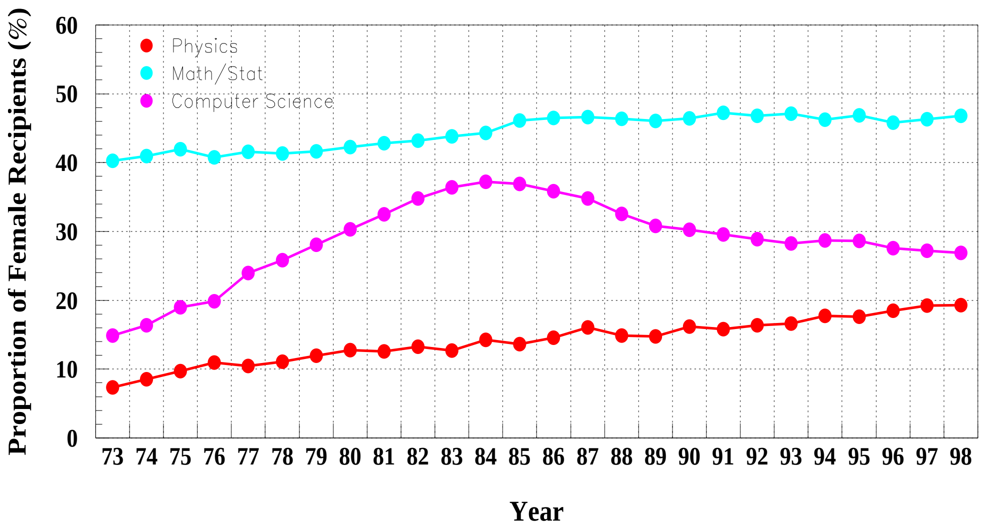


Figure 8: Proportion of women receiving the bachelor's degree in physics, mathematics and computer science.

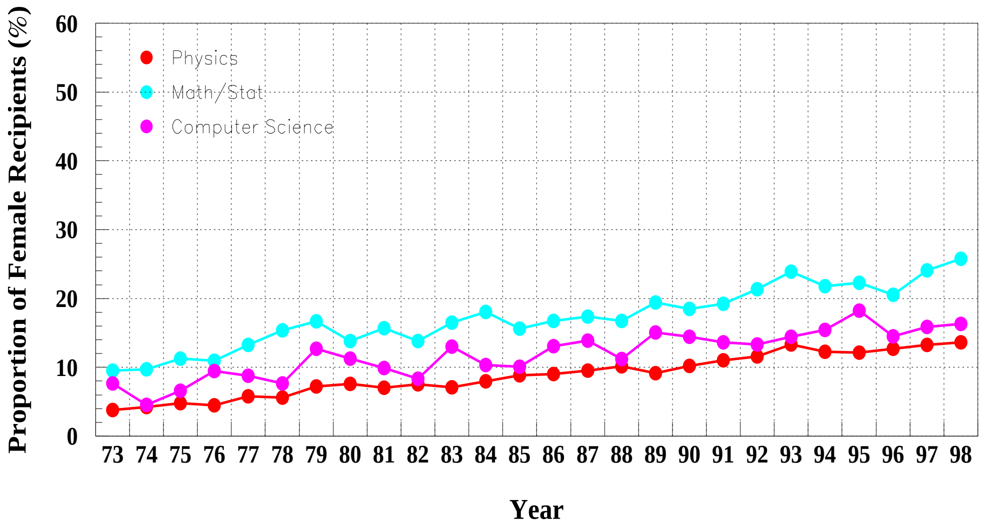


Figure 9: Proportion of women receiving the PhD in physics, mathematics and computer science.

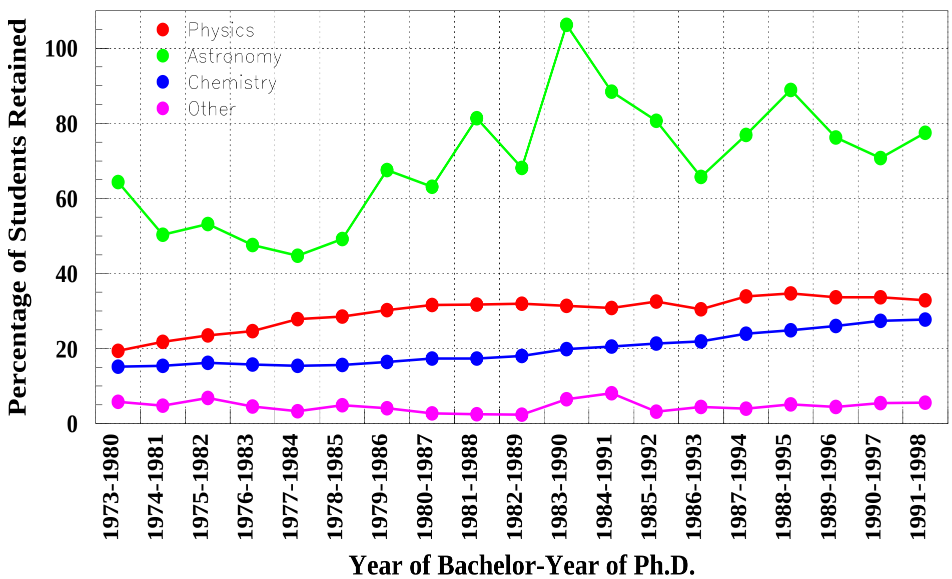


Figure 10: Retention of students in physical science disciplines.

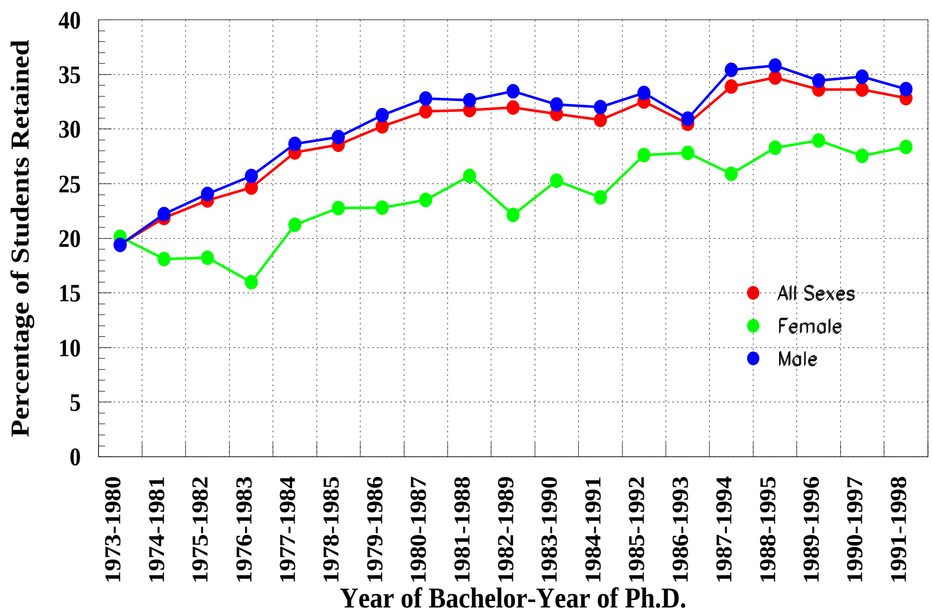


Figure 11: Retention of physics students.

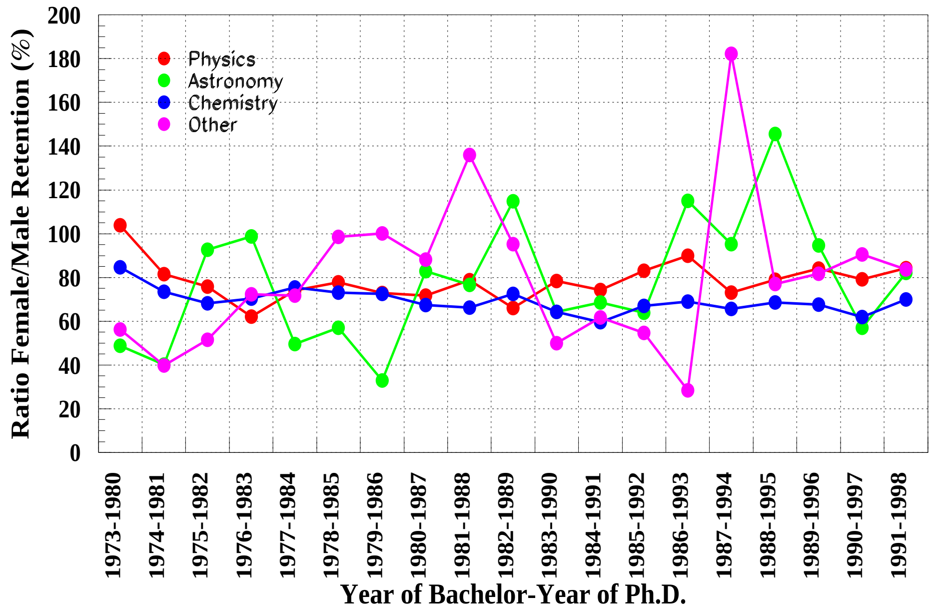


Figure 12: The ratio of female retention to male retention in physical science disciplines.

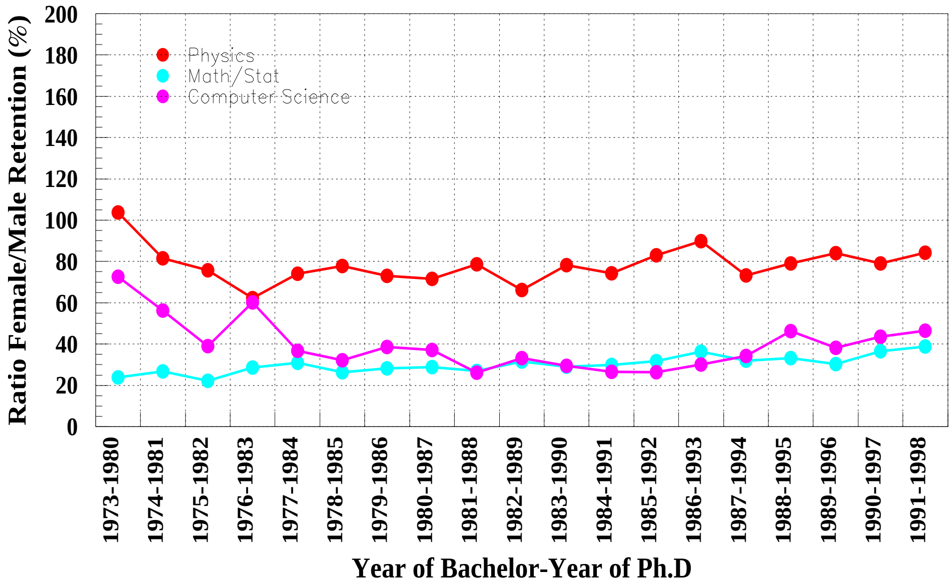
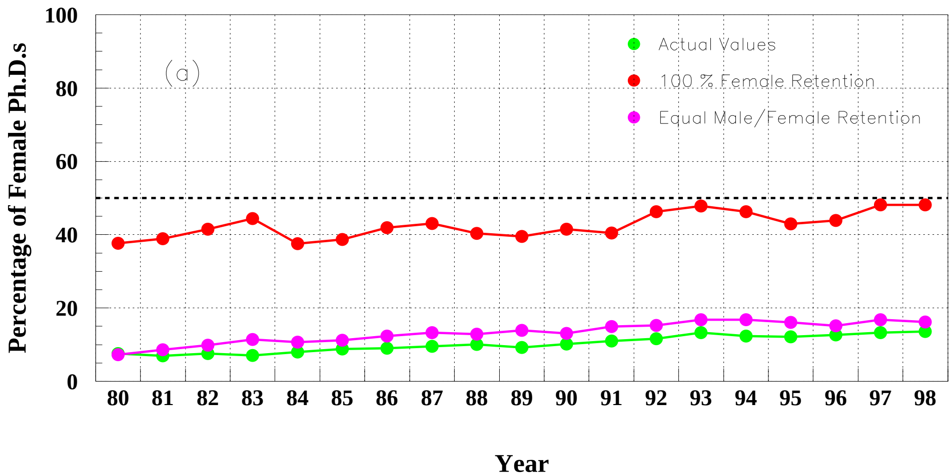


Figure 13: The ratio of female to male retention in physics, mathematics, and computer science.



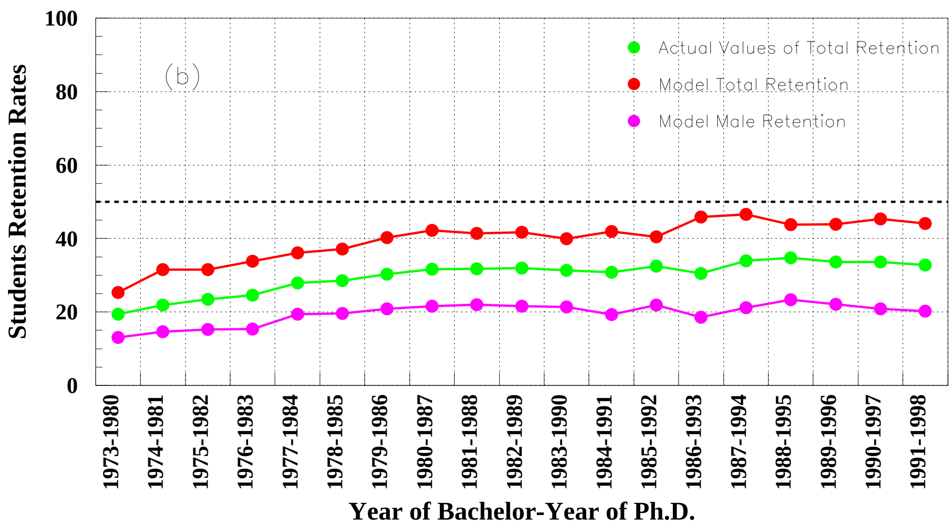


Figure 14: (a) Percentage of female PhD's in physics compared with the projections obtained by assuming a 100% female retention rate, and equal male and female retention rates; (b) Actual values of the total retention rate in physics compared with the total retention rate and with the male retention rate in physics resulting from a 100% female retention rate.

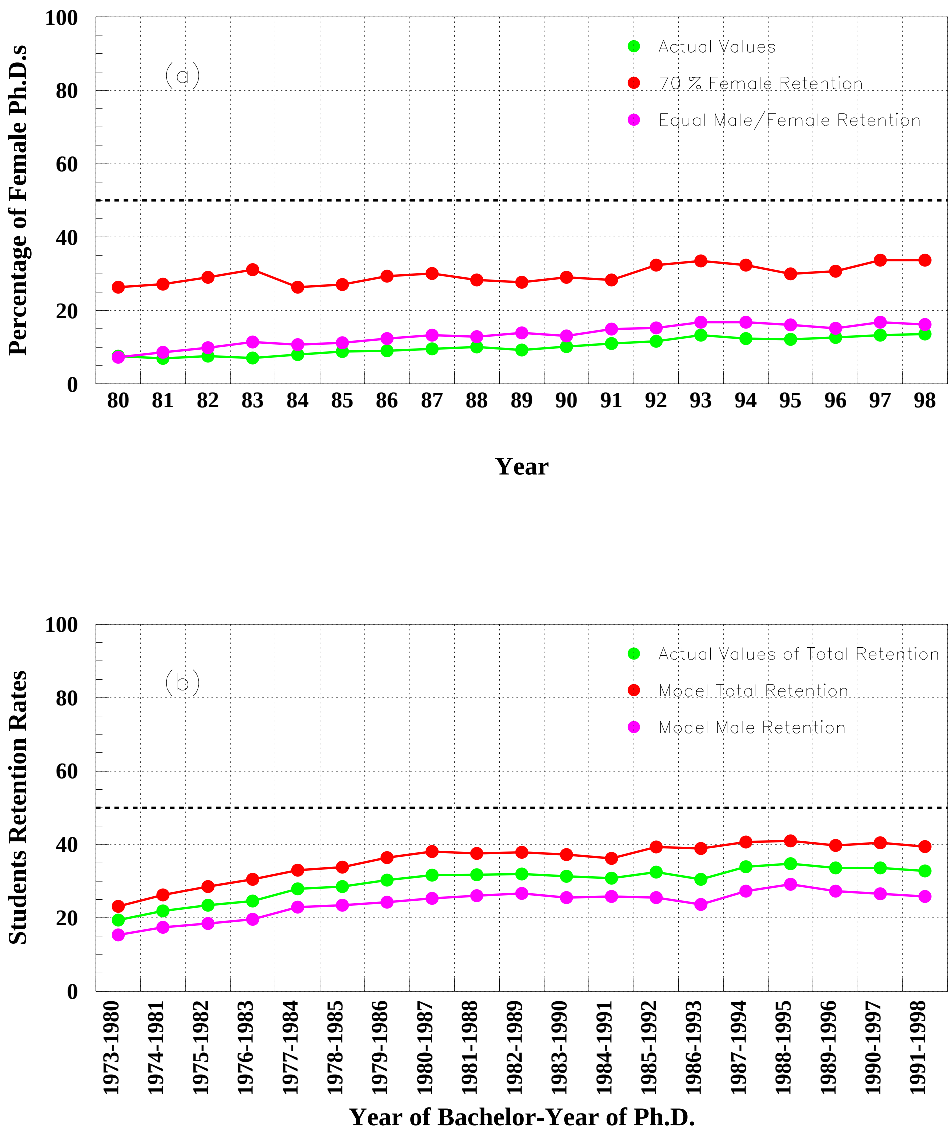


Figure 15: The same as Fig.14, with a 70% model retention rate.