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Gender Disparity in Engineering as a Function of Physics Enrollment and Its Implications for Civil Engineering

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ABSTRACT

Despite tremendous advances by women in the natural and applied sciences, where in selective fields women have surpassed men in the earning of doctoral degrees for more nearly 20 years, female enrollment levels in engineering continue to be a fraction of male enrollment. Gender disparities of more than 60% persist in undergraduate engineering enrollments and have recently worsened. As American female Civil Engineering enrollment has been flat for over 25 years, efforts must be taken to understand this stasis. This paper focuses primarily on secondary education preparation in terms of both attitudes towards and enrollment levels in pre-engineering courses such as calculus, chemistry, and physics. Additional consideration is given to enrollment and achievement in advanced placement courses, as reflected in national examination rates. This paper concludes that secondary school participation and achievement in physics courses is a critical differential factor as one explanatory element of female engineering enrollment levels and provides specific recommendations as to how to increase interest, enrollment, and achievement in physics, including the segregation of entry-level engineering courses based on previous experience.

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KEY WORDS: Engineering Education, Women, Mathematics, Schools, Undergraduate study, Workplace Diversity

INTRODUCTION

Although female enrollment in American science and engineering (S&E) programs has substantially improved over the past half century (NSF/DSRS 2007a, 2007b), a disproportionate amount of the gains in equity have occurred in the natural sciences, while engineering still remains with more than a 5:1 male to female ratio and is down from a late 1990s peak (NSF/DSRS 2007b). At more advanced degree levels, the percentages also worsen for American born women. What is curious is that at entry-level courses in American junior high school and high school, girls actually outnumber boys. As the disparity in degree recipients has a significant impact on the quantity and diversity of available employees for the Civil Engineering profession, the topic is of great importance to the Civil Engineering community. This paper explores the role of high school level physics as a major potential catalyst for this cleavage.

BACKGROUND

Irrespective of the enormous gains for women and girls in some science and technology fields in the United States (Table 1), the pipeline of females into American engineering programs at the bachelor's level has continued to rise only incrementally with most areas largely stagnant since the mid-1970s and even an overall decline in recent years from a peak of nearly 20% (NSF/DSRS 2007b). The higher the degree level, the greater the disparity grows for American citizens and permanent residents (fig.s 1 and 2), with most of the gain in female graduate enroll-

ment comprised of foreign nationals. Yet, these low numbers are not reflected in female enrollment in American doctoral programs across the disciplines, even within the sciences. In the physical sciences, the number of doctoral degrees earned by women is 50% more than that being earned in engineering. In the biological sciences, the rate is almost three times, and in psychology, women represent well over 65% of all doctoral degrees being earned in the United States (NSF/DSRS 2007a).

Differences in enrollment rates are reflective of many things, including long-standing disparities and motivational issues such as the desire to help other (e.g. Morgan et al. 2001), but the fact remains that American engineering has not benefited from a continuous increasing influx of females, and further study is needed to find all structural, as well as societal impediments that would prevent the Civil Engineering profession from enjoying the full benefit and contribution of any potentially interested individual. In 1954, female enrollment rates at the bachelor's level in the natural sciences were already at 19%, versus 0.4% in engineering. Fifty-three years later, with a 279% enrollment increase, female bachelor's enrollment levels in the natural sciences exceed 45.3%. In contrast, during the same period despite a 425% enrollment increase in female engineering enrollment, female bachelor's level enrollment was as of 2005 only 17% -- a decrease from a high of nearly 20% in 1999, but consistent with a 5 year downward trend (NSF/DSRS 2007).

Female enrollment in engineering programs at the undergraduate level is certainly a function of many factors, but broad attitudes about math and science do not appear strong contributors (fig. 3). In 8th, 10th, and 12th grades, although male students exhibited a consistently higher level of

interest in both math and science, the gap remained less than 10% in all categories and accompanying performance results are equally unpersuasive (fig. 4) as overall achievement only slightly favors male students. Furthermore, the difference in attitude is not reflected in high school enrollment figures (fig. 5), where girls outnumber boys in all major math and science high school courses, except for calculus and physics, where males hold a small enrollment advantage. This small enrollment reversal (compared to other math and science courses) would at first appear nearly negligible. Yet these two courses are critical components of an engineering program and mark the beginnings of a cleft in the university level curriculum for students pursuing undergraduate degrees in engineering versus those in natural sciences, medicine, dentistry, and veterinary medicine. What bears further exploration is the next level of academic achievement, in terms of enrollment and performance in advanced placement (AP) courses.

When evaluating high school enrollment levels in AP calculus and physics classes, the gender divide becomes substantially more pronounced. Based on students who sat for the national placement examination in 2000 and 2006 (fig. 6), female students outnumbered male students in biology, environmental science and psychology, and were nearly equal in statistics. In calculus AB (the first calculus class), the female students began to lose ground, a gap that continued to widen in calculus BC (the second calculus class), yet this disparity peaked at only a 12% difference. In contrast, Physics B (the first AP physics class) had barely 35% females, and this nearly 1 in 3 ratio drops to barely more than 1 in 4 in Physics C (the second AP physics course) for both the electricity and magnetism option and the mechanics program.

At the bachelor's level, engineering enrollment for women at American institutions is only 1 in 6 (NSF/DSRS 2007b), with rates in Civil Engineering directly mirroring this. Such figures bear the question of whether the physics curriculum is the bottleneck for female engineering enrollment, as it has already been shown by Huang and associates (Huang et al. 2000) that entry and persistence of women in undergraduate S&E can be strongly influenced by previous enrollment in advanced high school math or science courses.

In figure 6, the values superimposed on the columns reflect national testing averages distinguished by gender, with results from 2000 shown in parentheses. Here, females are consistently out-performed by males by half a grade difference (on a scale of 1 to 5). Although half a grade may not seem significant, typically colleges will only grant credit for courses in which an AP examination grade of 3 or better is earned. Of the available math and science courses in the AP program, on average the mean male score met or exceeded 3.0 in 9 out of the 10 categories in 2000 and 11 out of 12 in 2006, including 2 of the 3 physics examinations (fig. 5). For females, passing the 3.0 threshold was on average true in only 4 of the 10 courses in 2000 and 3 in 12 in 2006, which also raises questions about the quality of instruction received by females in upper level math and science courses at the high school level. The relatively poor achievement of females on these tests may also discourage their further consideration of engineering as a profession. Furthermore, despite the opportunity of receiving college credit for AP scores, many college-level freshmen students choose to take the classes as "easy A's", instead of requesting the academic credit. Even students receiving a score of 5 (out of 5) are not precluded from taking the course for full credit, as if they have never been exposed to the material. With approximately 78,000 students taking AP Physics each year (Gollub and Spital 2002), this puts students (female

and male) who are experiencing the courses for the first time at a distinct disadvantage. Levin and Wyckoff (1990) identified that performance in freshman chemistry, calculus and physics were the most accurate predictors for retention in undergraduate engineering programs, yet under the current system actual knowledge gained is not measured as the pool contains large numbers of students with previous mastery of the subjects. This structural flaw in enrollment policies has major implications for drop out rates amongst female, undergraduate, engineering students, as described below.

PERSISTENCE

The Center for Institutional Data Analysis and Exchange at the University of Oklahoma longitudinal study, conducted from 1992 to 1998, of a cohort of college students in 119 colleges and universities, reported about 25% of all entering, first-time freshmen in 1992 declared their intention to major in a science and engineering field. By their second year, 33% of these students had dropped out of an S&E program (C-IDEA 2000). After six years, only 38% had completed an S&E degree, and women and underrepresented minorities dropped out of S&E programs at a higher rate than men and non-minority students. Consequently, degree completion rates in S&E fields were lower for women (35%) and underrepresented minorities (24%).

Since a large percentage of the students who decide to drop out decide to do so in the first semester, even though they may postpone taking action on the decision (Felder et al. 2002), success in the first semester is critical to long-term, high-level achievement. As such, without a good physics background trying to compete against students who have already completed advanced place-

ment physics in high school but are enrolled in the introductory course in college is extremely challenging. Interestingly, at North Carolina State University (NCSU), although first year students do not take physics in their first semester, women students reported a loss of confidence in their physics abilities (Fuller et al. 1997), as measured by the Pittsburgh attitude survey (Besterfield-Sacre and Atman 1994).

RECOMMENDATIONS

As an initial set of steps to creating a gender-neutral environment for females in physics and calculus in American educational institutions six action items are proposed:

1. Have high schools offer in their early math and science courses (where female students are most likely to encounter them) information sessions related to more advanced math and science courses within their high school curriculum.
2. Develop methods to increase high school physics enrollment, such as sponsoring summer programs for girls, as early as middle schools and starting physics' clubs in the high schools to encourage continued participation in physics.
3. Provide gender equity training for high school math and science instructors, especially physics as the community has been documented to be "chilly" towards females at all levels of study and engagement (Curtain et al. 1996).
4. Furnish an intensive, experimentally based experience for young women and instructors in the pioneering and testing a new series of laboratory experiments that intensively address engineering basics. More hands-on, laboratory based approaches to physics have

been shown to change the in-classroom dynamic and the level of achievement by young women in these courses.

5. Create mentorship and leadership opportunities for female graduate students to work with high school students, especially in physics' related scenarios.
6. Segregate freshmen university physics and calculus classes by students' previous enrollment history (e.g. clustering those who have never been enrolled, those who had regular high school classes, and those with advanced placement exposure), in the same way that universities demand language placement tests and self-identification of native speakers of foreign languages prior to enrollment in entry-level courses. Alternatively, prohibit students who have achieved a 4 or better (out of 5) on their AP test to not be able to take the class for credit. This is also another standard practice in foreign language courses.

Elements of the first 5 of these suggestions have been tried, implemented, and assessed, at least on a limited basis in a wide range of different engineering-oriented programs. Clewell and Darke (2000), in their evaluation of 40 programs for women and girls that directly served over 31,500 participants from elementary school students through university faculty, documented the success of such efforts in 5 critical categories for science, math and engineering and technologies (SMET) programs. As summarized in Table 2, student outcomes ranged from changes in self-confidence and improved attitudes toward SMET courses, higher SMET enrollment rates, elevated plans to enter SMET careers, and enhanced mastery of SMET content. Teacher, administrator, and parent outcomes focused on better awareness of gender equity issues and greater adoption of gender equity strategies. The sixth suggestion is provided by the author not only based her own first hand experience but by the highly damning work done by Morgan and Ram-

ist (1998) comparing the grades of students with AP experience and those without, at 21 American universities (fig. 6). Even though data was unavailable for the first semester Physics course, the trends for the second course are extremely similar to that shown for the first semester Calculus course. The implications of this research are clear: (1) many students who have excelled in their AP work courses are enrolling in entry level university classes covering the same material, and (2) without having previously had these advanced courses, achieving competitive grades in these entry-level undergraduate classes is extremely difficult. Further considering the parallel to foreign language courses, where a fundamental distinction is made between students having a priori knowledge, there is a widespread understanding amongst educators that allowing native speakers or others with significant exposure or training into a beginner's course is disruptive and counter-productive for students wholly or largely new to the foreign language. This is why most universities and colleges require a language placement examination prior to enrollment in a beginning class. Why a fundamentally different approach exists in engineering is unclear.

As success in a student's first undergraduate term is critical to confidence building and student retention, creating a non-prejudicial learning environment, where new students are not competing directly and on a curve with students who have in all effects previously taken the course seems to be an absolutely critical step. The playing field will never be completely even, as some students are simply more gifted and/or hardworking than others, but the implementation of an approach based on demonstrated past achievement is not only more academically honest both in assessing students' instructional attainment and instructor effectiveness, but it is ethically the proper course of action and may have highly beneficial knock on effects for retaining women interested in pursuing undergraduate degrees in Civil Engineering, for whom it is has been shown

are at a higher risk of dropping out than their male colleagues.

CONCLUSION AND SUMMARY

Despite nearly similar attitudes by junior high school students towards math and science, trends demonstrate a disproportionately higher female enrollment in math and science in high school courses, until they encounter what is typically considered senior level courses for college-bound students, namely physics and calculus. The more advanced the level of these classes [(regular versus advanced placement and AB advanced placement (first course) versus BC advanced placement (second course)], the more the gender gap widens. This disparity strongly parallels gender-based undergraduate engineering enrollment levels. The achievement rates for females in these and other advanced-standing science courses also lag behind male performance rates. The apparent conclusion is that unless the factors that generate secondary education enrollment and achievement disparities are removed, substantial changes in female engineering enrollment and retention are unlikely to occur. In the field of Civil Engineering, where undergraduate female enrollment has failed to increase substantially and consistently in nearly three decades, this should be a major issue for all involved. To break this deadlock, six intervention strategies are proposed ranging from increasing exposure and interest of potential students to advanced calculus and physics courses, to providing gender-equity training to instructors and role models for students, and finally by proposing a new approach for enrollment in entry-level math and science courses for the bachelor's degree, one that is akin to how a priori foreign language knowledge is handled and most major universities and colleges.

ACKNOWLEDGEMENTS

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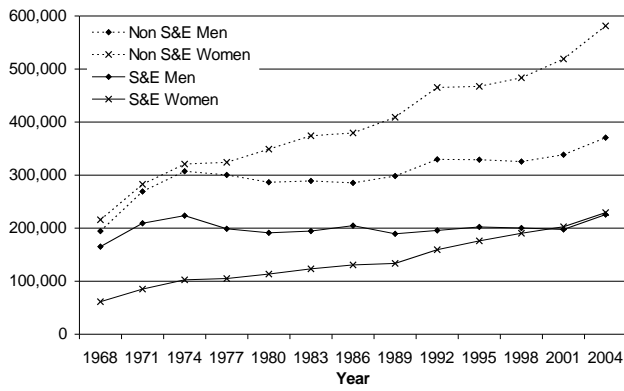
<http://nces.ed.gov/nationsreportcard/lt/results2004/nat-math-scalescore.asp> (accessed Aug. 4, 2007).

Table 1. Female Enrollment at the Bachelor's Level for the Natural Sciences and Engineering
(data from NSF/DSRS 2007a and 2007b).

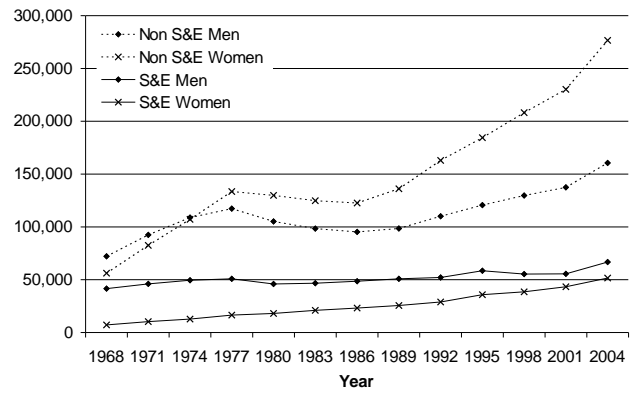
| Year | Natural Sciences | Engineering |
|------|---------------------|-------------|
| 1954 | 19% | 0.4% |
| 1980 | 37% | 11% |
| 1998 | 45% | 19% |
| 2004 | 53% | 17% |

Table 2. Potential Positive Outcomes from SMET Programs for Women and Girls (adapted from Clewell and Darke 2000).

| | Outcome | Definition |
|------------------|--|--|
| Student Outcomes | Affective enhancement for SMET study <ul style="list-style-type: none"> • Self-confidence in SMET • Attitudes towards SMET and females in SMET | Changes in attitude regarding competence in SMET from pre- to post-intervention. |
| | SMET course-taking <ul style="list-style-type: none"> • Enrollment in SMET courses • Interest in, or plans for, SMET study • SMET majors in college • Retention in SMET study • Pursuit of SMET graduate study | Students' enrollment in SMET courses and changes in intentions to pursue SMET study from pre- to post-intervention. |
| | Mastery of SMET content | Students' knowledge of SMET content from pre- to post-intervention. |
| | SMET career plans <ul style="list-style-type: none"> • Plans to pursue a SMET career • Entry into a SMET career field | Students' entry into a SMET career post-intervention or change in intention to pursue career from pre- to post-intervention. |
| Adult Outcomes | Awareness and use of gender equity strategies <ul style="list-style-type: none"> • Awareness of gender equity issues • Use of gender equity strategies | Change in educators' or leaders' knowledge of gender equity issues in SMET settings and change in use of specific strategies to create an equitable environment for all students from pre- to post-intervention. |



(a) Bachelor's Degrees



(b) Master's Degrees

Fig. 1. Degrees in S&E and Non-S&E Fields

(data from NSF/DSRS 2007a and 2007b).

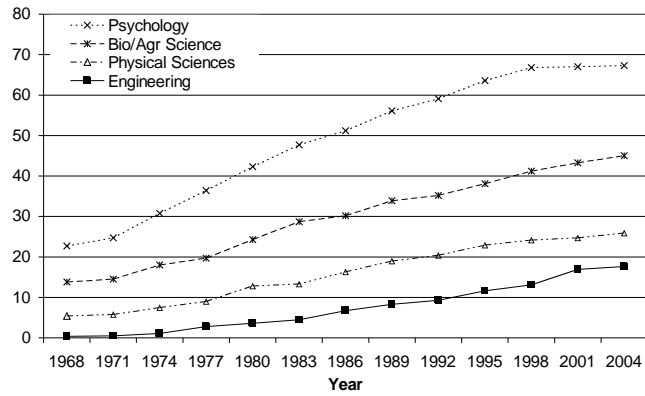


Fig. 2. Sampling of Female Enrollment in Doctoral Programs as a Percentage of Total Enrollment by Major Area (data from NSF/DSRS 2007a and 2007b).

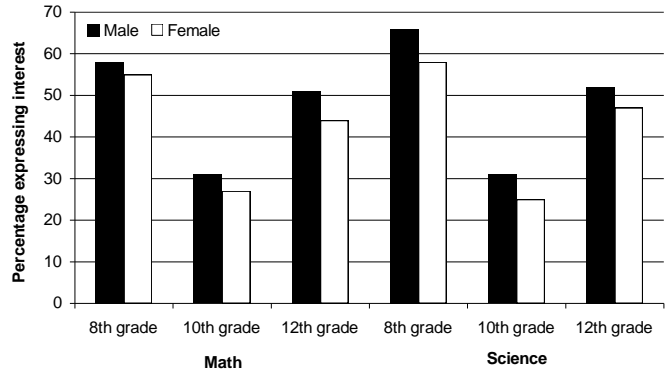


Fig. 3. Interest in Math and Science Learning:
 Percentage of 8th, 10th, and 12th graders from 1988-1992
 (data from Huang et al. 2000).

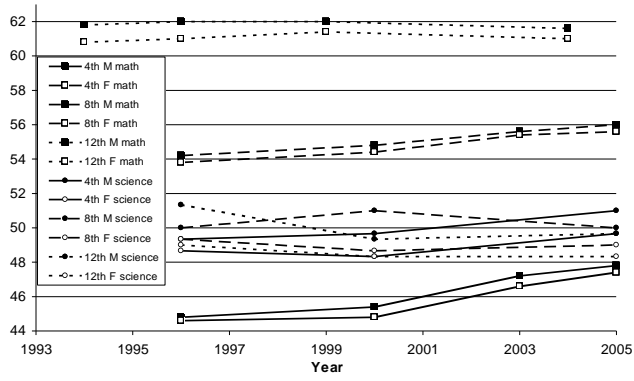


Fig. 4. Performance in Math and Science by Gender
 (data from USDOE/IEW/NCES 2004, 2005b, and 2005c)

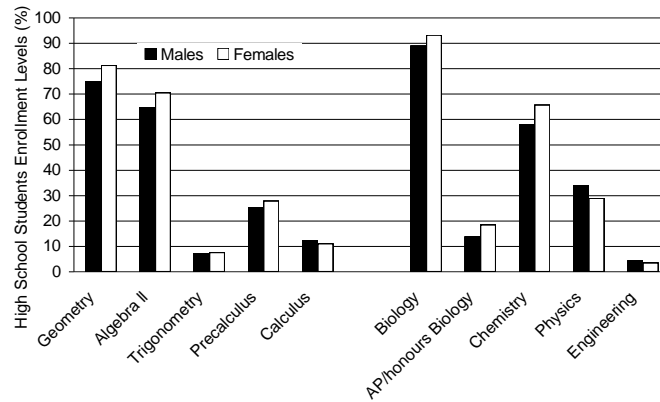
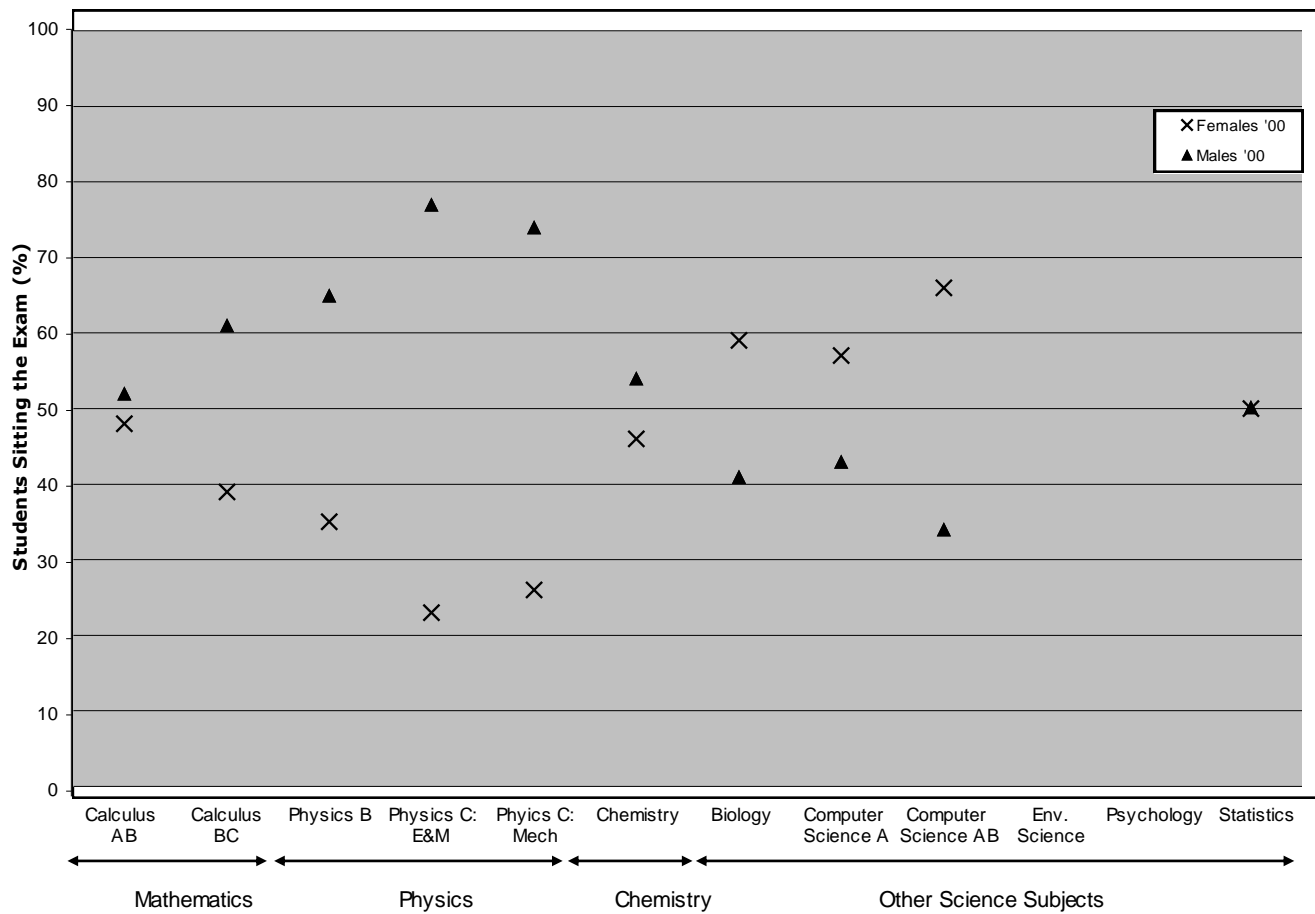


Fig. 5. Percentage of 2004 High School Graduates' Enrollment
in Math and Science Courses by Gender
(data from USDOE/IEW/NCES 2005a).



* Environmental Science and Psychology were not AP courses in 2000.

Fig. 6. Participation and performance level by Gender for the AP Examinations in the Maths and Sciences with Average, Gender-specific Scores Superimposed for 2000 and 2006 (data from CBAPP 2000 and 2006).

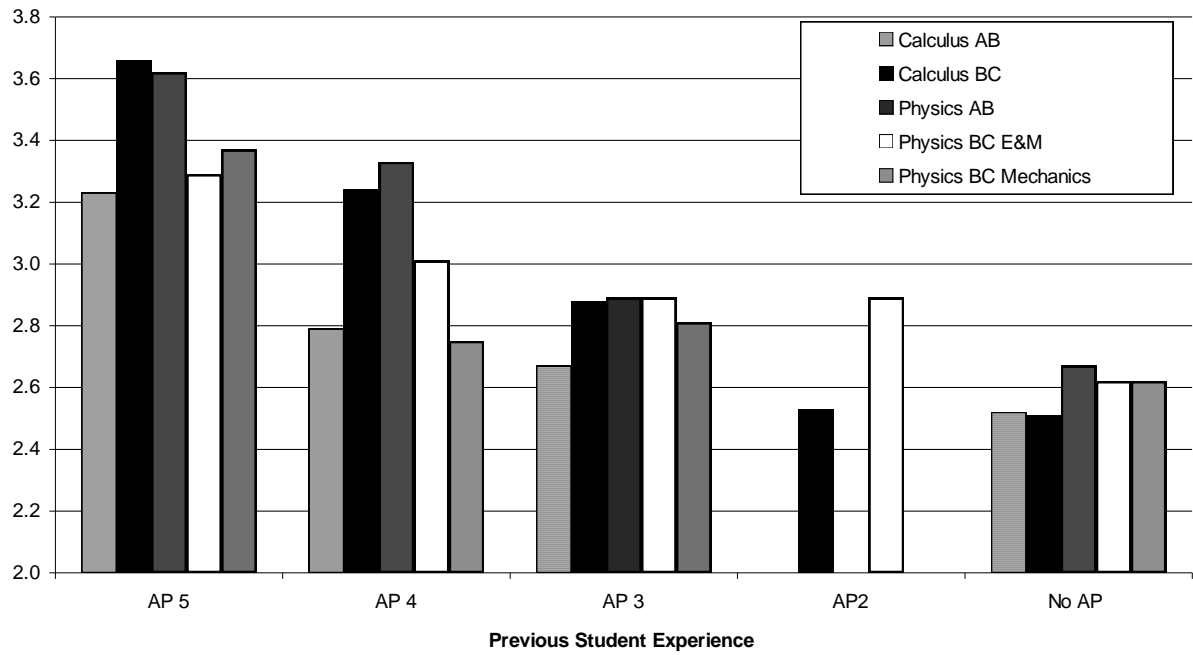


Fig. 7. Impact of Advanced Placement Achievement in College Level Calculus and Physics

Courses

(data from Morgan and Ramist 1998).