Investigating the Notion of Critical Mass of Women in Engineering using Longitudinal Student Records

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CONTEXT:

The concept of "critical mass" in social interaction is that a sufficient number or percentage of individuals of common experience inspire collective action that is different from individuals acting independently (Oliver, Marwell, & Texeira, 1985). Critical mass is well-studied in the leadership of corporate and academic organizations (Kanter, 1977; Wolff, 1950; Etzkowitz, Kemelgor, Neuschatz & Uzzi, 1994; Etzkowitz, Kemelgor, Neuschatz, Uzzi & Alonzo, 1994).

Based on her experiences at MIT, Widnall (2000) anecdotally notes 15% as the critical mass for women in the engineering classroom, citing that above that threshold the academic performance of women improves. In search of literature supporting Widnall's anecdotal account, we discovered a significant literature base that asserts the existence of a critical mass (Blum, 2001; Doerschuk, Liu, & Mann, 2007; Sanders, 2005; Lewis, McKay & Lang, 2006; Powell, 2008; Dresselhaus, Franz & Clark, 1994; Roberts, Kassianidou, & Irani, 2002; Cohoon, 2001)

While none of this literature provides original evidence of the existence of a critical mass, some of these cite other works as evidence of the critical mass phenomenon. Unfortunately, none of the works cited as sources regarding critical mass (Margolis & Fisher, 2002; Cohoon, 2001; MIT EECS Committee on Women Undergraduate Enrollment, 1995; Matyas & Dix, 1992) provide evidence that such an effect exists. One such reference could not be located (Cobbin, 1995). A variety of European and Australian research studies women in engineering, but does not use the rhetoric of critical mass (Sagebiel & Dahmen, 2006).

Ultimately, we agree with Seymour (2002, p. 92), who notes that there is a lack of evidence of a critical mass saying, "what is not proven, however, is the theory that: networks of such collaborations can build into a "critical mass" in favor of reform." This question is particularly unanswered among undergraduate students, who lack the dynamics of power associated with a critical mass of women in organizational leadership.

RESEARCH QUESTIONS:

Noting that this is an open question, we ask, "is there a critical mass of women in the engineering classroom (as a percentage or an absolute number) beyond which collective behavior emerges?" Specifically, ***as the number or percent of women in engineering classes increases…***

- does the academic performance of women improve?
- does the academic performance of women become more similar?
- does the persistence of women in engineering improve?

THEORETICAL FRAMEWORK:

While a critical mass effect has not been demonstrated, various researchers suggest that such an effect might come about from women's greater emphasis on group affiliations, community, and collaboration (Hegelson, 1995, and Maier, 1999), because mentoring is important to women's success (Ambrose, Dunkle, Lazarus, Nair, & Harkus, 1997, and Ragins & Cotton, 1999), because of the effects of feelings of isolation and a lack of support systems and effective networking opportunities (Baum, 1990; Seymour & Hewitt, 1997). Widnall (2000) suggests from her MIT experience that critical mass is supported by the links between acceptance and self-esteem and performance. This is consistent with Bandura's observation that individuals who have little or no experience are likely to establish their self-efficacy by comparison to others (Bandura, 1997). Given that women have less computing experience when they start college (Margolis & Fisher, 2002), a critical mass would permit social comparisons to people with a similar experience level.

Encouraged that various theories could explain a critical mass effect, we search for quantitative evidence of such an effect by using institutional data analysis to study large numbers of women students with the common experience of being enrolled in the same course section. Our work is a departure from the microsocial model of Marwell, Oliver & Prahl (1988), in that we will not be attempting to predict the collective behavior of entire cohorts of students, but only the collective behavior of students with social ties.

METHODOLOGY:

The Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) includes student records from all undergraduate students at nine public universities in the southeastern United States. Course and grade records for over 100,000 engineering students are aggregated so that the unit of analysis is the class section.

We operationalize academic performance as the average grade of the women in each course, computing this for each course with at least one woman enrolled and with at least 10 total students enrolled. We study persistence by focusing on graduation in engineering. The choice of graduation introduces a negative bias in that students enrolled in courses in the later years of the database will not have had time to graduate in the term of the database. The results of this bias are easy to anticipate and interpret. The alternative, focusing on the continued study of engineering, would introduce a positive bias that is much stronger and more difficult to estimate.

We also study the distribution of women among classes as students move through the curriculum from freshman to sophomore to junior to senior courses. This is important for two reasons. The first is that changes in that distribution might serve as a secondary indicator of critical mass. If the typical percentage of women in a class increases from year to year, that would suggest that women are aggregating—intentionally enrolling in the same sections of classes to create their own critical mass. This distribution is also investigated because it could confound our third research question. We would certainly expect women in their senior year to have a higher persistence than women in their sophomore year. If the percentage of women in classes increases from freshman to sophomore to junior to senior year, it would appear that the increasing percentage of women resulted in the higher persistence.

FINDINGS AND CONCLUSIONS:

The histogram at the top of Figure 1 shows how many classes were identified with varying numbers of women enrolled in the class. The scatter-plot in the bottom of the figure shows the average grade that women earned in each course. To avoid overprinting, the data are jittered so that each unique value is represented by a square, and the density of the square represents the number of identical data points. The curve in Figure 1 was sketched by hand with the expectation that the low density of data in the lower right of Figure 1 was indicative of a critical mass effect.

If this were indeed a critical mass effect, it would suggest that when there are only a few women students in a discipline, it is important to group them together. Yet, Figure 1 does not prove the existence of a critical mass effect. Rather, the trend is consistent with probability—

with more females in a class, their average grade would tend to regress towards some mean. To assess the idea, we used the real distribution of grades from courses with one female to predict the *probable* average grades in classes with more females. The result of the simulation is shown in Figure 2.

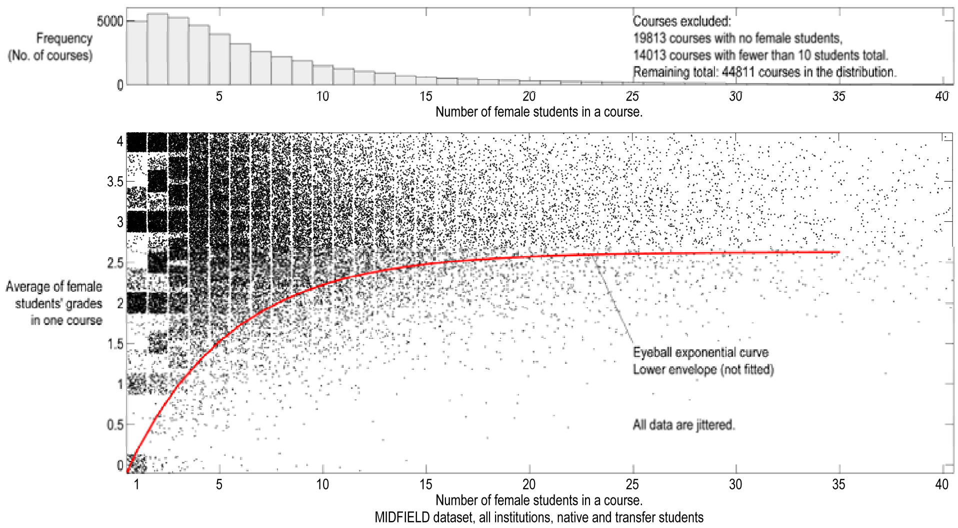

Figure 1. Average grades in courses with varying numbers of women.

Probability appears to explain the trend. The distribution of grades is just as easily predicted by randomly assigning (fictitious) women to courses, thus we choose not to investigate our second research question, that the grades of women become more alike as their numbers increase. In fact, as the number of women in a class increases, their real grades (in Figure 1) are more variable than the grades (in Figure 2) predicted by the probabilistic model.

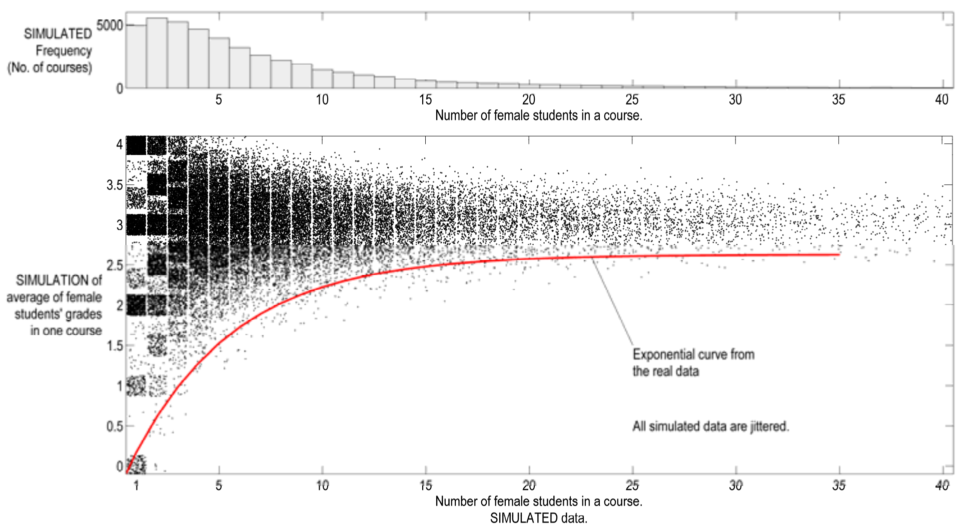

Figure 2. Simulated data demonstrate that Figure 1 shows a random effect.

Next, we studied the distribution of numbers of women in a course for courses at different levels—freshman through senior, defined by averaging earned credit hours of enrolled students. Since first-year students have a range of credit hours, ranges overlap, smoothing the result without changing the median for each class level noticeably. The result for industrial engineering courses is shown in Figure 3. Similar plots result for other disciplines; the distribution and resulting median do not vary in any interesting way among the class years and disciplines.

As noted earlier if the percentage of women in classes increases from freshman to sophomore to junior to senior year, it would create the spurious correlation that increasing the percentage of women resulted in higher persistence. The stability of the percentage of women in engineering classes shown in Figure 3 alleviates this concern.

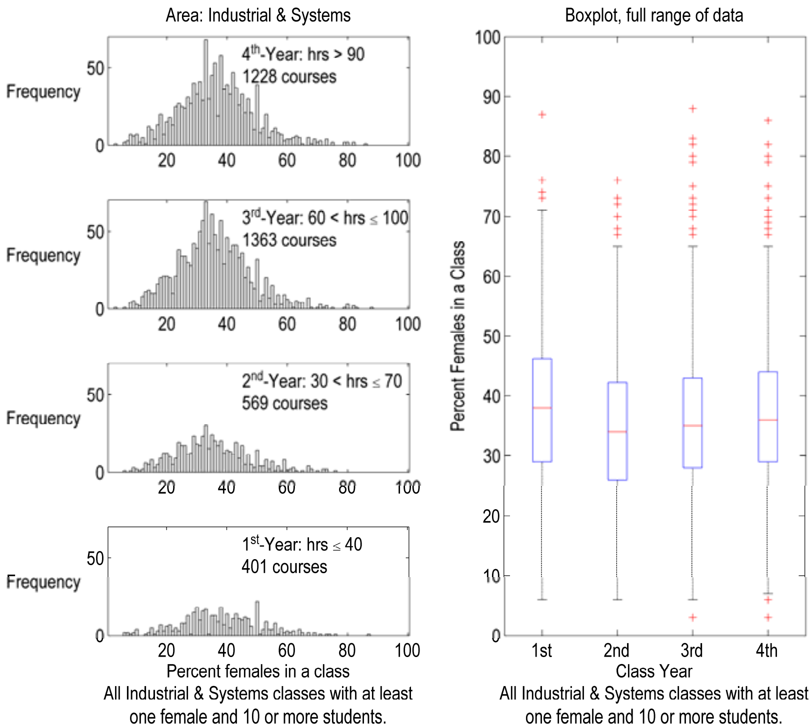

Figure 4 illustrates how the percentage of women in a class affects the percentage that graduates. As in Figure 1, the result is probabilistic. The large number of courses in which no women (0 %) graduate is due to the inclusion of courses in later terms of the database as described earlier. The high frequency of courses for which 100% of women graduated is a real effect. The distribution in between is probabilistic, favoring the larger percentages because the persistence of women in engineering is approximately 60% in the aggregate of MIDFIELD institutions.

Figure 3. Median number of women per class in each successive year of the Industrial Engineering curriculum.

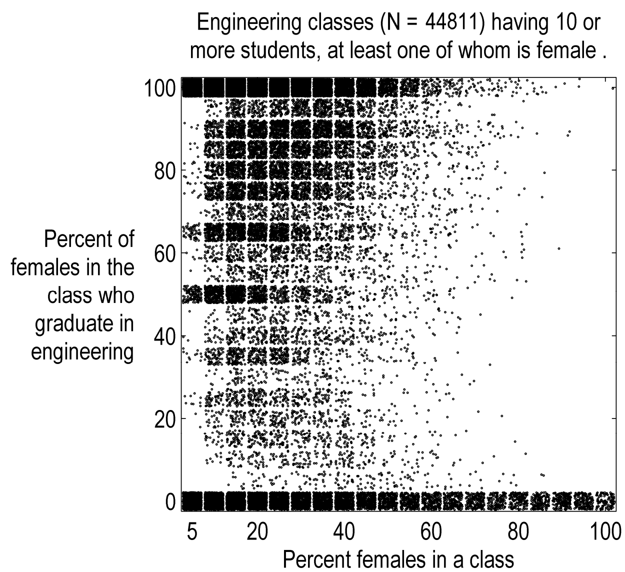

Figure 4. Persistence of women in courses with various fractions of women.

RECOMMENDATIONS:

The absence of a critical mass effect for women in engineering suggests that we cannot fix the problems with the culture of the engineering classroom (Seymour & Hewitt, 1997) by simply adding enough women. This agrees with our sense that diversity—both in the classroom and the profession—can only be achieved by inviting women and minorities not to adapt to engineering as it is, but to be welcomed with the expectation that their presence will change engineering for the better. We plan to investigate to see if a critical mass exists for minorities in engineering.

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