

ACCESS AND MERIT:

A DEBATE ON ENCOURAGING WOMEN IN SCIENCE & ENGINEERING

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ABSTRACT

Among students, teachers, and practitioners of science and engineering in Canada, women are often in the minority. Approximately 22% of undergraduate students and about 5% of faculty in Engineering are women. In Biology, approximately 60% of the undergraduates are women, but faculty, at 25%, revert to the minority pattern. Trend data indicate that with no outside interventions, these ratios are fairly persistent. Interventions, that is, programs which promote the participation of women or other minorities, have been criticized by some for diluting the quality of science delivered by the intervention group. These 'meritocrats' argue that merit suffers when access and equality increase. This talk presents a counter-argument. It shows that by using a narrow definition of what constitutes scientific knowledge, the 'meritocrats' have missed the reality, and the potential, of modern science. From both the academic and the social points of view, quality of science is enhanced by a diversity of thinking styles. The conclusion is that by preserving the status quo, we miss substantial opportunities for advancement of science and engineering in Canada.

INTRODUCTION

Gender differences in participation in science, technology, and engineering are a simple question of statistics. In any well-defined group, it is possible to count the men and women. For example, undergraduate engineering students in Canada in 1998: 22% women, 78% men. Faculty members in engineering in Canada in 1998: 5% women, 95% men. At Memorial University in 1999, undergraduate biology students: 60% women, 40% men. More data are available on the websites of the five Canadian Chairs for Women in Science and Engineering. The purpose of this paper is not to present these data, but to try to understand the processes which lead to those results.

Scholarship on this question has gone through phases of increasing understanding and sophistication. The first phase, the debate over whether there was a role for women in science and engineering, has been going on for centuries [1, 2]. In the next phase, researchers tested for gender differences in innate ability, especially those linked to ability to do science. Attention then shifted, not surprisingly, to the effect of experience, socialization, and expectations on ability test results. The current phase focuses on the motivation and experience of women who have chosen science and engineering in some form. Examples from these later phases are noted in the paper.

Some researchers, exploring the rich complexity of the human brain, continue to look for neuro-physiological explanations for gender differences in intellect and personality. What we have learned from these studies is that the explanation is a lot more complicated than saying brains are different because he went hunting with a club while she stayed home and swept the cave.

The study reported here has several motivations. First, the Chairs for Women in Science and Engineering are faculty position in science and engineering, with special responsibilities to promote the participation of women in these fields.

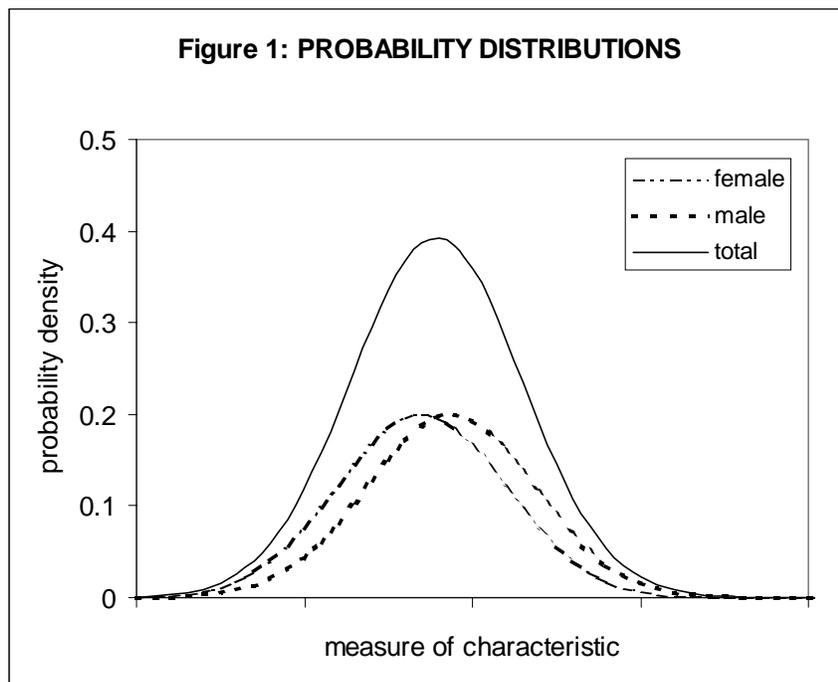
The conception and design of effective programs requires an understanding of the underlying issues. Second, programs which selectively encourage women have often, and recently quite vigorously, been accused of improving access at the expense of quality; this in spite of documentation which shows them to be effective, e.g. [3, 4]. Finally, since most of the literature on women in science and engineering is about these people, and not, except for first person accounts, by them, there is a gap which might usefully be addressed. The title of this paper shows the influence of another study [5] which informed some of the arguments here.

The paper first reviews the nature of gender differences by looking at how these differences are generally manifested statistically in populations. This somewhat dry beginning helps to explain our perceptions of what such differences are, and has a key role in the argument which follows. Then, in order to reduce a very large subject, the paper focuses on Mathematics as a reasonable proxy for science and engineering. Looking at the subject and its influence from the inside leads to conclusions not consistent with some reached by social scientists. The paper then brings in information about gender differences in learning styles, and, with a relational argument, shows how our persistent academic traditions have limited participation in a fashion which is not beneficial to Mathematics. The conclusions address motivations of the study and provide recommended actions.

STATISTICAL GENDER DIFFERENCES

Men and women are different; men and women are the same; every individual is different. The fundamental point is that gender differences are not clear. For any given, measurable, characteristic, there is a range of values which describes individuals, and a distribution of occurrences which describes a group. The distributions which describe the groups of men and women are distinguishable, and overlap. Figure 1 shows a generic example, in which the male and female populations have similar normal distributions, with the means offset by a small amount. The total population, half male and half female, is also a normal distribution.

When there is so much overlap, do gender differences matter? Figure 1 might represent distributions of height, with the average height of men larger than the average of the women. Survival suits on an offshore platform are supplied in a range of sizes, with more of the middle sizes than the very small or very large. Most of the time, there is a suit to fit everyone. However, if you are a woman, and the suit size distribution was chosen according to the height distribution for men, then there is a greater chance, when you get to muster station, that the suit will be too big.



In this paper, we do not claim that one size fits all. We are looking at ranges of characteristics, and distributions representative of different populations, male and female populations to be precise, and how those distributions influence such things as career choice.

Small differences in distributions can affect our perceptions. For a neutral example of Figure 1, consider a population of 1000 students, with a range of musical abilities. Out of that group, there may be 2 people who will be concert performers, and 2 others at the other end of the musical ability spectrum. Now suppose that 500 of those students have blue eyes, and 500 have brown eyes. And suppose further that the musical ability distributions of the blue and brown eyed populations are offset slightly, by one notch on the ability scale. Then one of the concert musicians has blue eyes and the other could have either, and one or possibly two of the tone-deaf students has brown eyes. Although the extremes of the population are highly visible, it would be wrong, on the basis of those observations, to conclude that blue eyes are more musical than brown eyes. In the top 30% of musical abilities in the population of 1000, 51% of them have blue eyes and 49% brown eyes. With a small influence by only one other factor, say willingness to practice, the percentage difference could be wiped out in actual performance results. (All calculations based on normal distributions.)

FOCUS ON MATHEMATICS

Women's participation rate in science and engineering is a large topic. To avoid generalizations which are difficult to substantiate and even harder to use, we SELECT Mathematics as a proxy for science & engineering. The characteristics which distinguish Mathematics include:

- Identifiable – in any subject area, practitioners can pick out the math;
- Pervasive – math is in every subject;
- Essential – there are math requirements in every science program;
- Evocative – math generates discussions;
- Personal – everyone has a math story.

Women in Mathematics may be considered as a special case (the intersection) of two larger issues: women in science and engineering, and the mathematical achievements of boys and girls. We are consciously taking the approach that studying the special case will be a useful step in understanding the general case. Or, to put it another way, we are not ignoring the boys. Furthermore, examination of the gender differences in attitudes towards Mathematics is a step to understanding the cognitive issues.

To understand the processes which would lead to gender differences in participation in Mathematics, we first review, very briefly, current research and understanding.

Studies of Mathematics ability among elementary school students have produced confusing, even conflicting, results as researchers progressed in understanding of the influence of cognitive convention, culture, and children's experience on the outcomes. Relative abilities of boys and girls are usually close, seem to depend on the type of test, and, as in the musician example above, can be reversed by other factors. However, a consolidation of current research identified consistent themes [6]. The abilities of girls and boys are very similar, and there are larger differences in performance within each sex than between the two sexes. Skills are learned rather than innate. Girls like subjects where they get recognition, and boys like subjects where they win, so both for boys and girls, math ability and interest correlate.

For the high school performance in mathematics, as for elementary school students, some past results were inconsistent, but conclusions have converged in recent years on the main points:

- No substantial gender difference in math performance tests;
- Student (boys & girls) perceptions are that boys' skills are higher;
- Self-evaluation is lower, relative to performance, for girls;
- Self-evaluation is higher, relative to performance, for boys [7].

For selecting a career path, high school girls are more influenced than boys by

- Marks and self-evaluated ability,
- Advice of parents & teachers,
- Job opportunity,

- Desire for career flexibility, balance career & family, and
- Desire to make the world a better place [8].

The most recent information on high school student attitudes comes from an survey of over 200 B. C. high school students [9]. The study focus was on computer science, but the questions were quite general. The same features identified above emerge, although the gender differences (in large, urban, high schools) are smaller.

The high school information indicates, since girls choose subjects they think they do well in, and since girls perceive their ability to be a little lower than the boys, that the ratio of women enrolled in Mathematics and math-related subjects in university will be a little less than 0.5. In some Mathematics programs in some universities, this expectation is met; in other Mathematics programs and in Physics, Computer Science, and Engineering, the ratios of women are 0.2 or less. The inconsistency shows that other factors are present and influential.

There is very little information in the literature on women in science and engineering to explain these ‘other factors’. There is, however, a wealth of anecdotal information, to which the reader may also contribute. Among people who have attended university, math attitudes fall into several groups: a) “never liked math” (or worse); b) “always loved math” (other end of the distribution); c) “did alright in math, but couldn’t see the point”; d) “always liked math until I got to University, and then I had trouble”; and, most intriguing, e) “always had trouble with math, but it finally started to click when I used it in ...”.

It has been argued [10] that engineers’ training in “abstract mathematics” is the cause of gendering of the engineering workplace, and that using math, which is “abstract thinking” and therefore male, to “weed out” in engineering schools ‘genders’ the selection of people who succeed. The characterization of math as “abstract thinking” and therefore male has been adopted by other authors, e.g. [11]. A study which focused on Physics students [12] presented a similar characterization of Physics, but went further to question whether it was the subject, or the form of course and curriculum material. We continue the focus on Mathematics by reviewing the nature of the discipline itself.

MATHEMATICS – SUBSTANCE AND EXPRESSION

In the academic as well as the anecdotal assessments above, there is a confusion of expression for substance. The students are judging Mathematics based on their classroom experience, for the most part introductory level, and the academics are likely working with approximately the same material. To use the music analogy again, this is equivalent to listening to CD’s from one small section of one store, and then assessing music. The cognitive substance of Mathematics is much larger and richer than that presented in introductory calculus, and even that well-worked topic could be expressed in many ways.

Mathematics is the study of form and relationships, and the use of form and relationships to organize information. The **substance** of Mathematics is extremely important in our modern world. The outstanding characteristic of the end of the 20th century is enormous quantities of information, in engineering, health care, finance, communications, and entertainment. Not only in careers, but in any slice of life, Mathematics is there, in some expression, structuring the information and making it accessible. Since, for many people, Mathematics means what they learned in school, they do not see the connection with the rest of their lives. What one learns in school, particularly university, is the academic **expression** of Mathematics.

The accompanying adjective ‘abstract’ has an undeservedly unfriendly reputation. It is true that to study form and relationships, we must abstract them from their manifestations, but it is not difficult. If we have three cups of coffee, three days until the end of the week, and \$3 for lunch, we understand that the ‘3’ in each example is the same. The concept of ‘3’ is an abstraction which we use without difficulty. Similarly, we know that ‘two-way’ can describe traffic direction, trade relations, and telephone conversations. The abstract concept of reciprocity is one which we transfer easily from one application to another. It is not the ‘abstract’ which generates the reactions to Mathematics, but rather the way Mathematics is expressed in academic settings.

Our academic expression of Mathematics conforms to the axiomatic tradition, which flows to us through the Greek-Roman-European history pipeline. It was probably Thales (ca 600 B.C.) who first proved a theorem in a logical fashion. His students proved three more, and the fad was picked up by the Pythagorean school, where “all is number” [13]. Within a philosophical tradition in which Mathematics represented value, purity and beauty grew the idea that one

progresses in knowledge from elementary principles, or axioms, through deductive reasoning, to more complex relationships. As an illustration of the strength of this ‘academic tradition’, we note that Archytas (b. 428 B.C.), a 3rd generation Pythagorean, prescribed four essential elements of education as arithmetic, geometry, music, and astronomy (the mathematical quadrivium), while his contemporary Zeno added the trivium of grammar, rhetoric, and dialectics. These seven liberal arts formed the backbone of classical education until the modern era. And in 1898, Hilbert went back and cleaned up a few axiomatic rough spots in Euclid’s work to put geometry on a strictly axiomatic foundation [14], confirming the preeminence of the axiomatic tradition.

The axiomatic tradition permeates modern Mathematics writing and teaching, and influences many of the other sciences. The conventional format for communication of mathematical results is still axiomatic, and ‘rigour’ is a proxy for merit. Post-secondary mathematics courses usually present concepts and proof first, and applications as exercises. The characteristics of the axiomatic tradition are:

- Legitimacy through argument and proof;
- Concept is primary; application is secondary;
- Progression is hierarchical.

For many people, the legitimacy of a concept comes not through argument and proof but through observation and testing. When they say that Mathematics is abstract, they probably mean that the axiomatic approach is not their way of arriving at knowing. These people are relational learners [15]. The characteristics of relational learning are:

- Legitimacy through observation and experience;
- Relationships are primary; structure evolves;
- Validation and extension are continuous.

As with other features, learning styles distribute over a range of values. Contrasting with relational is hierarchical learning. The characteristics of hierarchical learning align closely with those of the axiomatic tradition. Legitimacy through argument and proof is the “given, required, proof” of high school geometry, and the hypothesis, method, results, conclusions of the science lab. For hierarchical learners, deductive proof is both necessary and sufficient. For relational learners, it is neither. They need to see the concept work, in different forms. The relational learning environment is information rich, and they progress by developing its structure. Hierarchical learners will find this situation confusing and lacking in motivation.

Relational learners in an axiomatic environment:

- Question legitimacy;
- Question motivation & relevance;
- Feel anxiety due to missing validation;
- Miss steps in the progression or are slower.

There is a strong correspondence between the experience of relational learners in an axiomatic environment and the anecdotal experiences of women in university Mathematics. Precise correlation is difficult because, since individual learning styles distribute over the range, attribution depends on where the line is drawn, or, as with earlier research, on the measuring instrument. However it seems reasonable to conclude that most women are relational learners (93% in one study [16]). Furthermore, most men are relational learners (using [15] and back-calculation suggests 77%). The impact of these data is that many men are disadvantaged by the axiomatic tradition of Mathematics. Or, to put it positively, a change in the traditional expression would make math more accessible to men and women.

Of the small percentage of the population who are hierarchical learners, approximately 80% are men. Among the relatively small group of people who have high mathematical ability, the hierarchical learners are favoured in traditional pedagogy, testing, and competitions. Hence the outliers, the concert performers, are likely to be men. Erroneous but common conclusion: girls can’t do math.

We conclude this section by returning to the distinction between substance and expression. Some people will say that it is easy to prove a theorem, once you see how everything fits together. Others will say that you must prove the theorem so that you will understand how everything fits together. The Mathematics is how it fits together. Mathematicians, in pure research and in applied fields, use different thinking styles (empirical, deductive and relational) to arrive at an understanding of how it fits together. In fact, the cognitive structure of Mathematics is highly relational. Creativity in Mathematics, and the ability to apply mathematics outside the academic discipline both depend on relational thinking.

The axiomatic culture of Mathematics is not the cognitive essence, but rather a tradition of expression. The exclusive environments of the schools, monasteries, and early universities sustained this axiomatic tradition. Its persistence ensures that Mathematics remains an exclusive discipline, but it does not constitute Mathematics.

MERIT IN SCIENCE AND ENGINEERING

The discussion above implies that changing the expression of mathematics would improve access to mathematics and possibly to other science and engineering fields. In the academic culture, ‘making it easier’ always raises warning flags about reduction in academic merit. More generally, we know that ‘easier’ and ‘better’ are often divergent paths. In this section, we consider three aspects of merit in science and engineering: **validity**, **relevance**, and **quality**. Our proposition is that encouraging diversity of thinking styles in science and engineering would improve access without diminishing merit.

The consequences of mistakes in science and engineering range from embarrassing to costly to tragic. **Validity** means that what we understand, or think we know, is true within some defined parameter space. Newtonian Physics is valid provided that the speeds of objects are much less than the speed of light. Logical argument from an initial set of principles is one way to establish validity, and in the axiomatic tradition this is necessary. However it is not sufficient, for even impeccable arguments cannot overcome flaws in the initial assumptions. A great deal of scientific knowledge is acquired statistically, and is valid with a limited degree of certainty, again within a defined parameter space. Statistical, or empirical, knowledge has long been the core of the life sciences. In the many disciplines which use numerical simulations, from complexity theory to geophysics, high speed computation capacity has led to increasing use of empirical validation. Some knowledge is hypothetical: its validity increases if the hypothesis survives rigorous testing, but the knowledge remains hypothetical until all possible tests have been applied. Understanding, expression, and validation may proceed by different routes. Understanding acquired by one route and tested by another is at least as robust as a understanding achieved and tested within the same regime. Opening up the expression of science to admit a diversity of styles encourages critical thinking about validation, and hence preserves or enhances merit.

While usefulness is not the only reason to study science and engineering, **relevance** to our experience and to our society is a merit factor. Relational technologies which are relevant to our society include:

- www (world wide web) and internet technologies;
- HVS (human visual systems) and digital image processing;
- DNA (deoxyribonucleic acid) and genetic engineering;
- Climate modeling and study of global warming.

In fact, it is difficult to identify a modern manifestation of science and engineering which does not have relational characteristics. At the same time, hierarchical thinking and design play important roles in all of the technologies listed above. There is value to society (social merit) in widespread understanding of science and engineering topics. Hence science and engineering must be accessible to relational, as well as hierarchical, thinkers. Furthermore, there is scientific merit in having both relational and hierarchical styles of thinkers participate in the development of the science.

Quality of science, a characteristic of science distinct from validity and from relevance, is difficult to define without context. In the context of a university, Simpson [5] gives us both the definition and the argument. Simpson assumes that the university’s defining purpose is the advancement of knowledge, and gages quality on the ability of the institution to fulfill its purpose. If we adapt this definition by defining quality as advancement of knowledge in science, we may then, to advantage, adopt his elegant epistemic argument for the general principle, that pluralism is a stronger basis for the advance of scientific knowledge than homogeneity. Diverse thinking styles introduce additional perspectives and criticisms, and thus contribute to the quality of the science.

Quid est demonstratum. Encouraging diversity of thinking styles will improve access and enhance merit in science and engineering. The argument here has been from a point of view of the science disciplines themselves; other arguments from the point of view of the philosophy of science, e.g. [17], have come to similar conclusions.

CONCLUSIONS AND ACTIONS

Taking Mathematics as a special case in science and engineering, this discussion shows that although within Mathematics there are various thinking styles, a restrictive academic tradition of axiomatic expression has favoured

success for men more than for women. For Mathematics in particular, and for science and engineering in general, merit is enhanced by a diversity of thinking and expression styles. Hence improving access for women will enhance, not diminish, merit.

The motivations for the study have been addressed. We have explored one of the underlying issues which affect the participation of women in science and engineering. The outcome shows clearly that programs which improve access to science and engineering will tend to enhance, rather than diminish, merit. A new perspective was gained by looking at the information from within science and engineering, rather than as an external observer.

There remains the question of how to change the traditions which limit access to science and engineering. The culture of academic science is deeply embedded, and intractable [18]. The discipline cultures are stable, in a stabilizing academic environment. In such cases, action by an external agent is required to initiate change. Intervention programs and programs which selectively encourage women are examples of change measures. Significant and lasting change requires widespread initiatives from within the disciplines. The internal change agents will be educators who recognize alternate routes to understanding science, researchers and academics who value new approaches and alternate ways of exploring in the traditional disciplines, and policy makers who recognize the positive correlation between access and merit in science and engineering.

REFERENCES

- [1] Noble, D.F., *A World Without Women. The Christian Clerical Culture of Western Science*. 1992, New York: Knopf.
- [2] Schiebinger, L., *The Mind Has No Sex? Women in the Origins of Modern Science*. 1989, Cambridge, Mass: Harvard University Press. 355.
- [3] Emerson, C. and F. Murrin. "I Know I Can Be Whatever I Choose": Outcomes of a Summer Job Experience. in *Women in the Workplace: Achieving Harmony*. 1998. Vancouver: CCWEST/DAWEG.
- [4] Frize, M., et al. Pinnocchio's Nose, the Long and Short of it: A Special Day for Grade 10 Female Students at Nortel. in *Eleventh Canadian Conference on Engineering Education*. 1998. Halifax.
- [5] Simpson, E., *Equality and Merit*. (to appear), 2000.
- [6] Jackson, A., *Encouraging Women in Math and Science*. Notices of the American Mathematical Society, 1990. **37**(1).
- [7] Junge, M.E. and B.J. Dretzke, *Mathematical Self-Efficacy Gender Differences in Gifted/Talented Adolescents*. *Gifted Child Quarterly*, 1995. **39**(1): p. 22-26.
- [8] Marini, M.M., et al., *Gender and Job Values*. *Sociology of Education*, 1996. **69**(January): p. 49-65.
- [9] Chan, V., et al. *Gender Differences in Vancouver Secondary Students' Interests Related to Information Technology Careers*. in *New Frontiers - New Traditions*. 2000. St. John's: NSERC/Petro-Canada Chair for Women in Science and Engineering, Memorial University of Newfoundland.
- [10] Hacker, S., *The mathematization of engineering: Limits on women and the field*, in *Machina ex Dea: Feminist Perspectives on Technology*, J. Rothschild, Editor. 1983, Pergamon: New York.
- [11] Miller, G.E., *The frontier 'cowboy' myth and entrepreneurialism in the culture of the Alberta oil industry. Professional women's coping strategies: an interpretive study of women's experience*, in *Faculty of Management*. 1998, University of Calgary: Calgary. p. 246.
- [12] Tobias, S., *They're Not Dumb, They're Different*. 1990, Tucson: Research Corporation. 94.
- [13] Boyer, C.B. and U.C. Merzbach, *A History of Mathematics*. Second ed. 1991, New York: John Wiley & Sons.
- [14] Hilbert, D., *Foundations of Geometry (Grundlagen der Geometrie)*. 1988 (originally 1899): Open Court Publishing Company.
- [15] Booth, S. and C. Brooks, *Adult Learning Strategies: An Instructor's Toolkit by Ontario Educators*, . 1985, Ontario Ministry of Skills Development. Toronto.
- [16] Brooks, C., *Instructor's Handbook: Working with Female Relational Learners in Technology and Trades Training*, . 1986, Fanshawe College and Ontario Ministry of Skills Development.
- [17] Longino, H., *Science as social knowledge*. 1990, Princeton: Princeton University Press.
- [18] Subramanian, B. and M. Wyer, *Assimilating the 'Culture of No Culture' in Science: Feminist Interventions in (De)Mentoring Graduate Women*. *Feminist Teacher*, 1998. **12**(1): p. 12-28.