BUILDING ON THE FOUNDATION FOR AN ENGINEERING CAREER

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Summary

A predictable and preventable hurdle stops a majority of young women from entering the scientific and technical fields. This cuts down the individual's career possibilities, and cuts in half the pool of potential U.S. engineers later available to industry. The waste of talent does not advance our country's competitive position.

The typical American adolescent girl has acquired all the basic mathematical skills needed to pursue science and math, but, from adolescence on, she does not build the foundation of science and math courses that she would need later in life to work in engineering.

Several questions are addressed: Why are some young women stopped cold in their mathematical tracks during adolescence? What is the influence of psychology, including discussion of the personality traits quantifiably shared by women in technical fields? How should the school system adapt to keep their female charges learning math and science?

Introduction

Several recent studies indicate a disturbing possibility that young women are typically stopped cold in their mathematical tracks during adolescence. The typical adolescent girl does not build the foundation of science and math courses that she will need later in life to work in engineering. This has the end result of limiting the number of young women who are later able to work in the scientific and technical fields.

Before adolescence, many different articles (refs. 1 and 2) have discussed studies showing girls competing equally with or out-performing boys in the fields of study most important to the technical professions: mathematics and science. However, after girls reach adolescence, their average performance and participation in these fields drops significantly.

The effect persists to the highest levels of education. The National Research Council (ref. 3) regularly surveys Ph.D. scientists and engineers in the United States. In their highlights from the 1989 survey, they reported that among doctoral scientists and engineers, the proportion of women grew from 8.6 percent in 1973 to 17.3 percent in 1989. Women represented approximately one-third of the Ph.D.'s in psychology and the medical sciences, but less than 5 percent of the Ph.D.'s in engineering. Women are going on to higher education, increasing both in numbers and percentages, but they are apparently avoiding engineering.

One explosive new study (ref. 4) states bluntly that schools are shortchanging girls. Recent studies have shown that during adolescence, girls suffer a significant drop in self-esteem, which affects their performance. Other studies have shown (ref. 5) that women in technical fields share certain personality traits. Are these the same traits that helped these individuals avoid or survive a drop in self-esteem and performance experienced by the average adolescent girl? How can the school system change to keep these students performing in math and science during this phase of their lives? Studies suggest an emphasis on cooperation and problem solving (ref. 6) rather than competition does reduce alienation of these students. In addition, science and math events tailored to girls (ref. 7) appear to convince them that science and math are fundamental to many careers.

Physical changes accompanying adolescence are probably no more difficult for girls than for boys, because radical physical changes take place in all adolescents. There is no evidence of a significant difference in overall mental capabilities, although intriguing differences in some components of mathematical thought, such as pattern recognition and spatial resolution, have been uncovered. The societal forces appear to simply be harsher on girls, and to be responsible for the adverse changes in mathematical performance.

Why do the majority of adolescent girls appear to lose interest in mathematics? Why are other students unimpeded, as is proved by the growing representation of women in the technical fields?

Regardless of the causes, it is important to take steps to help adolescent girls get past this predictable hurdle in their lives. It is important to keep girls involved in learning mathematics and science to keep their future options open. After a brief overview of current developmental theory, the results of recent studies are summarized in the following sections. Proposed solutions are repeated in the summary.

Background: Psychological Framework

A condensed outline of current psychological developmental theory is sketched out below to provide a framework for discussion of adolescence and pre-adolescence.

The personality is defined by psychiatrists as the sum total of all an individual's experience, because it is believed that every event that happens to a person has an impact on their personality (ref. 10). There are three main schools of thought on development of the personality:

- heredity vs. environment
- mechanistic vs. organismic
- critical periods

The heredity vs. environment theory refers to the well-known nature vs. nurture issue. The mechanistic vs. organismic theory argues that a person is either like a mechanism, rigid and unchangeably responding to events in life, or more like an organism, evolving and flexibly changing when necessary. The critical period theory asserts that a person is staged to learn and evolve only at certain critical times in life. The critical period theory is the cornerstone of Erickson's "eight stages of man" model, which is almost universally accepted today. For this reason, it is discussed below.

Erickson's eight stages of psychosocial development (ref. 8) are shown in table 1. Erickson's framework for development covers a model for development over the individual's entire life. Few age limits are shown in the table, because each person has a different maturation rate. Psychiatrists believe that most individuals do not progress through all stages completely. The stages of life relevant to this discussion are latency and adolescence.

Latency is the period of life from ages 6 to 12 for most people. This is a joyous time for children, as they are expanding their horizons and grasping new concepts. Their attention is easily engaged, and they repeatedly experience a sense of mastery over new skills . In grades 1 to 7, they learn to read, to write, to solve problems in mathematics, to ride a bike, etc. The crisis of latency is the clash between the active industry of learning and the developing feeling of inferiority. For the first time they are cognitively aware of shortcomings in themselves. Self-doubt, possibly even shame, over one's self or family now comes to the forefront of consciousness. Positive role modeling can have a significant impact here, before the child becomes a teenager. The most important relationships center around the school and the neighborhood.

Adolescence is the next period of life. Because this stage is so variable for different people, Erickson provides no age delimiters. The central crisis at this stage of life is that of ego identity versus role confusion. The ego identity or sense of self is strong, and children want to be treated more as individuals. Freedom, independence and the right to choose one's own friends, clothes, or books become important to them. This is when children start to question authority, in particular, their parents. They mentally put a distance between themselves and their families, and want their friends to replace their parents as the center of their social lives. This is the time when children are "launched" into the world. Role confusion refers to the sorting of sexuality and of where they fit in the world. They already know where they fit in their families. This stage can be very painful for some children. They feel a strong need to be in agreement with their peers, rather than conforming to their parents. The leadership models at this stage are usually an idealized teacher, a rock star or movie star, or the most popular and attractive child at school. The smartest adolescents never appear to be idealized by their peers.

Erickson's theory asserts that the social clues and cues are different for the two genders as they grow. The media, role models, books, schools, parents and relatives all send out subtle, or not so subtle, messages about what is expected of a person.

Children absorb new information and messages constantly. According to Piaget (ref. 9), it is the job, or the life's work, of children to develop the ability to measure things out, to delay gratification with some degree of stability and internalized control, and to be able to understand and conceptualize differences. Piaget did widely accepted work on how children organize information, how they take in new concepts and information and gradually learn to apply it to the environment. They are constantly adjusting their ideas, synthesizing new information and using the new synthesis in new applications.

Piaget gave an example to illustrate the changes in the child's process of thought. Witnessing a one-gallon container of water being poured into a tall, narrow, empty container, a younger child will insist that the tall container holds more fluid, because it is so much taller. An older child understands that the two containers hold the same amount of fluid, because the child saw that all the water came from the one gallon container.

Adolescence is an important time in life. According to English and Finch (ref. 10), an adolescent has several jobs at this stage of life.

- to attain emancipation from the parents
- to choose a vocation
- to accept their sexual identity and goals
- to integrate their personality in the direction of altruistic goals
- for girls: to make the difficult choice between a career, homemaking, or only recently, a balance of both career and homemaking.

Regardless of psychiatric theory, most girls do not choose a vocation at this stage of life. There are two probable causes. First, the marriage-versus-career choice may consume so much of their energy that they are unable to focus beyond that conflict, although many girls try to deny the existence of the conflict entirely. Second, girls are not forced or encouraged to choose a vocation by the adults in their lives, their parents and counselors.

In summary, theories of psychological development provide a framework for understanding the changes and conflicts confronting the adolescent girl.

Non-traditional Women?

In her study and overview of the literature on women in male-dominated professions, Ashburn (ref. 5) reported that

> "those women who have entered the top professional fields have had to have extraordinary motivation, thick skins, exceptional ability, and some unusual pattern of socialization in order to reach their occupational destinations. Intelligence and education are apparently not sufficient conditions to predict professional achievement."

Asburn painted a stark picture in the 1977 work. The stereotype existed in the popular literature of the professional women as the masculine, dominating, aggressive, insensitive, probably less-than-competent woman in a man's world.

This stereotype was not affirmed by statistical analysis of available surveys and personality inventories, which portrayed a positive image of actual professional women. The personalities of women in non-traditional occupations exhibited four main focal points: independence, intelligence, feelings and ego-strength. They were more independent and inner-directed than the average, they were not as sociable, and they were more radical and adventurous. Presumably because they are a minority both among women and among professionals, they had less ego-strength and were less self-assured. Like all women, women scientists had been trained to be supportive of others, to listen, to stroke. Ashburn remarked that these behaviors were probably incompatible with aggressive professionalism and ego-strength. In a typical finding, female and male medical students were equally intelligent, effective, aggressive, etc., but the women placed more importance on relationships, were more accepting of feelings, and more alert to moral and ethical issues.

Psychiatrists attempting to explain and categorize women making non-traditional career choices have produced two theories: the "deviance" hypothesis and the "enrichment" hypothesis. The "deviance" hypothesis asserts that such women are deviants from traditional middle America, in what appears to be a tautology. The "enrichment" hypothesis asserted that women who chose nontraditional work have been exposed to more alternatives and recognize a greater variety of options for women, often by contact with a different culture or a variety of jobs. Ashburn cited quantitative evidence for the enrichment hypothesis.

Things have changed to a large extent since large numbers of women returned to the work force outside the home. Women don't have time to "think pink" anymore. Up to the 1960s, gender differences had more cultural relevance than today, and they determined a person's role in life to a greater extent.

In summary, analysis of personality surveys of women scientists showed an unusual constellation of personality traits and experiences. These traits may have been necessary for these women to survive the school system and embark on scientific careers.

The Impact of the School

For the AAUW report, Bailey (ref. 4) surveyed a large body of recent statistical studies on the effect of the school system on female students. Bower (ref. 1) and Brush (ref. 11) recently summarized this and other related work for a wider audience. One statistical study indicated that girls suffer from a large drop in self-esteem when they become teenagers. Girls also expressed less interest in professional careers, less interest in math and science, and less confidence in themselves than did boys. The students with higher self-esteem liked science and math more than the average student in the study.

The effect on self-esteem was measured by surveying 2400 girls and 600 boys, aged 9 to 16. One fourth of the students were Black or Hispanic. The students were from 36 schools spread across the United States. The survey included questions about a student's sense of well-being, if they liked themselves, etc. The study reported sharp drops in self-esteem as the students began junior high school for both sexes, but that the number of girls who were unhappy with themselves was greater, and the loss of self-esteem was worse in girls.

Girls rarely play with boys after age 5. However, girls and boys do compete in the classroom. Scholastics is the only area that the two groups interact or compete in. Girls and boys act and learn in different ways, but coeducational schools tailor their instructional methods to the learning style of boys (ref. 1), emphasizing, for example, competition. This has the result of causing girls to doubt their academic abilities.

Coeducation itself appeared to have a detrimental effect on the girls learning. Gilligan (ref. 6) showed that small mixed-sex groups have been shown to have an adverse effect on girl's learning. Girls who said they did poorly in math and science blamed themselves, but boys who said they were unsuccessful in math and science blamed the subject itself, saying they thought it was useless.

Ashburn (ref. 5) proposed an interesting new perspective on the value and significance of competitive drive, citing studies on the motivations of scientists. Almost 40% of the men but only 25% of the women gave the "publish or perish" or the competitive atmosphere of their institutions as a strong motivation, whereas 75% of the women and almost half of the men cited "fascination with the problem" or a preference for research as a reason. Also, considering recent scandals among scientists, the value of competitiveness must be questioned. A competitive environment has been repeatedly shown (ref. 2) to discourage girls, and a cooperative environment has been shown to encourage girls. Gilligan (ref. 6) reported that girls generally learn best and had the greatest self-confidence working in collaboration with other students and teachers, rather than in competitive situations. Boys, on the other hand, did best on competitive tasks or in games with a strict set of rules.

Kimball (ref. 2) summarized a formidable body of academic literature, relying on statistical analyses of girls' performance in mathematics. The article focused on a significant, well-documented, but largely ignored finding: that girls receive better grades in math than boys, although boys do better on standardized test than girls, as has been much publicized.

Sex-correlated difference in mathematics performance on standardized tests appear in grades 8 or 9, and generally favor boys. Older studies or studies reflecting smaller sample sizes reported larger sex-related differences on standardized tests than do more recent studies. Meta-analysis indicates that this probably reflects recent improvements in girls' performance in mathematics, due to reduced stereotyping of math as a male domain and increases in the number of math classes girls currently take as opposed to reflecting a change in publication policy allowing studies showing small-magnitude effects to be published.

However, when mathematics grades are used to analyze differences in mathematical performance between girls and boys, the opposite trend is observed (ref. 2). Differences, when measurable, almost always favor girls, and this holds consistently across high school and college samples.

This is particularly surprising because many studies have shown that the classroom environment is less favorable to girls than to boys. Boys receive more of the teacher's attention, are more active in class, and receive more encouraging remarks.

To illustrate, in grade 2, boys had more academic contact with teachers, a difference that has been estimated amounting to 6 hours of instruction over one year. Studies of grades 5 to 9 found few overall differences, however, when math and sciences classes were separately studied, trends appeared correlating the students role-related expectancies with their performance. One surprising finding indicated that the students who received the most attention in these classes were high-achieving boys and the low-achieving girls. In high school classes for older students, consistent differences in treatment are still found. For example, girls received 84% of the discouraging comments and 30% of the encouraging comments.

Overall the classroom appeared to be an unfavorable and depriving environment (refs. 1 and 2) for girls when compared against boys' experiences.

This may account for the fact that girls are consistently less confident of their math abilities than boys. Mathematics may serve as a red flag to indicate a student's confidence level (ref. 2), because students with low confidence may tend to avoid math, where one is likely to make highly visible errors. Highly confident students may prefer math to more subjective verbal subjects, because in math the student is likely to be able to demonstrate, to objectively prove, her/his ability by the successful solution of a math problem.

That boys take more elective math courses than girls has been well-documented. In addition, studies have shown that boys have more experience outside the classroom related to science and math than do girls. However, the effect of enriching experiences with mathematics outside the classroom has not been well studied. One aspect of such extracurricular experience is toys. One study (ref. 2) of a group of girls in accelerated math and science classes documented that,

> "a commonly remembered experience was trouble convincing their parents to buy them toys such as Legos. In particular, chemistry sets had been much desired with little success unless they were only children, the oldest of several girls, or separated from their brothers by a large age span."

Specific studies are needed to relate the extent of extracurricular math experiences to mathematical or scientific achievement, to determine the significance, if any, of experience with mathematics or science outside the classroom.

Why do girls take fewer math classes than boys, given their higher grades? Kimball suggests that the girls' lesser extracurricular math and science experience, and a presumed rote approach to mathematics undermines their confidence and their motivation for pursuing math courses. Studies suggest that, even when they did very well in their current math classes, girls were more likely to believe this resulted from hard work than innate ability, so they did not regard this as proof that they would continue to excel in math. Sex-role conflict plays a role as well, in terms of discrimination, stereotyping, and downplaying of even a gifted girl's achievements in science or math. In addition, the conflict between motherhood and a demanding career may reduce a girl's interest in pursuing an engineering or scientific career.

Kimball recommended that good math grades earned by girls be taken seriously, by parents teachers, counselors, and the girls themselves. Grades are an important measure of achievement, and it is unclear why grades show an opposite trend of girls' and boys' abilities from that of standardized tests.

It is believed that good grades have not been used to help girls fulfill their potential, due to the low expectations for the girls' future held by the parents and other significant adults. Parents and teachers can be influenced, even by popular media reports, to take a girl's good grades seriously. This may in turn improve the girl's confidence and performance, and encourage her to take more math courses.

A recent article by Brush (ref. 11) probes why women are still under-represented in the sciences at this time, and proves that the early school and social environments are not solely responsible for the shortage of women in engineering and science. The obstacles of the college and work environment may even override earlier effects.

A great deal of effort has gone into recruiting women into technical fields, but not to keep women from dropping out. Furthermore, in light of the institutional barriers still in place, Brush suggests that individual women may in fact be even acting in their own better interest to drop out of these fields. This work summarized an extensive body of literature on the chilling effect of the college and the work environment on women's careers. The following have been quantitatively demonstrated or are strongly suspected to be effective obstacles to women's success in science and engineering: stereotypes of scientists, textbook stereotyping, publicity about older, dubious studies on women's supposed mathematical inferiority, bias in the Scholastic Aptitude Test, financial aid cutbacks, sexist and combative attitudes among students and scientists, and the glass ceiling. Brush's recommendations are included with other recommendations in the summary.

The current laws, books, and newspaper want ads, have either fundamentally or superficially reduced sexual stereotyping. On toys and in commercials, the "doers" still tend to be boys, with the girls depicted as "helpers". This is progress from the "helpless" image portrayed before the 1960s. In the 1978 edition of a well-known physics text, the earlier illustrations, all featuring males, were replaced with new illustrations, which could be construed as either male or female.

The large body of data on cognitive sex differences has been publicized and has a strong impact on popular thought, but objective examination shows dubious claims have been made. Brush shows that no significance can be attached, for example, to the differences in spatial perception abilities favoring boys for two main reasons: the effect is small, e.g., one-half of one standard deviation, and the effect is inconsistent with spatial ability measurements in cultures where this ability has some actual relevance in everyday life. In addition, recent studies have shown girls outperforming boys on a different component of mathematical thought, that of pattern recognition. Brush suggests publicizing the recent studies, to defuse the popular belief that it has been somehow scientifically proven that girls are "inferior" in math.

On the effects of the tenure and similar promotion systems, Brush points out that it is counterproductive to discourage women from entering science for fear of a temporary drop in productivity due to time spent caring for young children, and it is also counterproductive to discourage highly intelligent citizens who are scientists and engineers from having children.

Summary and Conclusion

The focus of this work is on fostering survival of the adolescent girl through the earlier school years without her getting sidetracked from the mathematical and scientific curriculum. Regardless of the environment awaiting her, it is impossible for her to enter the scientific and technical fields without the right educational background.

Specific remedies proposed include improving the school system's treatment of its female charges, emphasizing grades in counseling and scholarship decisions, de-emphasizing the SAT, publicizing recent research that refutes stereotypes on females' mathematical abilities, reducing the emphasis on competitiveness, funding long-term intervention programs for girls, and tearing down institutional barriers that conflict with family life.

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Table 1: Erickson's eight stages of psychosocial development

Stage/age	Conflict	Significant relations	Favorable outcome
Oral-sensory (0–12 mos.)	Trust versus mistrust	Primary caretaker	Trust and optimism
Muscular (12–36 mos.)	Autonomy versus shame	Parents	Self-assertion, self-control, feelings of adequacy
Locomotor (3–6 yrs.)	Initiative versus guilt	Family	Sense of initiative, purpose, direction
Latency (6–12 yrs.)	Industry versus inferiority	School, neighborhood	Productivity and competence in physical, intellectual and social skills
Adolescence	Identity versus role confusion	Peers, leader models	Integrated image of oneself as a unique person
Early adulthood	Intimacy versus isolation	Partners in friendship, sex, etc.	Ability to form close personal relationships and make career commitments
Middle adulthood	Generativity versus stagnation	Shared labor and household	Concern for future generations
Maturity	Integrity versus despair	"Mankind"	Sense of satisfaction with one's life; ability to face death without despair

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
February 1994

3. REPORT TYPE AND DATES COVERED
Conference Publication

4. TITLE AND SUBTITLE
1993 Technical Paper Contest for Women

5. FUNDING NUMBERS
JO-M1009

6. AUTHOR(S)
Edited by Robin Orans, Sophie Duckett, and Susan White

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ames Research Center
Moffett Field, CA 94035-1000

8. PERFORMING ORGANIZATION REPORT NUMBER
A-93034

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CP-10134

11. SUPPLEMENTARY NOTES
Point of Contact: Teresa Alvarez, Ames Research Center, MS 241-7, Moffett Field, CA 94035-1000;
(415) 604-6510

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified — Unlimited
Subject Category 99

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The NASA Ames Research Center Advisory Committee for Women (ACW) sponsored the second ACW Technical Paper Contest for Ames women in order to increase the visibility of, and to encourage writing for publication by Ames women scientists, engineers, and technicians. The topics of the contest papers mirrored in the topics of the 1993 Society of Women Engineers (SWE) National Convention, which included technological, workplace, global, and family issues.

14. SUBJECT TERMS
Tilt-wing control, In-flight simulation, Aircraft acoustics, Computerized maintenance management systems, Women in engineering

15. NUMBER OF PAGES
139

16. PRICE CODE
A07

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102