Girls Can and Should Do Mathematics, But Most USA Ones Don’t Due to Socio-cultural Factors

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1. INTRODUCTION. At a conference held in Cambridge, Massachusetts in January, 2005, Dr. Lawrence Summers, then President of Harvard University, hypothesized that a major reason for the paucity of women mathematicians among the tenured faculty of elite universities in the USA might be sex-based differences in “intrinsic aptitude” for mathematics, especially at the very high end of the distribution (39). This commonly held belief is largely based upon data from standardized tests such as the Quantitative Section of the Scholastic Aptitude Test (SAT) I. However, these standardized tests are fairly low-level. They examine proficiency in grade-level knowledge with multiple-choice questions under stringently timed conditions. Thus, they cannot distinguish the 99.99 percentile from the merely 99 percentile.

To circumvent the grade-level problem, The Study of Mathematically Precocious Youth (SMPY) defined children as highly gifted in mathematics if they could achieve a score of at least 700 (on a 200 to 800 scale) on the quantitative section of the SAT I before the age of 13. Prior to 2005, this exam, normally taken by 11^{th} and 12^{th} graders, covered only arithmetic, Algebra I, and some topics from 10^{th}-grade Geometry. Using these criteria, Benbow and Stanley reported in 1980 large gender differences in “mathematical reasoning ability” (6). They concluded that “the hypothesis that sex differences in achievement in and attitude towards mathematics result from superior male mathematical ability . . . [that] is probably an expression of a combination of both endogenous and exogenous variables.”

However, data obtained from multiple choice, standardized tests are unable to provide much information regarding the existence of children with extremely high innate ability in mathematics, that is, ones who may go on to become top research mathematicians, since these examinations lack questions that require creative thinking and insight into higher-level mathematical concepts. Thus, they cannot differentiate between profoundly and moderately gifted children, regardless of age at which the examinations are administered. Therefore, the SMPY simply identified the subset of moderately gifted children with the motivation, opportunity, and social environment that enabled them to accelerate through or to skip over the three years of largely redundant USA middle school mathematics. Thus, this study identified many children who, while quite bright and ambitious, were not, necessarily, profoundly gifted in mathematics.

The SMPY also, undoubtedly, failed to identify many children with extreme innate ability in mathematics who lacked one or more of the socio-economically privileged environmental factors necessary to be recognized by this mechanism. Consistent with this latter hypothesis is the fact that the ratio of boys to girls identified by this means has steadily and dramatically declined throughout the past quarter century from the high of 13:1 originally reported in 1983 (7) down to 3:1 in a recent report (9) from this long-term, ongoing study. The fact that 29% of Ph.D.s awarded to USA citizens in the mathematical sciences went to women in the 2004-2005 academic year (3) agrees with this latter ratio being a more accurate reflection of current interest and ability in mathematics among USA females. It is probably not merely coincidental that this dramatic change has occurred post-Title IX, which resulted in greatly increased educational opportunities for females in the USA. This article presents an analysis of data from several competitions that identify students with extremely high ability in mathematical problem solving. The findings indicate that women exist who are profoundly gifted in mathematics; however, socio-cultural factors likely inhibit most highly mathematically gifted girls and many boys in the USA from studying mathematics at the level necessary either to be identified as very highly able or to go on to pursue a career in the field.

2. METHODS. To identify children who possess profound innate ability in mathematics, data were analyzed from the William Lowell Putnam Mathematical Competition, the International Mathematical Olympiad (IMO), and the USA Mathematical Olympiad (USAMO). These competitions consist of extremely difficult essay problems that identify college and high school students with truly exceptional skills in mathematical problem solving, for example, students gifted at the one-in-a-million level, even higher than the giftedness of the average tenured mathematics professor employed at top-ranked research universities in the USA. Furthermore, the IMO is taken by the very top mathematics students from approximately 90 countries throughout the world. Thus, it provides information regarding cultural differences among countries as well.

3. RESULTS. Putnam. The Putnam Mathematical Competition is an inter-collegiate 6-hour, 12-problem essay examination that has been given annually (with a few exceptions) since 1938 (20, 42). In recent years it has been taken by 3,500-4,000 undergraduate mathematics students from throughout the world who are attending colleges in the USA and Canada. The median score on this extremely difficult test is usually 0, 1, or 2 out of 120 possible points, that is to say, most of these already highly self-selected students are unable to solve any of the 12 problems. The top 25 scorers typically achieve 50 or more points, with the top-5 "Fellows" often scoring in the 80-100 range. Some Putnam Fellows (for example, David Mumford, John Milnor, and Daniel Quillen) have gone on to be awarded the Fields Medal, the so-called Nobel Prize of Mathematics. Others (for example, Richard Feynman and Kenneth G. Wilson) have received a Nobel Prize in Physics. Some who never quite achieved Fellow status have also gone on to become Nobel Laureates (for example, John Nash of *A Beautiful Mind* fame). At least 14 Fellows became members of the US National Academy of Sciences. Comparison of the list of Putnam Fellows (42) against the list of tenured mathematics professors on the faculties at some of the very top-ranked research universities in the USA such as Harvard, MIT, and Princeton indicates that only 5-10% of even this elite group of world-class mathematicians managed to achieve Putnam Fellow in college (albeit some of them, including most educated in other countries, never took this examination).

Table 1 shows the name and country of origin of 11 women who ranked among the top 25 students in the Putnam during the past 15 years. Three of these women even achieved Putnam Fellow. Thus, women with this extreme level of ability in mathematical problem solving do, in fact, exist. Interestingly, only approximately 8 women ranked among the top 25 during the half century prior to 1992. This striking increase is consistent with the post-Title IX changes in participation of USA women in science, technology, and engineering as well as mathematics, that is, STEM fields (12). Also noteworthy is the fact that only 3 of these 11 women were born in the USA. Thus, much of the increase is due to an increase in immigration and matriculation to college of outstanding foreign students to the USA and Canada following the collapse of the Soviet Bloc and the opening up of China. Half or more of recent top-ranked men were foreign-born as well (34; Table 2). Remarkably, 2 of the 3 women Fellows were from Romania, a country with a population only $1/15^{th}$ that of the USA and few economic resources. Thus, USA-born women remain fairly highly under-represented among top Putnam scorers, not only with respect to men, but also with respect to even the small number of foreign-born women who attend college in the USA and Canada.

Also noteworthy is the fact that almost all of these foreign-born women and men who excelled on the Putnam originated from Eastern European and Asian countries where they had received extensive training in mathematical problem solving during high school. Many of the women and 100% of the 2006 top-26 non-USA-born men had been members of their countries' IMO teams prior to matriculating to college in the USA. For example, Ana Caraiani and Suehyun Kwon had achieved Gold Medals as members of the Romanian and South Korean IMO teams, respectively, before attending Princeton University (26, 34). Likewise, after training with the Russian IMO team, Olena Bormashenko had immigrated to Canada where she became the top-scoring member of Canada's 2003 IMO team, achieving a Gold Medal. Amazingly, Ioana Dumitriu achieved Putnam Fellow even though she had trained with, but not quite qualified for Romania's six-member IMO Team. Thus, most of these women and approximately half of the men identified by the Putnam exam as possessing outstanding ability in mathematics had honed their skills in mathematical problem solving elsewhere prior to coming to the USA and Canada.

IMO. The International Mathematical Olympiad is a pre-collegiate 6-hour, 6-problem essay examination that has been given annually (with one exception) since 1959. In recent years approximately 90 countries send 6-student teams to participate. Table 3 lists the 13 countries that have consistently ranked among the top 15 in the world on the IMO throughout the past decade. Striking is the fact that all but one of these countries is located in Asia or Eastern Europe. No country from Western Europe made the list, not even the historically mathematical powerhouses, France, England, and Germany. The USA did make the list, although approximately half of their team members were immigrants or children of immigrants from these other top-12 IMO countries. China and India likely produce top IMO teams, in part, because they have huge populations of students from which to identify a few with profound mathematical ability. However, population size cannot account for why a tiny country such as Bulgaria, with only 8 million people, also consistently produces a top-ranked IMO team. Nor can gross national product or per capita income explain why Romania readily makes the list. Rather, what these non-USA countries that consistently produce outstanding IMO teams have in common are cultures that highly value students who excel in mathematics, thus encouraging and supporting them to excel.

Table 3 also summarizes the number of girls who participated in the IMO as members of their country's top-ranked IMO teams along with the medals achieved by these girls. The total number of medals is typically greater than the number of girls from each country because many of these girls participated in the IMO more than once. Gold medals are awarded to the top $1/12^{th}$ of the outstanding group of students who participate in the IMO each year. Chenchang Zhu of China, Maryam Mirzakhani of Iran, Evgenia Malinnikova of Russia, and Yuly Sannikov of Ukraine even achieved perfect scores in the IMO, a feat usually accomplished by only a few students per year (26). These data confirm the Putnam results that there exist girls who possess truly outstanding ability in mathematical problem solving.

Also noteworthy is the finding that the frequency with which girls are members in these top-ranked IMO teams varies considerably from country to country (Table 3). Quite striking is the fact that Bulgaria's teams have routinely included girls, dating all the way back to the very first IMO competition held in 1959 (Table 4). One of them, Greta Panova, matriculated to MIT for college where she also ranked among the top 20 in the Putnam. Russia's teams have also frequently included girls. In stark contrast, the USA IMO teams (which contained 4, 6, or 8 members depending upon the competition year) consisted solely of boys throughout their first 23 years of existence, with a girl finally making their team for the first time in 1998. As expected, USA IMO team members Melanie Wood and Alison Miller also ranked among the Putnam top-

15. Sherry Gong has not yet had the opportunity to do so because she is still a high school student. This difference in participation rates by girls is not due to differences in ease of qualifying for the IMO since the Bulgarian, Russian, and USA teams as a whole and their girls in particular typically perform at comparable levels (Table 3). Despite their tiny population, Bulgaria fairly routinely produces high school girls as well as boys who are among the very top mathematical problem solvers in the world. Thus, there exist many girls who possess extremely high ability in mathematics. Some countries have fairly regularly identified and nurtured such girls; the USA has only recently begun to do so and, even now, does so rather poorly.

Bulgaria and Russia are not alone in producing girls with IMO medal-level ability in mathematical problem solving. South Korea and Taiwan, despite only participating in the IMO since 1988 and 1992, respectively, have both already had five girls on their teams. On the other hand, Japan has only identified one girl to date for their teams during a comparable time period, the gold-medalist star of her country's team in 1996. Even more striking is Romania, a country that has participated in the IMO every year since 1959, yet has only had 2 girls on their teams in all that time. Again, these two girls were both truly outstanding. One of them, Ana Caraiani, went on to become a twice Putnam Fellow. Remarkably, two Romanian girls who did not qualify for their country's IMO teams, nevertheless, went on to achieve top-25 in the Putnam (Table 1). In fact, two of the three women Putnam Fellows to date were born and educated prior to college in Romania. Therefore, while some of these top-13 IMO countries successfully nurture multiple girls in addition to numerous boys to become world-class mathematical problem solvers, others only rarely identify girls of this caliber. Furthermore, while there exists a strong geographical clustering of countries that consistently produce top-ranked IMO teams (that is, predominantly Eastern Europe and Eastern Asia), neighboring countries within these regions show marked disparities in whether they successfully identify and nurture their mathematically gifted girls (for example, Bulgaria vs. Romania; South Korea and Taiwan vs. Japan). This observation suggests that differences in socio-cultural factors among countries play major roles in determining not only which ones produce students with outstanding ability in mathematical problem solving, but also whether girls are included among them.

USAMO. Why is the USA among the countries with a poor track record in identifying and nurturing girls with exceptional talent for mathematics? To begin to answer this question, consider data from the primary competition and training camp that leads up to selection for membership on the USA IMO Team. Table 5 lists the high school students who were the USAMO Award Winners (that is, the top 12 scorers) in the USA Mathematical Olympiad in 2005 and 2006 (41), the first of two IMO-like examinations used each year to select the six members of the USA IMO Team. The students invited to write this examination are 7th through 12th graders attending schools in the USA and Canada who ranked among the top 250-450 students on two prior qualifying exams, the AMC10/12 and the American Invitational Mathematics Examination (AIME), all administered by the American Mathematics Competitions (AMC). Unsurprisingly, only one girl, Sherry Gong, a 4-times IMO participant to date, made the list, doing so in both 2005 and 2006. However, equally striking is the paucity of USA-born European-American boys who accounted for only 3 out of 12 in 2005 and 2 out of 12 in 2006. In fact, a majority of the USAMO Award Winners were born elsewhere despite this examination only being administered in the USA and Canada. Noteworthy is the fact that all but one of the foreign-born students originated from other of the top-13 IMO countries.

The results of the 2004 USAMO were similar (2, 41). Of the top 24 scorers, 3 were girls: Alison Miller (home-schooled European-American), Po-Ling Loh (child of immigrants from Singapore), and Elena Udovina (immigrant from Russia). The 21 boys were: 3 Canadians who were immigrants from Eastern Europe or China, a Thai (different from the 2005 USAMO Thai; member of Thailand's 2003 IMO Team), 11 USA students who were immigrants or children of recent immigrants from China, South Korea, Russia, or India (that is, other top-13 IMO countries), and 6 USA-born European-Americans, two of whom were home-schooled. Thus, USA-born, non-Asian-American boys as well as girls are already highly under-represented among high school students who excel in mathematical problem solving. Given the fact that all of these students except for the three who were home-schooled were attending high schools in the USA or Canada at the time they took the examination, socio-cultural factors, even more so than educational systems, must be playing a primary role in determining who succeeds in the USAMO.

MOSP. Most USA high schools do not teach the mathematics skills needed to excel in the USAMO. Thus, most USAMO Award Winners acquire this knowledge by a combination of self-study and participation in summer mathematics camps. The premier mathematics training camp in the USA is the Mathematical Olympiad Summer Program (MOSP), with all USA IMO team members required to attend it prior to participation in that summer's IMO. Admission to MOSP is extremely selective, traditionally restricted to the top 30 pre-college students in the USA based upon their scores in the USAMO and its qualifying exams, the AMC10/12 and AIME. Typically, 1 to 3 of the 30 students qualifying for the MOSP each year by these criteria is female (4). However, very few USA-educated pre-college students know how to write rigorous, essay-style proofs, a pre-requisite for success in the USAMO. Thus, with generous support from the Akamai Foundation, MOSP has been expanded in recent years to also include some 9th graders admitted on the basis of their performance in the AMC10/12 and AIME, regardless of whether they can solve even one of the USAMO problems. The year 2002 was the first one in which 9th graders were admitted by this alternative criterion, with MOSP 2002 consequently having a total of 162 mostly 9th-grade participants. Eleven of them (that is, approximately 7 percent) were girls (Table 6). Thus, girls are already highly under-represented by the beginning of high school among USA students identified as highly mathematically gifted. Eight of these 11 girls were ethnic Asians. Of the 3 non-ethnic Asians, one was born in Russia, one was home-schooled, and one lived in Lexington, Massachusetts, a town highly populated by Boston-area academics. Why was there less than 1 percent USA-born, public school-educated, European-American girls attending MOSP 2002, let alone any from historically under-represented ethnic groups? Approximately 43 percent of the boys attending MOSP 2002 were also ethnic Asians based upon their family names.

The data are similar for more recent MOSPs: 3 out of 30, 6 out of 55, 4 out of 55, and 2 out of 55 were girls at MOSPs 2003-2006, respectively (Table 6). Again, most of these girls were ethnic Asian, foreign born, or home-schooled. Furthermore, most of the USA-born ethnic Asians were children of recent immigrants. In the USA, approximately 4 percent of the population is ethnic Asian. Thus, ethnic Asian girls are two- to three-fold over-represented and ethnic Asian boys an order-of-magnitude over-represented by 9th grade among USA students who excel at the highest level in mathematics competitions. However, while USA-born white boys still account for approximately half of the mathematically talented students identified in 9th grade (that is, they are approximately two-fold over-represented), white and historically under-represented minority girls are already almost non-existent. Thus, socio-cultural factors must account, in large part, for this huge disparity in proportion to their percentage of the population between ethnic Asian and non-Asian students who qualify for the MOSP, a disparity of roughly 50-fold among the girls.

AwesomeMath Summer Camp. During the past decade several summer mathematics camps in addition to the MOSP have come into existence in the USA aimed at exposing children to numerous areas of pre-calculus mathematics not typically taught in USA kindergarten through 12^{th}-grade classrooms. AwesomeMath Camp is one such program, begun in 2006 for 7^{th}- through 12^{th}-graders interested in learning areas of mathematics one needs to know to perform well on the AMC10/12, AIME, and USAMO. It is run by the same instructors who direct the MOSP and oversee the USA IMO Team. Admission to the program is based largely upon interest, not prior knowledge. Of the 98 USA and Canadian students who participated in the camp last summer, 14 were girls. Eleven of these girls were Asian-Americans, with family names originating from China, India, Korea, and Vietnam. Once again, girls with ethnicities from other top-ranked IMO countries were approximately six-fold over-represented in proportion to their percentage of the USA population, while non-Asian-American girls were very highly under-represented. Of the three European-American girl participants, one has a family name that is likely ethnic Jewish and another attends Phillips Andover, an elite private high school. Two-thirds of the boys attending this camp also had Asian family names, a 15- to 20-fold over-representation.

MATHCOUNTS®. At what age are students with potential to excel in mathematics being lost from the pipeline? MATHCOUNTS® is a national mathematics enrichment, coaching, and competition program that promotes high-level achievement in middle school mathematics. Thousands of middle school teachers throughout all 50 states as well as the USA Territories use the MATHCOUNTS curriculum materials to supplement classroom materials or as an extracurricular activity. Students can compete individually or as part of a team in one of more than 500 competitions held nationwide each year. Top-performing students advance to the State Competition, with the top 4 students from each State and Territory advancing to the annual National Competition. Table 7 lists the top 12 scorers in the National MATHCOUNTS Competitions for 2005 and 2006 (37). As with the USAMO Award Winners, girls and USA-born white boys are highly under-represented relative to their percentage of USA middle school students, while Russian-born boys and children of Asian descent are highly over-represented. Thus, many USA-born non-Asian-American boys as well as most girls with high potential to excel in mathematics are already failing to be identified and nurtured by 7^{th} or 8^{th} grade.

B.A.s and Ph.D.s in Mathematics. In sharp contrast, 48% of bachelor's degrees in mathematics awarded in 2000 (21) and 27% of Ph.D.s awarded in mathematics in 1993-2002 (22) in the USA went to women. Eight percent of the women receiving these degrees were ethnic Asians. Three percent and 32% of these women receiving bachelor's and Ph.D.s, respectively, were non-resident aliens. Only 6% and 5% of the Ph.D.s in mathematics awarded in 2004 to USA citizen women and men, respectively, went to ethnic Asians, with women accounting for 29% of these degrees (3). Thus, the over-representation of ethnic Asians and under-representation of women in mathematics among USA citizens are at most two-fold at the undergraduate and doctoral levels. However, USA citizens received only 38% of the Ph.D.s in mathematics awarded by USA universities in 2004, with non-USA citizen Asian men and women accounting for 20% and 12%, respectively, of the total mathematics Ph.D.s awarded that year. Clearly, there exist a significant number of women in the USA with both the interest and ability to excel in mathematics who are neither Asian-Americans nor foreigners. Thus, the primary reason few USA-born non-Asian-American boys and almost no girls excel on the AIME, USAMO, IMO, and Putnam is that most of these students with high interest and intrinsic aptitude for mathematics never received the training necessary to do well in these examinations. Their schools did not teach the material. Neither did they seek out available extracurricular opportunities to obtain this knowledge.

Social Stigma Associated with Math. My younger son is among the USA-born white students who are fairly gifted and somewhat accelerated in their study of mathematics, yet do not actively participate in MATHCOUNTS, the AMC competitions, or school mathematics clubs and teams. When asked why, his response was, "Only Asian kids and nerds do math [extracurricularly]." In other words, it is deemed uncool within the social context of USA middle and high schools to do mathematics for fun; doing so can lead to social ostracism. Thus, girls, even more so than boys, typically camouflage their exceptional talents, especially in mathematics, in order to fit in well with their peers (29). This peer group social problem has been previously noted during interviews with both top Putnam students (34) and USA female Olympians (18). The overwhelming preponderance of foreign-born and Asian-American students in high school mathematics clubs is a nationwide phenomenon (for example, see 43). No wonder very few girls and most boys avoid excelling in mathematics in grades 7 through 12 regardless of how gifted they are in the field. All of the girls who have achieved USAMO Award Winner or Honorable Mention (that is, top 25) in this examination's 33-year history were foreign-born, Asian-American, or home-schooled except for Melanie Wood. Melanie possesses outstanding social skills. Her mother was the Principal of her middle school at the time she discovered her giftedness in mathematics (33). This combination of circumstances likely enabled her to overcome the social stigma associated with excelling in mathematics. Thus, the extreme paucity of USA-born non-Asian girls among the top scorers on the AIME, USAMO, and Putnam is probably due, in large part, to most girls in the USA with very high intrinsic aptitude for mathematics spending their free time on non-mathematical activities, never entering mathematics competitions to avoid social ostracism. The ratio of boys to girls among Asian and Asian-American participants at MOSP during the period 2002-2006 was approximately 8:1, much closer to the 3:1 ratio observed in recent years in the SMPY and awarding of Ph.D. degrees in mathematics in the USA. Since Asian-American girls attending public schools in the USA are also regularly hearing the messages that "girls can't do math" and "only nerds do math", this 8:1 ratio is probably an upper bound of the real gender disparity, if one exists at all, in very high end innate ability in mathematics. The highly significant over-representation of Asian-American and foreign-born boys indicates that USA-born non-Asian boys are also being adversely affected by the social stigma associated with doing mathematics, although not to the extreme extent it is affecting girls. Likely, some boys feel OK with doing mathematics because they are either less socially astute or less concerned about their social status than are most girls.

4. DISCUSSION. Skeptics might respond to these data by saying the paucity of females who excel in mathematics is still really due, in large part, to their lack of intrinsic aptitude for the field (for example, 13, 32, 35). This explanation is highly unlikely for several reasons. First and foremost, some countries identify and nurture females with very high ability in mathematics at a much higher frequency than do others. This phenomenon is observed, not only in the degree to which girls participate in the IMO (Table 3; see also 28), but also in their representation among the tenured mathematics faculty at universities (16), with a fairly good positive correlation existing between the two variables. For example, while the percentage of women mathematics professors in the 1990s was a shockingly low 2-3% in some European countries (for example, Denmark, Finland, Switzerland, and West Germany prior to reunification), it was as high as 30-50% in others (for example, Bulgaria, Georgia, Italy, Macedonia, Poland, Portugal, and Slovakia). A significant inverse correlation has been shown to exist between the magnitude of measured gender difference in mathematics performance by 8th graders in a country and other measures of gender stratification such as participation in the labor force (5). Second, girls perform as well if not better than boys in mathematics throughout elementary school; it is during the middle school years that they begin to lose interest and fall behind due to socio-cultural factors (1, 8, 14, 15, 23-25, 27, 31, 36, 38, 40, and references cited therein). Third, Asian and Asian-American girls are not under-represented relative to their percentage of the USA population among the very top students identified in these mathematics competitions; it is only USA-born European-American and historically under-represented minorities girls who are highly under-represented, under-represented by almost two orders-of-magnitude relative to ethnic Asian girls educated in the same school systems. Fourth, the paucity of females is much less pronounced in the sciences and engineering, fields that depend upon a solid understanding of mathematics. In fact, their percentages in these other STEM fields have been steadily increasing post-Title IX (12). In 2007, for the first time girls accounted for one-half of the 40 Intel Science Talent Science Finalists, including 6 of the top 10, a competition in which the winners are determined without regard to gender. However, as with the USAMO Award Winners, a survey of the 2004 Intel Finalists found that 60% of them were also children of recent immigrants (2). Girls were also almost half of the 2006 Fellows of the Davidson Institute for Talent Development (17; Table 8), a foundation that provides scholarships on a gender-blind basis to USA children identified as profoundly gifted in mathematics, science, technology, literature, and music. As in mathematics competitions, most of the Davidson Fellows in the STEM fields were children of immigrants or Asian-Americans, a phenomenon consistently observed every year since these fellowship were first awarded in 2001. On the other hand, the Fellows in literature and music were mostly whites. These highly significant differences in preferences of ethnic Asians for STEM fields and whites for the arts and humanities is consistent with socio-cultural factors, not innate ability, being the primary reason since gifted children are frequently multi-talented, with the fields in which they receive recognition reflecting the ones in which they choose to invest their time and effort.

Skeptics may still say that the skill set necessary to excel in mathematical problem solving and mathematics research are not identical, with there existing many world-class research mathematicians who never excelled in the IMO or Putnam. Yes, the competitions discussed here require the ability to solve difficult problems with known solutions under timed conditions while research requires the stamina to work on problems over extended periods of time, not knowing whether solutions even exist. Nevertheless, a very high correlation exists between the two since both require outstanding mathematical intuition and creativity along with the interest in devoting considerable time and effort toward acquiring extensive knowledge in the field. Thus, many of the women who excel in these competitions undoubtedly possess the ability to become world-class mathematicians if provided the educational opportunities and working environments afforded their male peers.

5. CONCLUSIONS and PROPOSALS. In summary, females with extremely high ability in mathematical problem solving do exist. Some Eastern European and Asian countries encourage mathematically gifted students of both genders to develop their talents; most other countries, including the USA, do not. Children of recent immigrants to the USA from these top IMO countries are highly over-represented among students identified as mathematically gifted. Thus, socio-cultural factors present in the USA, not lack of intrinsic aptitude, inhibit most mathematically gifted girls and many boys from fully developing their mathematical talents.

Girls and boys who possess high mathematical ability should be encouraged to pursue careers in STEM fields because jobs in these fields are plentiful, well-paying, challenging, and interesting. Their doing so is also vital to the future of the USA economy as elegantly documented in Thomas Friedman's *The World Is Flat: A Brief History of the Twenty-First Century* (19). *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (11) and *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering* (10) outline numerous steps the USA should take to insure we have the well-educated labor force needed to fill the STEM jobs of the future. To reduce loss of mathematical talent, especially among students with very high innate ability, the USA urgently needs to make changes in how it identifies and nurtures children with aptitude in the field. Here is a list of some proposals to help stimulate the national discussion necessary to induce the needed changes:

1. First and foremost, teachers, guidance counselors, parents, principals, university presidents, the lay public, and girls themselves need to become better informed about the fact that females truly can excel in mathematics, even at the very highest levels, so girls will be advised and encouraged to do so. When people believe they cannot do something, it becomes a self-fulfilling prophesy. To quote Henry Ford, "If you think you can or can't, you are right." The myth that females cannot excel in mathematics must be put to rest.

2. We need to greatly improve the lay public's perception of mathematicians via the news media, movies, and TV shows such as *Numb3rs* so pre-teens and teenagers of both genders will feel it is socially fine to enjoy mathematics and to do it extracurricularly. Girls, especially, must be made aware that most mathematicians do important, interesting work and are not nerds. Mathematics Olympians in the other top-ranked IMO countries are honored and praised similarly to sports Olympians. The same should be true here in the USA.

3. Mathematics should be taught by mathematics-certified teachers who majored in the field starting by 6^{th} or 7^{th} grade at the latest. Most English and social science majors with kindergarten through 8^{th}-grade certification typically lack sufficient knowledge to properly teach pre-algebra, especially to mathematically gifted students who ask out-of-the-box questions and propose novel solutions not present in the teacher's manual. Foreign languages, music, art, and physical education are usually taught by specialists in middle school. Why not mathematics as well?

4. There need to exist many more schools such as the Thomas Jefferson High School for Science and Technology, Stuyvescent High School, the Illinois Math and Science Academy, and the Davidson Academy of Nevada to provide a socially and academically supportive environment in which mathematically gifted children can feel free to pursue their interests. Essentially all USA-born students identified by these very high-level mathematics examinations

attended a special high school, had access to college mathematics courses, self-studied mathematics with help from a parent highly knowledgeable in the field, or had been home-schooled (for example, Table 9). Unfortunately, only a very small percentage of kindergarten through 12th-grade students in the USA currently has access to any of these educational opportunities. Without them, the USA is squandering one of its valuable natural resources.

5. We should facilitate the ease with which mathematically precocious kindergarten through 12th-grade students who lack access to programs for gifted children within their own schools can study mathematics above their grade level at local colleges and via correspondence and online programs such as Stanford University's Education Program for Gifted Youth, Northwestern University's Center for Talent Development's Gifted LearningLinks, and the Art of Problem Solving Foundation.

6. We should encourage mathematically gifted children to participate in summer camps such as All Girls/All Math, AwesomeMath Summer Camp, Canada/USA Mathcamp, the Hampshire College Summer Studies in Mathematics, Program in Mathematics for Young Scientists, and the Ross Mathematics Program so they can be exposed to areas of mathematics not currently taught in USA high schools and get to know other children with whom they can share their enjoyment of mathematics.

Yes, acting on these proposals will cost money. However, there will be a far greater cost to the future of the USA economy and our standard of living if we continue to fail to nurture and develop the talents of most of our mathematically gifted children, boys as well as girls.

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Table 1. Women Among Top 25 in 1992-2006 Putnam, a Mathematical Competition Written Only By Students Attending Colleges in USA and Canada.

Name	Year	Birth Country (HS[1])	IMO Medals
Olena Bormashenko	2004	Russia (Canada)	1gold,1silver
Ana Caraiana	2003(**F**[2]),2004(**F**)	Romania	1gold,2silver
Ioana Dumitriu	1995,1996(**F**)	Romania	-
Julie Kerr	1992	USA	-
Suehyun Kwon	2003	South Korea	1gold
Alison Miller	2004,2005,2006	USA	1gold
Greta Panova	2001	Bulgaria	1gold,2silver
Dana Pascovici	1992	Romania	-
Melanie Wood	2001,2002(**F**)	USA	2silver
Wai-Ling Yee	1999	Asian-Canadian	-
Inna Zakharevich	2004	Russia (USA)	-

[1]Attended high school in country of birth except where indicated otherwise.
[2]Putnam Fellow (among top 5), indicated in bold.

Table 2. Top 26 Students in 2006 Putnam Mathematical Competition.

Name (alphabetical order within category)	**IMO Team (Birth Country[1])**	**IMO Medals**
Putnam Fellows (top 5)		
Hangsheng Diao	China	1gold
Daniel Kane	USA	2gold
Tiankai Liu	USA (China)	3gold
Po-Ru Loh	USA	2gold,1silver
Yufei Zhao	Canada (China)	1gold,1silver,1bronze
6th – 15th		
Timothy Abbott	USAMO top 12[2]	-
Ralph Furmaniak	Canada	- (2003 Putnam Fellow)
Anders Kaseorg	USA	1gold,1silver
Sung-Yoon Kim	Korea	1gold
Yuncheng Lin	China	1gold
Alison Miller[3]	USA	1gold
Kevin Modzelewski	USAMO top 24	-
Andrei Negut	Romania	1gold,2silver
Aaron Pixton	USA	2gold
Eric Price	USA	1gold
16th – 26th		
Saran Ahuja	Thailand	2bronze
Doo Sung Park	Korea	1gold
Shinn-Yih Huang	Taiwan	1gold,1silver
Matthew Ince	USA	1silver
Theodore Johnson-Freyd	USAMO top 27	-
Cedric Lin	Taiwan	1silver
Thomas Mildorf	USA	1gold
Xuancheng Shao	China	1gold
Andrei Ungureanu	Romania	2gold,1silver
Yeo-Il Yoon	Korea	1gold
Rumen Ivanov Zarev	Bulgaria	2gold,1silver

[1]Country of birth presumed to be same as IMO Team except where indicated otherwise in parenthesis.
[2]Scored among top-12 Award Winners or top-25 or so Honorable Mention group on USAMO, but did not qualify for 6-member USA IMO team.
[3]Woman indicated in bold font.

Table 3. Countries Placing Among Top 15 in at Least 7 of the 1997 - 2006 International Mathematical Olympiads.

Region of World	Past Decade Team Median Rank (Range)	1st Year Participated	No. Different Girls on Teams	No. Girls Since 1988	Medals by Girls Since 1988
Asia (7)					
China	1st (1-2)	1985	6	4	1gold,2silver,1bronze
India	14.5th (7-15,18,35,36)	1989	5	5	1gold,3silver,2bronze
Iran	8.5th (1-11,17,18)	1985	3	3	2gold,1silver,1bronze
Japan	13th (7-15,16)	1990	1	1	1gold,1silver
South Korea	6th (3-12)	1988	5	5	4gold,1silver,3bronze
Taiwan	8.5th (5-14,16)	1992	5	5	2silver,2bronze
Vietnam	7th (3-15)	1974	5	3	3bronze
Eastern Europe (5)					
Bulgaria	5th (1-11,21)	1959	21	6	1gold,7silver,1bronze
Hungary	9.5th (2-12,17,21)	1959	ND[1]	at least 3	1gold,3silver,2bronze
Romania	7.5th (4-11)	1959	2	2	2gold,2silver
Russia (USSR)	2.5th (1-6)	1992 (1959)	7 since 1992 (at least 11 since 1959)	9	4gold,8silver,1bronze
Ukraine	11.5th (6-14,20,21)	1992	6	6	6gold,2bronze
Americas (1)					
USA[2]	3rd (2-10)	1974	3	3	1gold,3silver
Rest of World					
None - Germany closest with only 1 year better than 10th and 5 years worse than 15th.					

[1]ND, not determined.
[2] ~ 50% of recent USA IMO Team members are 1st- or 2nd-generation immigrants from these other Asian and Eastern European countries.

Table 4. Girl Participants in International Mathematical Olympiad.

Bulgarian Team - 21 girls
Tsvetana Penkovska: 1959
Nedka Ivanova: 1959
Brezitsa Popova: 1960
Atanaska Stoianova: 1961
Rumiana Proikova: 1961
Milka Popova: 1961
Milena Ivanova: 1962
Lidia Vashtinska: 1965
Ludmila Krasteva: 1966
Diana Petkova: 1967
Donka Pashkuleva: 1969
Virdzhinia Hristova: 1969,1970
Nadezhda Ribaska: 1977,1978
Milena Moskova: 1978
Galia Simeonova: 1983
Zvezdelina Stankova: 1987,1988
Dessislava Bakardzhieva: 1987,1988
Ludmila Kamenova: 1996
Greta Panova: 1999,2000,2001
Tsvetelina Tseneva: 2005,2006
Elina Robeva: 2006

Russian Team – at least 11 girls
(missing data from 9 years)
Lidia Goncarova: 1962
Elena Neklyudova: 1969
Maria Roginskaya: 1989
Evgenia Malinnikova: 1989,1990,1991
Yulia Pevtsova: 1992
Anna Dyubina: 1994
Natalia Dobrinskaya: 1994
Veronika Essaoulova: 1995,1996
Elena Roudo: 1996
Irina Anno: 1997,1998
Nadejda Petukhova: 2004

USA Team - 3 girls
Melanie Wood: 1998,1999
Alison Miller: 2004
Sherry Gong: 2005
(also 2002,2003,2004 on Puerto Rico's Team)

Table 5. Birth Country[1]/Ethnicity and Gender[2] of USAMO Award Winners, an Exam Taken Only by 7th-13th Graders Attending Schools in USA and Canada.

2006 Competition		2005 Competition	
Yakov Berchenko-Kogan	Russia	Robert Cordwell	European-American
Sherry Gong	Chinese-American	Zhou Fan	Chinese-American[3]
Yi Han	China	**Sherry Gong**	Chinese-American
Brian Lawrence	European-American	Rishi Gupta	Indian-American[3]
Tedrick Leung	Asian-American	Hyun Soo Kim	Korean-American[3]
Richard McCutchen	European-American	Brian Lawrence	European-American
Taehyeon Ko	Korea	Albert Ni	Chinese-American[3]
Peng Shi	China (Canada)	Natee Pitiwan	Thailand
Yi Sun	China	Eric Price	European-American
Arnav Tripathy	Indian-American	Peng Shi	China (Canada)
Alex Zhai	China	Yi Sun	China
Yufei Zhao	China (Canada)	Yufei Zhao	China (Canada)

[1]Currently residing in USA unless indicated otherwise in parenthesis.
[2]Female indicated in bold.
[3]Country of birth not determined.

Table 6. Birth Country/Ethnicity of Girl Participants at MOSP: 2000-2006.

Name	Birth Country/ Ethnicity	Years at MOSP	USAMO Award Winner (Honorable Mention)
Shuang You	Chinese-American[2]	2000	-
Alison Miller[1]	European-American	2000-2004	2002,(2003),2004
Inna Zakharevich	Russia	2001-2002	2002
Po-Ling Loh	Chinese-American	2002-2004	2003,(2004)
Sarah Cheng	China	2002	-
Ann Chi	Chinese-American	2002	-
Atoshi Chowdhury	Indian-American	2002	-
Rong Hu	Chinese-American	2002	-
Tiffany Ko	Chinese-American[2]	2002	-
Elizabeth Marcil	European-American[2]	2002	-
Irena Wang	China	2002	-
Stephanie Zhang	Chinese-American	2002	-
Sherry Gong	Chinese-American	2003-2005[3]	(2003),2005,2006
Linda Liu	China	2004	-
Maria Monks	European-American	2004-2005	-
Livia Zarnescu	Romania	2004	-
Sway Chen	Chinese-American	2005	-
Wendy Hou	Chinese-American	2005	-
Patricia Li	Chinese-American[2]	2006	-

[1]Home-schooled.
[2]Birth country not determined.
[3]Qualified for MOSP 2006, but participated in Intl. Physics Olympiad, instead.

Table 7. Race/Ethnicity and Gender[1] of Top 12 Students in National MATHCOUNTS Competition

2006 Ranking		2005 Ranking	
Neal Wu	Chinese	Neal Wu	Chinese
Daniel Li	Chinese	Mark Zhang	Chinese
Kevin Chen	Chinese	**Patricia Li**	Chinese
Nathan Benjamin	Russian/Chinese[2]	**Karlanna Lewis**	White
Daesun Yim	Korean	Sergei Bernstein	Russian
Sam Keller	White	Nathan Benjamin	Russian/Chinese
Brian Hamrick	White	David Benjamin	Russian/Chinese
George Silvis	White	Mike Jin	Chinese
Rolland Wu	Chinese	Andrew Ardito	White
Andrew Ardito	White	Alan Huang	Chinese
George Yu	Chinese	Pardha Ponugoti	Indian
Arjun Puranik	Indian	Kiran Kota	Indian

[1]Girls indicated in bold.
[2]Bi-racial.

Table 8. Race/Ethnicity and Gender[1] of Davidson Institute for Talent Development 2006 Fellows by Category

Math, Science or Technology		Music or Literature	
Sheela Krishnan	Indian	**Stephanie Chen**	Chinese
Varun Kumar	Indian	Kyle Dacuyan	White/Philippine
Albert Shieh	Chinese	**Heather Engebretson**	White
Adam Solomon	White	Travis Johnson	White
Shivani Sud	Indian	Drew Peterson	White
Yi Sun	Chinese	**Anna Stalker**	White
Anarghya Vardhan	Indian		
Michael Viscardi	Korean/White[2]		
Xin Wang	Chinese		
Steven Wu	Chinese		

[1]Females indicated in bold.
[2]Bi-racial.

Table 9. Mathematics Education Prior to College Matriculation of USA Students Among Top 26 in 2006 Putnam.

Name	Pre-undergraduate Mathematics Education[1]
Daniel Kane	MOSP, UW-Madison, UW-MTS[2], self-studied with math Ph.D. prof. parent
Tiankai Liu	MOSP, PEA[3], BAMC[4]
Po-Ru Loh	MOSP, UW-Madison, UW-MTS, self-studied with math Ph.D. prof. parent
Timothy Abbott	MOSP, TJHSST[5]
Anders Kaseorg	MOSP, UNC-Charlotte, Home-schooled
Alison Miller	MOSP, Union College, SUNY-Albany, home-schooled with math B.A. parents
Kevin Modzelewski	MOSP, PEA, self-studied with IMO team/Putnam Fellow parent
Aaron Pixton	MOSP, SUNY-Binghamton, self-studied with math prof. parent
Eric Price	MOSP, TJHSST
Matthew Ince	MOSP, Washington U.-St. Louis, Home-schooled
Theodore Johnson-Freyd	South Eugene HS, other ND[6]
Thomas Mildorf	MOSP, TJHSST

[1]Many participated as well in a variety of summer programs for mathematically gifted students.
[2]UW-Mathematics Talent Search, a correspondence competition in mathematical problem solving.
[3]PEA, Phillips Exeter Academy, a private high school with MOSP Director/USA IMO Team Leader on staff.
[4]BAMC, Bay Area Math Circle, Sunday seminars for 7th- through 12th-grade students led by former IMO Team members.
[5]TJHSSH, Thomas Jefferson HS for Science and Technology, a Virginia public high school for gifted students that offers college-level mathematics courses and a club that provides training for the AIME and USAMO.
[6]ND, not determined, but could have included U. of Oregon-Eugene.

Most USA high schools do not teach the mathematics skills needed to excel in the USAMO. Thus, most USAMO Award Winners acquire this knowledge by a combination of self-study and participation in summer mathematics camps. The premier mathematics training camp in the USA is the Mathematical Olympiad Summer Program (MOSP), with all USA IMO team members required to attend it prior to participation in that summerâ€™s IMO.Â represented minority girls are already almost non-existent. Thus, socio-cultural factors must account, in large part, for this huge disparity in proportion to their percentage of the population between ethnic Asian and non-Asian students who qualify for the MOSP, a disparity of roughly 50-fold among the girls. AwesomeMath Summer Camp.