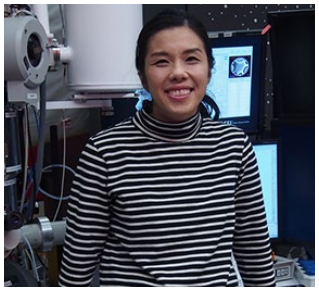
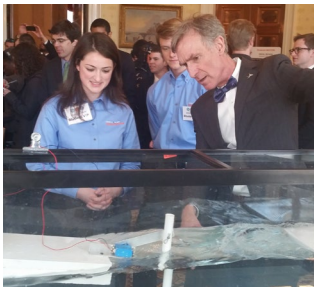
Policy Initiatives Needed to Foster Female Inventors' Contributions to U.S. Economic Growth









A DISCUSSION PAPER

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TABLE OF CONTENTS

Policy Initiatives Needed to Foster Female Inventors' Contributions to U.S. Economic Growth

Employment and the U.S. economy are a central focus of policy makers working to maintain high employment and economic growth. New initiatives and investment of resources to stimulate the economy offer an opportunity to design for inclusivity, thereby marshalling all of America's human talent as the nation works to (re)create jobs. This paper highlights the importance of policies that will tap into the creativity and inventiveness of women who have been underrepresented in the innovation economy to date. Specific recommendations are offered for supporting women's engagement in the development of new and novel solutions to problems and for the commercialization of their intellectual property through the creation of start-up companies.

Our call for deliberate efforts to empower women and their potential contributions to America's economic recovery stems from research that has revealed a significant difference between the percentage of men versus women listed on patents, as well as gender differences in those receiving funding for the commercialization of new discoveries. Findings from multiple studies suggest that greater involvement of women in inventing and bringing new products and services to market would yield benefits in four areas: growth in the national economy from gender diversity, leadership within the global economy, growth in local economies and jobs, and new possibilities for remedying gender-based wealth inequities. We further discuss these benefits hereafter.

Growth in the National Economy From Gender Diversity

Patents, awarded as a result of being able to demonstrate that one has created a novel solution (i.e., a patentable invention), are recognized as economic drivers given a patent's possibilities for commercialization. The "economic activity from patents is estimated at over $8 trillion, more than one-third of the U.S. gross domestic product (GDP)" (Fechner & Shapanka, 2018; Farre-Mensa et al., 2015). Studies indicate that the U.S. GDP would be 2.7-3.3% higher if we could achieve greater diversity in patenting, including greater participation of women and underrepresented groups (Fechner & Shapanka, 2018; Hunt et al., 2012). Studies of investments by venture capitalists have confirmed that diverse teams produce significantly better financial outcomes (Cook, 2019; Rock & Grant, 2016).

Leadership Within the Global Economy

Deliberate efforts to engage women in inventing and patenting would help to maintain the United States' leadership role in ensuring equal opportunities for women and women-owned businesses in the global economy. International patent data demonstrates that all countries struggle with women's participation in patent systems, but some countries are more successful on this front than the United States. Data from the World Intellectual Property Organization showed that 27% of international patent applications have at least one female inventor (UK Intellectual Property Office Informatics Team, 2016). The data from their 2015 report showed that France (11.71%), China (10.06%), and Russia (15.69%) had a higher proportion of female inventors than the United States

(8.72%). The percentage of female inventors in the United States is only slightly higher than the worldwide average of 7.2%. Countries with greater gender diversity have greater potential for tapping into the full range of insights into problems and ideas for solutions originating from differences in the lived experiences of men and women.

Growth in Local Economies and Jobs

Local communities in which women reside stand to benefit from jobs associated with women's inventions and related start-up companies. Companies are more likely to receive venture capital and to thrive if they have patents (Fechner & Shapanka, 2018; Milli et al., 2016). Graham, Merges, Samuelson, and Sichelman (as noted in Fechner & Shapanka, 2018) found that "start-up companies generate 10 percent of all new jobs in the U.S. each year" and Haussler, Harhoff, and Mueller (also noted in Fechner & Shapanka, 2018) stated, "companies with at least one patent application filed typically receive venture funding faster than companies with no patents and are more attractive for funding from other sources." The communities in which women who are capable of inventing reside will benefit from female-led start-up companies with at least one patent and greater gender diversity, as such companies may be more profitable and successful (Sanders & Ashcraft, 2019; Cook, 2019).

New Possibilities for Remedying Gender-Based Wealth Inequalities

Increasing the rate of patenting among women offers a powerful income-generation tool that could help combat income and wealth inequality experienced by women (Cook, 2019), many of whom are heads-of-household and dependent on earned income to support young children. A longitudinal study of data for inventor-patentees by the U.S. Patent and Trademark Office (USPTO) found that 58.5% of U.S. inventor-patentees achieved income in the top deciles across their lifetimes (Akcigit et al., 2017; USPTO, 2019a). Without this tool for generating wealth, women do not enjoy their proportionate share of innovation's benefits (Cook, 2019). In addition, higher rates of patenting would result in greater access to the "financial rewards, peer and professional recognition, promotion opportunities, and additional opportunities for collaboration" that come with patenting (Milli et al., 2016).

"It's sometimes harder for us to push ourselves and to have those opportunities that others can have. We work hard at it, but to see our invention happen, that's pushed me to want to go even further."

Melody Sanchez, 2018
InvenTeam member, Garey High School, Pomona, CA

Reaping the benefits that can be derived from empowering more women to invent and to commercialize their creations requires deliberate effort. New programs and related investments must be purposefully designed with the intent of overcoming long-standing gender-based inequities in patenting and commercialization activities in the United States. We summarize the data that informs our understandings of this nationwide challenge and our recommended solutions in the next section of this paper.

National Gender Gap in Patenting and the Commercialization of Patents in the United States

Recent studies that make visible the small percentage of women receiving patents served as a catalyst for this paper. Patents filed solely by women, either as a lone inventor or as a member of an all-female team, constituted only 4% of issued patents in the last decade (USPTO, 2019a). Men are much more likely to file patents as lone inventors or with all-male teams. An analysis of 2010 data showed that there was a 1:4 ratio for patents granted to female lone inventors or all-female teams when compared to male lone inventors or all-male teams (Milli et al., 2016). The share of patents awarded to women as first inventor—as either a lone inventor, as a member of an all-female team, or as part of a mixed-gender team—was 12% in 2016 (USPTO, 2019a).

Women were much more likely to be named as a co-inventor on a patent when they participated in mixed-gender teams. Women accounted for 21% of all patent holders (listed in any order) on patents issued in 2016 to teams with inventors representing both genders (USPTO, 2019a; USPTO, 2019b). This percentage represented a growth from 15% in 1998 (USPTO, 2019a; USPTO, 2019b), suggesting that being on a mixed-gender team from conception to reduction to practice may be a viable route for women who want to be involved in work that leads to a patent.

Policy leaders interested in growing the number of female inventors may be able to contribute to success by incentivizing mixed-gender teams so that inclusion rates change more rapidly. Researchers predict that, without some type of policy intervention, it will take 72 more years (i.e., it will be 2092) before half of all patents have at least one woman listed as a co-inventor (Milli et al., 2016).

Little information is available to inform our understandings of the nature of women's experiences and roles within mixed-gender teams that patent. Data from the USPTO showed that women were represented in 44% of patents by teams with four or more co-inventors in 2016 (USPTO, 2019a). The data, however, does not offer insights into the work that women performed on teams, the ways they contributed to the team, their roles, or reasons why participation did not result in opportunities to appear as the primary contributing inventor on team patents. Initiatives to promote female participation in patenting through mixed-gender teams will need to be crafted in ways that ensure contributory participation develops women's capabilities for future work as inventors.

Recent declines in the share of women on mixed-gender teams, a phenomenon occurring as the size of teams grows (USPTO, 2019a), creates additional questions regarding the potential for mixed-gender teams to lead to full inclusion of women in the patenting and commercialization system in the United States. The USPTO suggests that women comprised 37% of mixed-gender teams in 1976, and that the percentage decreased to 29% in 2016 as the size of gender-mixed patent-inventor teams grew (USPTO, 2019a). This trend will need to be considered in the crafting of new policies to close the gender gap in patenting.

We acknowledge that patenting is only one measure for assessing women's participation in the innovation economy. An equally important measure is the degree to which patents are commercialized. A study of commercialization rates found that women hold only 5.5% of commercialized patents (Fechner & Shapanka, 2018; Hunt et al., 2012). The preponderance of data demonstrating gender differences in patenting and the commercialization of patents has led some scholars to conclude that "technological innovation remains a largely white, male enterprise" (Wisnioski, 2019; Nager et al., 2016).

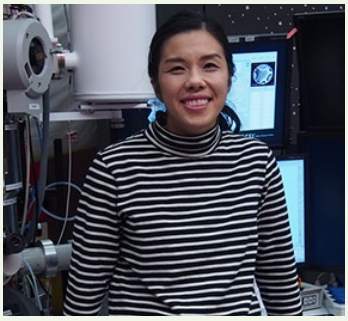
Policies that maximize opportunities for women to do their part to create inventions, coupled with policies and new investments to help women commercialize their patents through new businesses, can empower women to do their part to help America's economic recovery. Such policies will enable all brilliant minds and tremendous talent in this nation to work for the country's benefit and the benefit of society as a whole. We examine in the next section the ways policies can be crafted to encourage the private sector to do its part to support female inventors.

The Private Sector's Role in Promoting Women Inventors

Nearly 85% of USPTO patents issued in 2018 to U.S. assignees (those assigned rights of ownership) were assigned to businesses (National Science Board [NSB], 2020). Another 9% of patents were assigned to individuals (NSB, 2020). The data indicates that, because businesses account for the majority of U.S. patents, they have the greatest potential to make changes that will improve patenting outcomes for women.

"I tell girls to go out there and uncover things. Learn how a soccer ball works so you can make a better soccer ball…Invention doesn't happen in a vacuum, it happens in teams. So, if you build up your knowledge together, together you can solve most problems."

Kayla Nguyen, 2018 "Use it!" Lemelson-MIT Student Prize Graduate Winner, Cornell University



Businesses interested in doing their part to close the gender gap in patenting will ultimately need to hire more women in science and engineering occupations. Women account for less than one-third of all workers (with bachelor's or higher-level degrees) employed in science and engineering occupations in the United States (NSB, 2019c), despite representing half of the college-educated workforce. Businesses with especially important roles to play can be identified based on rates of patenting in particular sectors. Data from 2017 suggests that nearly 30% of patents were awarded in computer and electronic products and manufacturing, followed by computer systems design and related services (10%), transportation equipment and manufacturing (8%), chemicals manufacturing (including pharmaceuticals; 7.5%), all other manufacturing (7%), and software publishers (6%; NSB, 2020).

Women seeking to be hired in the fields or disciplines known for patenting must have the academic credentials, expertise, and social networks leading to employment in these fields. Data for 2018 shared by the USPTO indicated that 60% of patents granted to U.S. inventors related to electrical and mechanical engineering (NSB, 2020). Computer technology and digital communication accounted for the largest share of the increases in electrical engineering (NSB, 2020). The remaining 40% of patents issued to U.S. inventors in 2018 related to instruments, chemistry, and other fields (NSB, 2020).

It is important to keep in mind that many fields engage in work that cuts across the categories used to classify patents. This is illustrated by findings that health and medical inventions may cut across technology areas that were granted utility patents. The National Science Board notes:

> patents in the analysis of biological materials and medical technology contribute to growth in patenting in instruments, and inventions in biotechnology and pharmaceuticals contribute to growth in chemistry patenting. Similarly, advances in autonomous vehicles incorporate inventions in multiple areas, including optics, transport, electrical machinery, and chemicals. (NSB, 2020)

The USPTO has made available data that can inform our understanding of how particular companies are doing with respect to the inclusion of women in research and development efforts leading to a patent. Female patenting rates among chemical and pharmaceutical companies (21–24%), for example, are much higher than rates among technological sectors (9–16%) and electrical and mechanical engineering (4–6%; USPTO, 2019a). Variations across different types of companies were reflected in data analyzed by the USPTO for top patent assignees (2007–2016). The percentage of patents in which women were the first authors ranged from a high at Procter & Gamble Co. of roughly 29%, for example, to a low of roughly 4% at Deere & Co. (USPTO, 2019a). Corporate leaders in these sectors and particular companies can take stock of their relative standing, and can seize the opportunity to address the need for improvement in the gender diversity of their research and development activity.

The corporate data on rates of female patenting can be compared more generally to the larger data set for the percentage of females listed as first authors on patents in the particular types of patent categories. As we

noted earlier, 60% of patents granted to U.S. inventors in 2018 related to electrical and mechanical engineering (NSB, 2020). Within this group of patents, women received 12% of the patents in instruments, 11% of the electrical engineering patents, and 8% of mechanical engineering patents between 2007 and 2016 (USPTO, 2019a). We noted that 40% of patents issued to U.S. inventors in 2018 related to instruments, chemistry, and other fields (NSB, 2020). Within this group of patents, women accounted for 25% of inventors granted patents in biotechnology, 23% in pharmaceuticals, and 18% of the chemistry patents between 2007 and 2016 (USPTO, 2019a).

We do not have direct evidence, given the limitations of this study, that the gender differences in patenting are attributable to the cultural conditions in particular companies, industry sectors, or occupations. The high percentage of female-generated patents in biotechnology and pharmaceuticals could simply be related to the fact that women represent 48% of biological and life scientists (USPTO, 2019a). This hypothesis is consistent with studies noting that improvements in the gender balance in particular STEM fields have proven to be an early indicator of female patenting in subsequent years (USPTO, 2019a; Milli et al., 2016; Hunt et al., 2012). Representation in the field at rates approaching women's broader representation in society could also be attributable, however, to a general culture and climate in the biotechnology and pharmaceutical sector that is more conducive to participation by females, as opposed to other sectors.

A third explanation for higher rates of female participation in the biological and life sciences, as well as their greater representation in biotechnology and pharmaceutical patents, may stem from choices young women make and the experiences they have in their years at colleges and universities. As Table 1 indicates, a smaller percentage of women (compared to men) graduate high school and go on to enroll in mathematics, science, computer science, or engineering (28.1% vs. 34.1%; NSB, 2019a). Female enrollments in social science and psychology have been excluded from the enrollment numbers for purposes of this paper, as they are not fields known for patenting behavior (Cook, 2019; USPTO, 2019a; Marco et al., 2015).

"My InvenTeam experience was absolutely incredible. It was the first real experience I had with engineering in all aspects of a project, and it taught me to deal with problems better than any other project could have because, with this project, there is a real-life application. We had to encounter problems in real time and solve them in real time."

Katelyn Sweeney, 2012
InvenTeam member, Natick High School, Natick, MA and MIT alumna '18

"Northeast high School is producing students who are going to go out and be ready for their career before they enter college and that was sparked by the InvenTeam project and the Lemelson-MIT Program."

Clara Mabour, 2012 InvenTeam member turned 2018 InvenTeam educator, both at Northeast High School, Oakland Park, FL

Table 1: Undergraduate Enrollment for 2015 High School Graduates

GENDER	STEM MAJOR	MATHEMATICS, SCIENCE, COMPUTER SCIENCE, AND ENGINEERING
Male	43.6%	34.1%
Female	39.7%	28.1%

Women who do enroll in STEM degree paths in college are far more concentrated in natural sciences, biology, and medical and health sciences. The next section examines ways the preparation of women interested in mathematics, science, computer science, and engineering during their years of study at the college or university level may predispose them to working in fields related to biotechnology and pharmaceuticals as opposed to other STEM fields prone to patenting, which are also in need of greater female participation.

Understanding the Higher Education System's Role in Promoting Women Inventors

Earlier in this paper, we noted that nearly 85% of the patents issued by the USPTO to U.S. assignees (those assigned rights of ownership) were assigned to businesses (NSB, 2020). Another 9% of patents were assigned to individuals. The academic sector represented just 4% of assignees in 2018 (NSB, 2020). Patenting in pharmaceuticals, biotechnology, and medical technologies made up 41% of all USPTO patents awarded to U.S. academic institutions this same year (NSB, 2020). By comparison, these three areas accounted for only 10% of patents issued in all sectors to all types of institutions in 2018 (NSB, 2020).

This patent data suggests that females enrolling in courses and pursuing degree paths in biology, medical and health sciences, and chemistry would have opportunities to get to know and become engaged in the work of university faculty who are generating academic patents in pharmaceuticals, biotechnology, and medical technologies. Through this work with faculty mentors, women would have opportunities to get to know people in the field and build social networks with private-sector

partners who work closely with the colleges and universities specializing in this sector. Opportunities for college/university work in this field may shape female students' views of what they want to do with their life and career, where they want to work, or may make it easier to land a good job with a known entity once they graduate from the college or university. If this hypothesis is valid, policy initiatives that incentivize faculty inventors and private-sector collaborators to jointly mentor and support career pathways for women seeking degrees in fields known for patenting could lead to more women who ultimately contribute to patents on private-sector R&D teams with little female representation.

Our developing understanding of the role faculty inventors may play in the growth and development of female inventors caused us to wonder about potential differences in young women mentored by a female faculty inventor versus a male faculty inventor. This led us to explore the extent to which female faculty on university campuses are patenting, and the messages young women may be receiving as a result of their engagement with faculty inventors. Available studies indicate that women in academia patent at higher rates compared to industry and government (Sohar et al., 2018; Sugimoto et al., 2015). Women in academia, however, are less likely to submit disclosures to their patent office, and are also less likely to have their patent cited by others if they do succeed in getting a patent (Sohar et al., 2018; Sugimoto et al., 2015). In fields like life sciences, known for higher percentages of female faculty and women who patent, female life scientists are patenting at 43% of the rate of their male peers (Sohar et al., 2018; Ding et al., 2006).

Researchers hypothesize that female faculty members' lack of opportunity (Murray & Graham, 2007), research funding disparities, tendencies for women to be working "behind the scenes," the multiple demands on women, and a lack of motivation for making money as reasons for these types of statistics (Sexton & Ligler, 2018). Further research is needed to understand whether these differences experienced by female faculty and witnessed by female students influence young women's interest or perspectives in their own work as inventors. Policies that address the barriers faced by female faculty inventors, nevertheless, would contribute to closing the gender gap in patenting through higher rates of patenting and commercialization by females in academia. These policies could include legal support for filing patents, waivers of filing fees, and more intentional focus within universities and their technology transfer offices to support the development of female faculty as inventors and as mentors of female students.

If the experience of working with a faculty member who invents—and the related mentoring and social networking opportunities this provides—are impactful, we would expect differential outcomes for women based on the college or university they attend. There are significant variations in the amount of research and the degree of patenting activity that takes place on individual campuses. Many state colleges, for example, see their role as teaching institutions, as opposed to research that can lead to a patent. Rankings of the degree of patenting at particular universities are reported annually by the National Academy of Inventors. The rankings suggest that patenting activity among colleges and universities that generate the 4% of U.S. patents issued varies widely. The opportunities available to women, therefore, would depend on the college or university attended. Policies

"Don't be afraid of hard work. Nothing worthwhile comes easily. Don't let others discourage you or tell you that you can't do it. In my day, I was told women didn't go into chemistry. I saw no reason why we couldn't.

Gertrude B. Elion, 1997
Lemelson-MIT Lifetime
Achievement Award Winner

to address the gender gap in patenting could expand opportunities, through partnerships, for young women attending these colleges and universities and majoring in a field prone to patenting.

The notion that experiences of working with faculty inventors in the college years impact women's career trajectories, and the idea that female students' engagement with industry partners contributing to the work of faculty inventors is also important during their formative years, led us to wonder about female participation in the other majors (beyond the life sciences) that are prone to patenting. We wondered what percentage of females graduated with a doctoral degree in patent-intensive fields, potentially having been mentored by a faculty inventor, and therefore were prime candidates for joining corporate research and development teams working on discoveries that could be patentable.

The doctoral degree data for men and women in 2017 (the last year for which data was available) showed that attainment in any area of study was slightly higher for women (50.4% of total) than men (49.6% of total; NSB, 2019c). Science and engineering (S&E) degrees awarded to men as a percentage of all males receiving degrees was 71%. S&E degrees awarded to females as a percentage of all females receiving degrees was much lower, at 57.7%. Data for particular degrees within the two overarching categories of science and engineering reflected the gender differences we see in patent data. The percentage of female degree holders who majored in biology as a percentage of all females was 11.6% compared to 10.8% for males. Females were much more represented among medical and health sciences degree holders (12.6% female vs. 4.7% male).

Table 2 shows that females receiving degrees in other fields known for patenting, as a percentage of total female graduates, is much lower than their male counterparts. The percentage of female graduates in electrical engineering was 1.2%, mechanical engineering was 0.7%, and materials engineering was 0.6% of total doctoral degrees awarded to females. The percentage of doctoral degrees awarded to women in computer science was 1.2%, and in math and statistics was 1.4%. The percentage of doctoral degrees awarded in the physical sciences (such as chemistry) was 4.32%. The small percentages of women majoring in the fields known for patenting, especially when compared to data for men as shown in Table 2, help us understand why so few women are employed in these fields. The U.S.

Science and Engineering statistics for 2020 indicated that women in the workforce accounted for 27% of computer and mathematical scientists, 16% of engineers, and 29% of physical scientists (NSB, 2019b).

Table 2: **Gender Differences in Doctoral Degrees Awarded in 2017**

Field	Male doctoral degrees (n=35,291)	Female doctoral degrees (n=35,851)	% Male doctoral degrees (all granted to males)	% Female doctoral degrees (all granted to females)
Engineering (all types)	8,037	2,510	22.7%	7%
Electrical engineering	2213	456	6.2%	1.2%
Mechanical engineering	1260	238	3.6%	0.7%
Materials engineering	649	228	1.8%	0.62%
Science (all types)	17,011	18,171	48.2%	50.6%
Natural science	13,106	12,297	37.1%	34.3%
Biology	3,823	4,180	10.8%	11.6%
Medical & health sciences	1,671	4,530	4.7%	12.6%
Physical sciences (astronomy, chemistry, physics)	3,514	1,572	9.9%	4.32%
Computer science	1,497	437	4.2%	1.2%
Mathematics & statistics	1,403	522	3.9%	1.4%

We are not able to determine the degree to which female graduate students may choose the biological and life sciences as degree paths and as paths for future work as inventors due to interest, engagement, and support by faculty members and their partners in the private sector. Future studies and policy-related initiatives may explore the degree to which intentional long-term engagement of young women in these other degree paths—by faculty inventors and by industry professionals who invent—may encourage greater participation, improved degree attainment, and better representation in the private sector.

We recognize that the path to a doctoral degree is long and arduous, and that effective initiatives for improving S&E outcomes for young women will require more engagement of young women in the K12 years and across the undergraduate and graduate years. Engagement must include efforts to develop interest, confidence, and a sense of belonging or identity in these fields. While new approaches in these other grades are necessary, our review of K12 outcomes for young women suggests that early preparation cannot fully account for the disappointing data we have analyzed at the doctoral level. We describe the data used to make this statement in the next section.

Understanding the K12 Education System's Role in Women's Lack of Participation in Patenting

Understandings of the degree to which educators are preparing students in the K12 years for college and career pathways in fields and disciplines known for patenting are inferred from government-issued reports. The reports focus on science, technology, engineering, and mathematics learning outcomes from standardized tests, course enrollment data, and graduation rates. Those actively engaged in helping young people learn about the unique ways inventors find and solve problems that matter characterize inventing as transdisciplinary (Invention Education Research Group, 2019). They argue that students must be offered opportunities for learning how to apply knowledge and practices from many disciplines to problem finding and problem solving. Nevertheless, at present, the nation's success in preparing young inventors from diverse backgrounds is currently considered as being accomplished through efforts to improve STEM outcomes for all students (NSB, 2019a; Committee on STEM Education, 2018; Atkinson & Mayo, 2010). Conceptual knowledge and ways of thinking (such as divergent thinking needed to envision alternative possibilities or solutions) needed to invent are not considered to be any different than those needed in STEM, suggesting that improvements in STEM outcomes will translate into more students from diverse backgrounds who go on to invent in their later years.

Our review of course-taking and testing data across Grades K–12 has revealed differences in the performance of young women and young men in math and science at the different intervals in which tests are conducted. The differences represented in the Science and Engineering Indicators published by the National Science Board were not significant enough to support the notion that there are gender-based differences in young women's STEM capabilities. Test score data and enrollments in science courses were, overall, similar for both genders. There were, however, large differences in the data for students of different racial and ethnic backgrounds—a

topic related to opportunities for learning that we will revisit in subsequent publications.

The data we used to inform our insights into young women's development was published in the 2018 and 2019 Science and Engineering Indicators reports. These reports contained data from standardized tests of mathematics and science for a cohort of students whose performance was traced from kindergarten through fifth grade (Fall 2010–Spring 2016). The data indicated that girls and boys began their years of schooling with average scores in mathematics and science that were the same. Differences emerged, however, by the end of third grade, with boys scoring higher than girls (NSB, 2018). The gap continued in fifth grade with male students' scores in mathematics being slightly higher than those of female students (122 vs. 120). There was no significant difference in science among fifth grade students (NSB, 2019a).

In the middle grades (Grades 6–8), male students continued to do better on the 2017 National Assessment of Educational Progress (NAEP) math assessments for Grade 8 (283 males vs. 282 females). The reported small difference was found to be statistically significant. Science data was not updated, but findings from the 2015 NAEP assessments indicated similar demographic outcomes as the 2017 mathematics scores. Female students in Grade 8, however, outperformed boys on the NAEP's Technology and Engineering Literacy assessment.

By the end of high school, the 2015 NAEP data showed that young women's and young men's performance on 12th-grade science and mathematics assessments were nearly the same.

Our review of these data sources suggests that the preparation of young women in STEM subjects during the K–12 years is mostly on par with young men, with both genders graduating high school equally STEM-capable.

Test scores were not the only indicator that we examined. Grades and course-taking patterns came to our attention as we read about another longitudinal study—cited in the Science and Engineering Indicators 2020—examining data from a nationally representative sample of 20,000 students. The study took place between 2009 (when students

"You have the ability to make an impact. It's not about where you come from, the color of your skin, how many zeroes come with your paycheck. It's about where you're going, how you take your circumstances to create, innovate, and dream the path you want for yourself."

Daniela Orozco-Jimenez, 2017 InvenTeam member, DIY Girls, Pacoima, CA

"I had a wonderful experience working on an InvenTeam as my teammates and I became close friends by the end of our experience. Together, we learned the process of research and development, a phenomenon applicable to many areas. More importantly, we learned persistence and teamwork."

Corine Peifer, 2014 InvenTeam member, Wallenpaupack Area High School InvenTeam, Hawley, PA. Peifer and her team member, Kristian Sonsteby, represented their InvenTeam at the 2015 White House Science Fair, where they presented and showcased their invention to President Obama.

photo credit: Getty Images.

entered Grade 9) and 2016 (three years after their completion of high school). It found that grades and course-taking patterns in science and math (i.e., Advanced Placement or International Baccalaureate) for the students within this group were highly correlated with the declaration of a postsecondary STEM major by students of both genders. The report notes, "Fully 70% of students who earned more than one AP or IB science credit declared a postsecondary STEM major…37% of students who did not earn any credit in AP or IB science or mathematics declared a postsecondary STEM major" (NSB, 2019a).

The findings regarding the importance of enrollment in AP courses led us back to the 2018 Science and Engineering Report containing AP course enrollment data for the graduating class of 2013 (the last available year). The data for enrollment in AP mathematics and AP science courses, shown in Tables 3 and 4, demonstrated no significant differences in course enrollments based on gender (NSB, 2018). Data presented in the reports, however, highlighted the interaction of grades and course enrollments as variables. Data also included information for courses students took through dual enrollment (an AP-like alternative offered by community colleges), which also had benefits that were similar to AP course enrollment.

Table 3: Gender Differences in High School Science Course-Taking Patterns for 2013 Graduates

Science Course-Taking Data	Male	Female
General Science	80.2%	77.1%
AP Science	19.7%	22.0%
General Biology	87.7%	84.5%
AP Biology	9.7%	13.2%
General Chemistry	65.4%	70.2%
AP Chemistry	7.5%	7.9%
General Physics	36.8%	36.0%
AP Physics	6.6%	3.7%

Table 4: Gender Differences in High School Mathematics Course-Taking Patterns for 2013 Graduates

Mathematics Course-Taking Data (Highest course enrolled)	Male	Female
Algebra 1 or lower	3.7%	2.2%
Geometry	9.1%	6.5%
Algebra 2	23.7%	25.1%
Trigonometry	23.7%	24%
Pre-Calculus	20.4%	23.2%
Calculus or higher	19.5%	19.2%

After considering the AP course enrollment data and determining that there were no significant gender differences in who was taking advanced coursework, we returned to the longitudinal study of 20,000 students to examine the differences in the gender of those who went on to enroll in postsecondary education and to declare a STEM major for their undergraduate degree. As Table 1 indicated, a smaller percentage of women graduated high school and went on to enroll in mathematics, science, computer science, or engineering (34.1% males vs. 28.1% females). Social science and psychology were excluded from the definition of STEM for purposes of this paper, as they are not fields known for patenting behavior (Cook, 2019; USPTO, 2019a; Marco et al., 2015).

It is difficult to determine what accounts for the six-percentage-point differential in undergraduate enrollment in a STEM major in college. While the data we reviewed and described above seemed to indicate that women were as STEM-capable as men, a report from the American College Testing (ACT) service argued that women were less prepared for college-level work in STEM than men (ACT, 2019), according to their tests of college readiness. ACT's report also noted that only 45% of students (both genders) interested in STEM met ACT's science benchmarks and 48% met ACT's mathematics benchmarks. Conversely, 29% of students (both genders) not interested in STEM met the science benchmarks and 31% met the mathematics benchmarks. The ACT data is not disaggregated by gender, but it suggests that many women who are STEM-capable may simply not be interested in STEM or feel like they are not adequately prepared (given messaging received from college-readiness assessments) when they leave high school, even though they took the right classes.

The possibility that many young women are simply not interested in STEM aligns with our research. Each year, the Lemelson-MIT Program helps educators and teams of high school students learn to invent through its InvenTeams initiative. Students engaging in invention education find and define problems and design and build new, novel, useful, and unique solutions that contribute to the betterment of society (Committee for the Study of Invention, 2004; Couch et al., 2020). Research, student and teacher survey data, and anecdotal information

from students served over the past sixteen years have demonstrated that many young women were not interested in STEM before having opportunities in the program to apply their knowledge to a problem they identified in their local community. Their InvenTeams experience helped them discover their interest in STEM.

The year-long effort supported by the Lemelson-MIT Program centers around a team-based approach to finding a problem and designing and building a working prototype. While there have been teams comprised solely of women, mixed-gender teams are more common—just as they are among patent holders at-large. Young people ground their work in problem solving in their communities. This, in turn, teaches young people about civic engagement in their local context. Communities have responded favorably with various types of support, including donations, mentoring, publicity, and recognition by government officials. End-of-year experience surveys routinely indicate that young women are much more likely to cite increases in confidence in their abilities to solve problems as a result of their experiences in the program, when compared to young men (Couch et al., 2018). Many young women altered their plans after completing the program and have gone on to pursue STEM college and career paths. Students in our high school program are not expected to obtain a patent for their work; eleven teams, however, have done so.

These experiences lead us to call upon policy leaders to invest in longitudinal studies of the differences in STEM knowledge and interest, and collegiate-level enrollment in STEM disciplines by young women who have access to invention education offerings across multiple years of schooling. Offerings provided through enrollment in dual-credit courses offered by community colleges could substitute for Advanced Placement coursework, given data suggesting that those who take these courses enroll in STEM in college at rates that are very similar to those taking AP courses (NSB, 2019a).

K12 students' success (or not) in these early years and their college and career choices are influenced by their families and by others in their local communities. Policies to remedy the gender gap in patenting must consider ways to engage these influencers. We explore this last topic area in the next section.

Understanding the Roots of Women's Lack of Participation in the Patent System

The shaping of women's ideas and beliefs about themselves and what they are capable of doing in the world begins in the formative years of childhood and continues across all years of schooling. Cultural norms and expectations within families, therefore, are an active agent that is shaping women's opportunities for learning, perceptions of what is important to know and be able to do, and their perceptions of personal strengths and capabilities (Kim, 2016; Csikszentmihalyi, 1999). In her book, *The Creativity Challenge: How We Can Recapture American Innovation*, Professor K. H. Kim makes the case that many women are being raised in what she describes as a patriarchal culture that can suppress women's creativity and negatively impact American innovation (2016). The seven characteristics that she uses to describe a harmful patriarchal culture are:

1. Brainwashes women to be the inferior sex,
2. Results in the provision of different resources and expectations for girls and boys,
3. Pushes females to keep their focus inside the home and pressures them to be submissive and sensitive to others' needs,
4. Inhibits females' nonconforming attitude,
5. Forces females to choose between pursuing a career or starting a family,
6. Stifles cross-pollination for females (i.e., access to mentors and collaborators), and
7. Ignores females' professional accomplishments.

Kim's arguments suggest that the norms and expectations of people in women's everyday life-worlds create cultural conditions that impact ways women think about and internalize messages—both direct and indirect—about what they can know, be, and do in the world. Her perspective aligns with education researchers who argue that children take up gendered roles and expectations early in life through interactions with parents and others (Dasgupta & Stout, 2014; Eccles et al., 1990).

The notion that cultural norms and expectations are reinforced or challenged by others outside the family has been validated by researchers studying the developmental trajectory of inventors. Researchers found, for example, that children are more likely to patent if they have grown up in environments in which they have regular exposure to people working in innovative companies and universities (Couch et al., 2018; Bell et al., 2018). They are also more likely to patent in the technology area in which their parents worked (Fechner & Shapanka, 2018; Bell et al., 2018). The family's economic standing within the community also appears to make a difference.

> Individuals born to wealthier parents are far more likely to patent than individuals born to poorer parents. Specifically, for every 10,000 children born to families in the top one percent, 22.5 will receive a patent in adulthood. In contrast, only 2.2 of every 10,000 children born to families with incomes below the U.S. median income will receive a patent as an adult. (Fechner & Shapanka, 2018).

The influence of child-rearing practices and sociocultural and socioeconomic conditions in both the home and in the broader community suggests that efforts to address the gender gap in patenting need to start in the early years. The efforts also need to engage families and people in local communities in particular efforts to support young women's development as inventors.

We summarize in the next section the insights we have gained while doing this study, which inform the actions that parents, leaders in local communities, leaders in education systems, and corporate leaders can take to remedy the de facto bias reflected in the current patenting data.

Recommended Policies for Supporting New Pathways to Invention for Women

Our comprehensive examination of factors contributing to the gender gap in patenting and barriers women face when commercializing their patents reveals the complex nature of the problem. Leadership and changes are needed across multiple institutions. It is our hope that this paper can inform leaders as they craft inclusive economic development policies and initiatives. Unleashing the economic and employment benefits that can be generated from women's creative ideas will require investment in new approaches for supporting young women's development as inventors and entrepreneurs. Change is needed in K12 schools, colleges, and universities and in the private sector. All of these institutions shape women's perceptions of what they are able to do and accomplish.

Changing perceptions, beliefs, and actual experiences as women form and develop is difficult, given the number of people and institutions involved and the over-time nature in which belief structures are taken up by individual women. The historic nature of the problem is not likely to be addressed through incremental change. Bold policy initiatives that target the challenges described above are needed. Seven ideas for initiatives that emerged from our study were:

1. Incentives for patent-intensive industries in the private sector to hire more women in research and development focused on team-based projects with patent and commercialization potential.

2. Incentives for faculty inventors and private-sector partners to recruit, mentor, and continuously support female college students enrolled in college in patent prone fields in which women are underrepresented.

3. Support that empowers female faculty to further develop as inventors and to commercialization their inventions.

4. Resources and policy changes at the K12 level to allow for deliberate efforts as part of public schooling to support the development of young inventors and to increase interest in STEM college and career pathways among young women. Also, engagement of parents and others in the community in support of this effort.

5. Dual-enrollment options for high school students in which courses jointly offered by high schools and community colleges will focus on engaging students in problem-oriented problem-based learning.

Projects involve developing a working prototype of an invention that solves a problem student teams identify, and the course will carry dual credit to have the same bearing as an Advanced Placement course in calculating the grade-point average used for college admissions.

6. Provision of legal services and waivers of filing fees for women seeking to protect their intellectual property.

7. Longitudinal studies of the efforts described above to determine what works, under what conditions, and for whom.

The notion that America could intentionally support the development of a more diverse group of inventors and future patent holders suggests that inventors' talents are developed after birth, rather than as a result of having been born a "genius." It challenges adults and young people alike to get beyond the idea that inventing and/or invention education efforts only belong to those who score well on IQ tests or other measures selected to sort young people according to their "giftedness" and "talents." For those who continue to have doubts, we ask that you visit the Lemelson-MIT Program's website, where there is evidence of students from all backgrounds who have developed working prototypes of inventions at the high school and collegiate levels. Many of these innovators are young women and students who are Black or Hispanic. The young inventors give us hope for the future.

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