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ADDRESSING THE GENDER GAP AMONG PATENT HOLDERS THROUGH INVENTION EDUCATION POLICIES

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The gender gap among patent holders in the U.S. has been well documented. Some studies illuminating the need for greater diversity have included recommendations for new policies aimed at changing the differential ways men and women take up opportunities to develop as inventors and to obtain U.S. patents. However, limited studies are available to guide the design of programs and establishment of policies that reflect promising practices for teaching young women to invent and patent during their high school years. This article reports findings from the study of the Lemelson-MIT Program's 14-year-old high school InvenTeams initiative and related policy implications for increasing gender diversity among U.S. patent holders through invention education in high school. The initiative has engaged more than 2,200 high school students (34% female) in inventing, with seven of the 229 teams obtaining U.S. patents. The program's records, student surveys, and participant interviews serve as a foundation for the study. Our analyses of the interview transcripts examined what supported and constrained three young women's participation in the year-long, team-based invention process and how the InvenTeam experience influenced their ways of seeing themselves as leaders, inventors, and innovators. Factors that supported their work as inventors included the organization and processes of InvenTeams, various resources and people, and their own personal qualities, values, and beliefs. Factors that constrained their work included time, stereotypes, and lack of prior knowledge, exposure, understanding, and engagement.

Key words: Invention education; Policy; Women inventors; Gender gap; High school

GENDER DISPARITIES AMONG INVENTORS

Gender-based disparities among U.S. patent holders have been documented by numerous researchers (1-4) using a variety of methods even though the United States Patent and Trademark Office (USPTO) does not collect such data. A study by Nager, Hart, Ezell, and Atkinson, for example, demonstrated that today's leading innovators are 88.3% male and 11.7% female (1). Haseltine and Chodos went beyond the focus on gender representation among patent holders by also looking at the numbers of patents generated by men versus women. Their examination of data regarding members of the National Academy of Inventors, an organization whose membership ranks are comparable to the larger 'pool' of inventors (11% women), showed that the number of patents generated by women (mean of 9) was, on average, lower than the number generated by men (mean of 19 to 20) even though "both patent in the same areas" (5).

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Prior studies have identified a wide range of factors that contribute to the differences between men's and women's success in obtaining patents, including the social organization of scientists' work settings (6,7); the expense of the patenting process (6); the need for legal representation and access to lawyers (3,6); patenting behaviors of a parent (8,2); the effects of exposure, such as growing up (or not) in areas that have innovative companies and universities (2); and personal factors such as access to mentors (or social networks), family income, and race (2,6). Lack of representation by women among degree holders in science, technology, engineering, and mathematics (STEM) fields has also been identified as a factor that contributes to the gender gap (4). Statistics for the year 2013 show that women accounted for only 15% of employed college graduates in engineering (8% in mechanical engineering and 11% to 12% in electrical and computer hardware engineering), 31% of physical scientists, and 25% of computer/mathematical scientists—all fields that are known for patent generation (9).

Calls for new policies aimed at remedying the gender gap among patent holders are often co-present in studies that give rise to the visibility of the problem. The analysis conducted by Hunt, Garant, Herman, and Munroe, for example, found that increasing female representation in science and engineering would do little to change the percentage of women represented among patent holders, given the low levels of patenting activity by women with STEM degrees (4). They argued for "early intervention policies" that would support the development of female inventors by providing them with career pathways in patent-intensive fields of study, such as electrical and mechanical engineering, and in patent-intensive jobs that involve design and product development (4)—both of which are more common pathways for men. Bell, Chetty, Jaravel, Petkova, and Van Reenen called for "extensive margin" innovation policies that would expand opportunities for youth participation in the innovation sector and would expose young people—particularly those from underrepresented groups and low income families—to invention education, invention careers, and STEM fields from a young age (2).

This study seeks to inform policy development aimed at expanding youths' opportunities to learn to invent while in high school, with an emphasis on policy considerations that are particularly important for supporting the development of female inventors. The study is grounded in an understanding of inventing and in ways of thinking as an inventor, as detailed in a 2004 report issued by the Committee for the Study of Invention (10). We selected InvenTeams™, the national initiative of the Lemelson-MIT (LMIT) Program, as our site of study because the program's founder was a prolific inventor, its current faculty director is a prolific inventor, and because the program has a sustained fourteen-year history of helping high school students from diverse backgrounds (gender and race) develop working prototypes of their inventions.

The LMIT Program is a sponsored program within the School of Engineering at the Massachusetts Institute of Technology (MIT). Since the creation of the program fourteen years ago, 229 teams of high school students across the U.S. have received grants of up to $10,000 to develop working prototypes, ultimately showcased at MIT during a multi-day capstone event called EurekaFest. Documentation of the program indicates eight phases of work for InvenTeams, as shown in Table 1 (11).

Historical records of InvenTeams demographics for the nine years between 2008 and 2017 indicate that an average of 34% of the program's 2,215 youth participants have been female, and nine teams have been all-female teams. Figure 1 illustrates that the percentages of female InvenTeam participants increased after 2012, and, though their numbers fluctuated each year from a low of 23% to a high of 53%, they have remained above the historical average since 2013. One of the 15 teams in 2017 comprised females only, and of the 196 total team members, 37.7% were females. Female representation among InvenTeams is higher than the national averages of women in STEM and female patent holders and is a reflection of the program staff's recruitment and strong encouragement for diversity among the teams' composition during the application phase. Staff also attribute female participation to the team-based nature of the program and the diverse roles that an individual student can opt into. Administrative, communications, finance, and sustainability roles make it easier to recruit students from diverse backgrounds who might be

Table 1. Summary of the Phases of an InvenTeam Grant Cycle

Phase	Phase Description	Months	Duration in weeks	Activities	Milestone
Teacher-focused phases					
1	Recruitment for and submissions of initial applications for Excite Award	Oct.–Apr.	24	Application requires invention proposal, information on school, resumés of teachers, letter of support from administrator, and statement of interest for invention projects	April deadline
2	Finalists' selection by LMIT staff	Mid-Apr.	2	LMIT evaluation of educator's applications utilizing rubric	35 educators receive Excite Award to attend EurekaFest
3	Professional development	Mid-Jun.	1	Excite Award recipients attend professional development during EurekaFest at MIT, view current year's projects, receive feedback on proposed projects, and review guidelines for the final application	Invitation to Excite Awardees to submit final application if they attended Eureka Fest
4	Summer work with students	Jul.–Sept.	8	Excite Award recipients work with students to form teams and complete the final InvenTeam application	Final applications submitted
5	Judging	Sept.	4	National jury review and ranking of applications, and recommendations to LMIT for staff to make final selection	15 teams selected for $10,000 InvenTeam grants and notified
Team-focused phases with teachers, mentors, and students					
6	Invention project launch	Oct.–Feb.	20	Grant agreements signed, procurement cards released, communications and financial training for teams, on-site visits from LMIT while teams iteratively build, test, and refine invention prototypes based on results and feedback, and beginning-of-year survey	Mid-grant technical review with community in February
7	Post-technical review	Mar.–Jun.	12	Final invention modifications and prototype building, raise travel funds to attend Eureka Fest at MIT, and end-of-year survey	Working prototype shipped to MIT
8	Capstone event	Mid-Jun.	1	Team travels to MIT, showcase inventions, present to peers, meet collegiate inventors, and attend seminars	EurekaFest

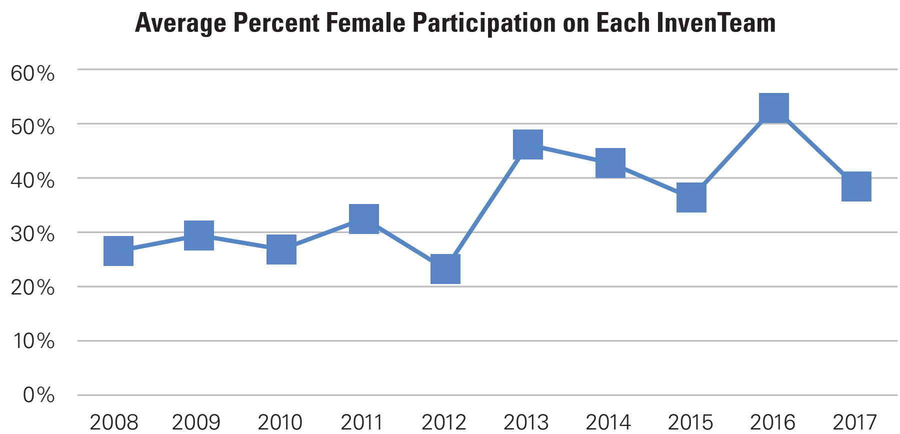

Figure 1. Female participation on InvenTeams from 2008–2017.

hesitant to opt in for a purely technical role.

All student participants are asked to complete online surveys at the beginning and end of each InvenTeam year, enabling program evaluation and assessment of students' attitudes and learnings. Students mark their level of agreement or disagreement with statements about skills and knowledge employed or developed and their experiences during the school-year-long invention project using 5-point Likert-scale items. Survey results consistently indicate students' strong agreement that participation on InvenTeams was positive, influential, and impactful.

Our research focused on understanding female participants' experiences during the project, given LMIT's longitudinal record of including female and other diverse students on InvenTeams, and the positive results found in end-of-year surveys documenting the impact of student participation in InvenTeams. Three questions guided our research and analyses:

1) How and in what ways do high school students who have conceptualized, designed, and built an invention as InvenTeam members represent their experiences on the end-of-year surveys? Are there differences in the self-reported experiences of young women and young men?
2) How and in what ways did young women participants' ways of thinking, knowing, or being change (or shift) as a direct result of their experiences working on an InvenTeam?
3) What supported and/or constrained the young women's participation in STEM and/or their work as an inventor on an InvenTeam?

RESEARCH APPROACH AND PARTICIPANTS

We addressed the first research question by examining the results of the 2017 end-of-year survey. The second and third questions were investigated by creating a purposeful sample of three young women (12). We elected to focus on three women and to explore their accounts of their participation in InvenTeams to develop understandings of specific experiences that supported and constrained their development and their self-identification as inventors or innovators. After all, as Erickson argued, understanding of general or universal patterns first requires examining the specifics of particular situations (13); therefore, understanding specific experiences of a few participants enables us to construct theoretical inferences that potentially can inform broader understandings of initiatives aimed at supporting young female inventors (14).

Two of the three women chosen for analysis in this study were on the same InvenTeam enabling us to conduct both inter-team and cross-team comparisons of experiences. The women participated in semi-structured interviews in which the researchers asked specific questions but also allowed for responsive interviews and discussions that could inform the meaning of words and language from students' perspectives (15,16). The semi-structured approach to interviewing "allowed for gathering rich, detailed data directly" from InvenTeam students to help us generate insights and empirical evidence for making warranted claims in relation to the research questions (17). Students were invited to select their own pseudonyms. Interviews were recorded, transcribed in a pragmatic way to match the content-focused research purpose (18), and analyzed using ethnographic research methods, including semantic analysis (19). The tracing of the three young women's perspectives and experiences afforded opportunities to uncover changes in their ways of thinking attributed to their InvenTeam experience and factors that supported and constrained their work.

ANALYSES

Gender-Based Differences in Survey Responses

We utilized the most recent (2017) end-of-year survey to examine the first research question focusing on how InvenTeam members represent their experiences and whether there were differences in the self-reported experiences of young women and young men. The 2017 survey, in which 73% of the students responded, showed 81% of total respondents (n = 126) agreed or strongly agreed that "working on our InvenTeam project taught me to learn from failure," 84% of respondents (n = 124) agreed or strongly agreed that "I developed self-confidence in my ability to solve problems," and 84% of respondents (n = 126) agreed or strongly agreed that "working on an InvenTeam taught me to be persistent." Table 2 demonstrates that significant differences emerged between female and male "strongly agree" responses to the three questions.

Based on these descriptive statistics, we were not able to determine why the percentage of female students strongly agreeing with each of the statements was significantly higher than male students. Our attempts to find a reason for the difference led us to a deeper investigation of another survey question in which students were given a set of descriptors that could potentially be used to describe themselves and were asked to mark all terms with which they identified. There was no significant gender-based difference in the students who identified as inventors, as 21 females (34.4%) identified as inventors, compared to 26 males (32.9%). However, a gender-based comparison of InvenTeam participants' selections of other types of descriptions of self revealed a difference between female and male participants. Table 3 shows that "leader" and "innovator" were the two top choices for females, garnering response rates that exceeded 50%. "Engineer" was the only term garnering a response rate of 50% or greater by males. Like their female counterparts, a high percentage of males identified as leaders.

The survey responses indicating greater agreement in the "strongly agree" category for "learning from failure," "developing self-confidence," "persistence," and inscriptions of self as innovators and leaders by more than 50% of the females—versus the males' choice of engineer—hinted at gender-oriented differences among the experiences students brought to, developed, and then took away from their InvenTeams work. However, survey data alone was not sufficient to help us understand why differences existed between female and male students. The differences led us to the second and third research questions, focusing on what experiences among young women had led to particular kinds of self-identification and what supported and constrained the work of the young women as they invented. We explored these questions by interviewing three female InvenTeam participants.

Table 2. Significant Differences in Male and Female Students' Agreement Responses

2017 End-of-Year Survey Questions	Female/Strongly Agree (n = 54)	Male/Strongly Agree (n = 72)	*P*
Learn from failure	59.3%	34.7%	0.019
Self-confidence in ability to solve problems	49.1%	29.6%	0.039
Persistence	55.6%	31.9%	0.019

Table 3. Self-Descriptors Selected by 2017 InvenTeam Participants

Female InvenTeam members		Male InvenTeam members	
Self-descriptor	Number and % of respondents	Self-descriptor	Number and % of respondents
Leader	39 (63.9%)	Engineer	41 (51.9%)
Innovator	31 (50.8%)	Leader	35 (44.3%)
Creator	29 (47.5%)	Maker	35 (44.3%)
Maker	26 (42.6%)	Creator	33 (41.8%)
Engineer	25 (41.0%)	Scientist	33 (41.8%)
Scientist	22 (36.1%)	Innovator	31 (39.2%)
Inventor	21 (34.4%)	Technologist	30 (38.0%)
Technologist	10 (16.4%)	Inventor	26 (32.9%)
Entrepreneur	16 (26.2%)	Entrepreneur	18 (22.8%)
No response	4 (6.6%)	No response	8 (7.6%)
Total	223 (81%)	Total	288 (79%)

Table 4. Self-Descriptors Selected by 2017 Female InvenTeam Participants Compared to Three Female Research Subjects

Self-descriptor	Number and % of respondents	Celaena	Magdalena	Chelly
Leader	39 (63.9%)	X	X	
Innovator	31 (50.8%)	X	X	X
Creator	29 (47.5%)	X	X	
Maker	26 (42.6%)	X	X	
Engineer	25 (41.0%)			
Scientist	22 (36.1%)		X	
Inventor	21 (34.4%)	X	X	
Technologist	10 (16.4%)	X		
Entrepreneur	16 (26.2%)	X		
No response	4 (6.6%)			
Total	223 (81%)			

All three women interviewed started with their InvenTeams in the spring of 2016, participated throughout the 2016–2017 school year, and attended the culminating capstone event, EurekaFest, at MIT in June of 2017. Two of the three participants, Celaena and Magdalena, attended the same public STEM magnet school and were on the same InvenTeam. Their team consisted of both males and females, and the team's work was supported by two male teachers employed by their school. Planned InvenTeam meetings took place at the school during the week and on Saturdays. The third participant, Chelly, was part of an all-female team. Her team met after school and was supported by a female STEM teacher and a female engineer mentor in a local STEM-focused afterschool program that met at the team members' high school.

Table 4 shows that Celaena and Magdalena were among the females self-identifying as inventors, and they identified with numerous other descriptions, including leader, creator, maker, and innovator. Chelly self-identified as an innovator.

Because Celaena and Magdalena were on an InvenTeam from a STEM magnet school with over half of the work being done outside of the school day, and Chelly was in an afterschool program, we wondered how their work on their teams and their school environments may have influenced their self-identifications. Therefore, we first examined how the three participants described shifts in the way they saw themselves and possibilities for their future as inventors. Subsequently, we examined the contexts that they described as supporting or constraining their engagement in STEM and invention education.

Shifts Experienced by Three Young Women on InvenTeams Made Visible in Interviews

Following the survey responses on the self-identification question, we began our analyses by examining how the three participants described the shifts they experienced while working on their InvenTeams. "Shifts" refers to changes in ways of thinking, knowing, or being that each young woman articulated in the interview. Table 5 demonstrates that, for Celaena, the key changes included a shift in her ability to have intellectual conversations with adults, a shift from disliking math to seeing it as her "strongest subject," a shift to loving engineering and the processes of innovation, and her overall shift toward self-identification as an inventor.

Celaena shared in the interview that her work on the InvenTeam helped her develop the ability to have in-depth intellectual conversations with adults. She attributed this new ability to her work with adults and people she characterized as being "high up on the food chain." The people she saw as important included community members, Lemelson-MIT staff, mentor teachers, and other adults who supported the students throughout their InvenTeam experience. Celaena stated that these "in-depth intellectual conversations with adults" led to "driving up [her] confidence" as a learner, a leader, and an inventor.

Celaena's second shift revolved around overcoming her dislike of math and science and starting to see math as her "strongest subject." She credits this to her introduction to the type of STEM she likes, which has led to both "liking STEM" and taking accelerated mathematics courses that allowed her to complete two years of math requirements in one year. She now considers math her strongest subject, and she even had to take math at the nearby community college because she ran out of math classes at her high school.

Like the shift around math, the shift to loving engineering and the creative process was linked to Celaena's school experiences in STEM. She indicated

Table 5. Shifts Described by Celaena During the InvenTeam Year

Celaena's shifts	Attributed to	Leading to
Ability to have in-depth intellectual conversations with adults	Work with adults and people high up in the food chain (during InvenTeams)	Increasing confidence
Overcoming dislike of math and science and seeing math as "my strongest subject"	Exposure to the type of STEM that I like	Liking STEM, doing accelerated courses, taking two years in one year; running out of math classes, taking Calc 2 classes at [a local community college]
Love of engineering and the creative process, as well as innovation, chemistry, and biology	Experiences at STEM school	Desire to have the ability to help people
Self-identification as an inventor	Experiences at STEM school and InvenTeams that enable expressing creativity	Hope of being a successful inventor in the next year or two who helps people and actually creates something that people can benefit from

that, during her two years at the STEM school, and particularly in the last year of working in InvenTeams, she developed a deeper "love of engineering and the creative process" as well as an enjoyment of innovation, chemistry, and biology. She explained that her love of engineering and the other STEM subjects led to a desire to further develop her abilities to "help people," a principle stemming from InvenTeams' focus on developing a prototype that helps solve real problems that have a social impact. Her desire to help people was visible in the way she described her shift to seeing herself as an inventor too. She attributed her status as an inventor to her experiences at the STEM school as well as to her experiences with InvenTeams. She stated that the InvenTeam processes enabled her to express her creativity and, in turn, gave her hope for becoming a "successful inventor in the next year or two." She defined "successful" as being able to help people and actually create something that people can benefit from. The fourth shift indicates Celaena's growth from someone who did not like STEM to a young woman who not only fell in love with math and science but also started seeing herself as an inventor confident in her ability to converse with other adult scientists and members of the community.

Celaena attributed her shift toward an inventor identity to both InvenTeams and her STEM-school experience, while Magdalena emphasized InvenTeams more than the school environment, even though both attended the same school. Table 6 demonstrates that, for Magdalena, there were two primary shifts in new ways of seeing herself: as a leader and as an inventor.

Magdalena talked about learning to see herself in new ways. Having taken on a leadership role that involved resolving differences and "learning to work" with a fellow student with whom she previously "butted heads," Magdalena developed her leadership skills and belief in herself as a leader. She also saw herself as being able to "do a lot more" if "I put my mind to it." She attributed this new view of herself as a leader to her leadership role and collaborative work on the InvenTeam.

She also credited her InvenTeam experience with enabling her to see herself as an inventor. Magdalena shared in the interview that the year-long InvenTeam process provided her opportunities to realize that inventors are creative thinkers who create innovative solutions to problems. She understood that many people can use a variety of skills to become inventors even if they don't display technical expertise. Magdalena said that, due to the InvenTeam experience, she now saw herself as an inventor and described her plans to continue inventing in the year ahead with the goal of producing inventions to support a community with a specific physical disability.

Table 6. Shifts Described by Magdalena During the InvenTeam Year

Magdalena's shifts	Attributed to	Leading to
New way of seeing herself as a leader	Leadership role on the team and success in learning how to work with a fellow student she butted heads with	Belief in self as a leader
	InvenTeam experience	Belief in her capacity to do a lot more if she puts her mind to it
Seeing herself as an inventor	InvenTeam experience	Realization that inventors are creative thinkers who create innovative solutions to problems (even if they don't display technical skills)
		Plans to continue to invent in the year ahead with the goal of producing inventions to support [a community with specific physical disability]

Unlike Celaena and Magdalena, who came from a STEM school and saw themselves as inventors, Chelly, whose InvenTeam work was an afterschool project, did not call herself an inventor yet. However, the year-long invention process precipitated shifts in the way she saw invention projects, STEM subjects, and her own future. Table 7 demonstrates four shifts, the experiences that influenced those shifts, and the outcomes of those shifts.

Analysis of Chelly's transcript revealed her first shift in ways of thinking of herself when she described her experiences in the Mid-Grant Technical Review (MGTR) that all InvenTeams undertake in February. The MGTR involved the team presenting their work-to-date to the community, intended recipients, and invited audience members, including local media and elected officials. Reviews are intended to gather feedback that helps teams continue and/or improve their projects. Chelly's account of the review and feedback process indicated that the interviews she experienced "here and there" and the significance conveyed by adults shifted her thinking of the InvenTeam project from being an "after-school activity" for which "we just never got that concept" to being a major project in which she played a significant role. She said that once she understood the significance of the InvenTeam work, she deepened her commitment to producing the prototype and presenting it at the capstone event, EurekaFest, at MIT.

Understanding the importance of the project and seeing the significance of her role also supported Chelly's shift in the way she saw STEM and engineering. She shared that the InvenTeam experience helped her to overcome her dislike of engineering and learning about STEM fields, which led her to consider studying "something in STEM" in college. She even started shifting her thinking toward wanting to learn how to code, exploring more majors, and possibly studying computer science. Possibly the most significant shift for her was developing confidence in her "ability to see ways of going through those hardships in college." Having experienced "highs and lows and doing something of this magnitude" led to her seeing InvenTeams as a unique experience and invention as a possibility for her future. Though she did not refer to herself as an inventor, the year-long team experience helped her claim that she was an innovator who shifted her ways of thinking about STEM and started envisioning herself as pursuing a career in STEM.

The shifts the three young women described in their interviews made visible that engagement in team-based invention education provides opportunities for females to envision themselves in STEM fields and invention pathways. We draw on the young women's interviews in the next section, exploring the elements of their sociocultural environments that supported and/or constrained their entry, participation, and future pathways in STEM overall and specifically in invention.

Supports and Constraints to Women's Participation in STEM and Invention

Analyses of the interviews of the three female InvenTeam participants suggest that the InvenTeam experience increased the likelihood of their pursuing STEM college/career pathways, with two expressing identities as inventors and one identifying as an innovator and switching from an undeclared college major to considering computer science or a STEM-related field. Their accounts alluded to multiple factors that influenced their pathways toward STEM and invention; therefore, we revisited the transcripts to examine further what supported and what constrained the young women's work as InvenTeam members and their developing identities as leaders, inventors, and innovators.

Supports

Collectively, the three participants identified four factors that supported their work and four that functioned as constraints, with three factors providing both a support and a constraint. Factors that supported the work of InvenTeams included: 1) the organization and processes of InvenTeams; 2) resources; 3) people; and 4) personal qualities, values, and beliefs.

When describing their experiences with inventing during the year, the participants talked about the InvenTeam initiative's organization and processes as important supports. Celaena emphasized the distributed leadership model used in InvenTeams, saying it was "good to give each person who was a leader something to lead … to take charge." Each team member

Table 7. Shifts Described by Chelly During the InvenTeam Year

Chelly's shifts	Attributed to	Leading to
Seeing InvenTeam project as significant and a major thing	Significance conveyed by teachers, support at the mid-grant technical review from people (Congressman, community members, teachers, family), and interviews "here and there"	Commitment to producing the prototype and presenting at EurekaFest
Overcoming not liking anything about engineering and becoming knowledgeable about STEM	InvenTeams	Possibility of studying something in STEM in college
Thinking about learning how to code	InvenTeam experience	Looking at more majors at college she will attend for possibility of studying computer science
Ability to see ways of going through hardships in college	Experiencing such highs and lows and doing something of this [InvenTeam project] magnitude	An invention and characterization of the experience as unique

played a significant role in the accomplishments of the whole group by sharing responsibilities and leading different aspects of the InvenTeam processes. The young women talked about the MGTR as one of the critical parts of the program that supported their invention work, in addition to the team-building and distributed leadership models promoted by InvenTeams.

The MGTR is a required step and involves each team presenting their work-in-progress to their local community, intended users, and invited guests (teams often invite local elected officials). Community members are asked to provide feedback about the technical aspects of the developing prototype, and an LMIT staff member supports the teams in planning out their next steps and finding necessary resources. Chelly said that the MGTR helped her team realize that what they were doing was "very significant and a major thing," while Celaena emphasized that this step in the program was instrumental in reminding them that "what we were doing benefited people and they said they have been looking for a solution for this problem." All three participants viewed the MGTR as a support that validated their work, helped them feel motivated, and provided feedback that they "had to think through more" since they saw that the "customer wanted our product" (Celaena). The certificates from the mayor (Magdalena), the feedback of a director from a major university (Celaena), and the support of the many people in attendance (Chelly) enabled them to proceed and to think of "the future" and "how we would be once we were [at MIT presenting their projects]" (Chelly).

The interviewees also talked about resources within and beyond the teams. Chelly talked about the value of the afterschool program and emphasized the importance of online resources as a key support for her work on InvenTeams. She said that another afterschool program, known as "Project Grad," focuses on getting under-represented students to take the coursework needed for college eligibility and helped her "learn what it took to go to college." In addition, online resources provided much-needed technical help for the InvenTeam work. Since Chelly's team worked exclusively in an afterschool environment with less technical support, they needed to find "video tutorials, instructables, projects … as a place to start … to get a hang of it." Meanwhile, the two young women from the STEM school did not talk about resources explicitly, signaling that the resources may have been invisible or taken for granted in their STEM-rich school environment.

The third major support the young women saw as instrumental in their work on InvenTeams was people. The people included "customers," community members, LMIT staff, and others who provided support and feedback at the MGTR and along the way. However, the most significant people supporting their journeys were parents and teachers. Magdalena talked about her teachers, who provided guidance and shared their technical expertise, while Celaena and Chelly talked about their parents more. Celaena stated that her parents "forced me to go to STEM" but then provided the support needed for her to succeed in school and the InvenTeam project. Chelly, on the other hand, emphasized her mother's role in pushing "that idea [to go to college] on me" and getting her to join Project Grad and the afterschool InvenTeam.

The InvenTeam organization and processes, the resources, and the people were significant supports in the young women's engagement with invention, but, ultimately, they saw their own personal qualities, values, and beliefs as forces driving their success in InvenTeams and STEM. Celaena took pride in her "ability to speak to people" and to create "harmony" when "dealing with a bunch of people." Magdalena emphasized the importance of her leadership skills and her ability to "take charge … so that things are happening." Meanwhile, Chelly talked about her "many interests" and associated her ability to look at "engineering [as] a growing industry I should learn about" with her "love to learn" attitude and her recollection of "always loving school." She also said her wanting to "do something good … that will impact community" sustained her through the "highs and lows" of the experience, leading to more confidence in her ability to persist and to "make it" in college.

Constraints

The young women interviewed for this research emphasized their successes and supports, but they also shared the constraints and challenges they experienced. Our analyses of the interviews identified three factors constraining the work of InvenTeams: 1) time; 2) stereotypes; and 3) lack of knowledge, exposure, understanding, and engagement.

InvenTeam students have one school year to complete phases 4 through 8 of the InvenTeam grant cycle outlined in Table 1. Periodic check-ins and one site visit by LMIT staff help the teams maintain momentum and use their time effectively, but, as the young women shared, time was a challenge. InvenTeam work was an afterschool activity for Chelly, so she and her teammates had limited time to fully engage in and understand all of the processes necessary for inventing. As mentioned above, it was not until the MGTR in February that Chelly realized the importance of her team's project—not just for the team but also for the larger community interested in seeing the prototype. Time was an issue for Celaena and Magdalena, who worked on their InvenTeam project during the school day, afterschool, and on Saturdays because they had multiple demands. Celaena stated that her "tenth grade was the hardest year. I had to prioritize InvenTeams over robotics …[and] got really overwhelmed." Magdalena also talked about "scheduling difficulties" and a conflict with robotics, noting that the inventing "wasn't going as quick as it needed to be," and she "was scared" because they "were going to lose a lot of [team members with coding experience] for a while" due to schedule conflicts with robotics. Thus, as the participants made visible in the interviews, inventing requires significant amounts of time, which becomes a challenge for high school students who have multiple demands on their time. Magdalena estimated that she spent seven to eight hours per week working on the invention, while Celaena and Chelly both thought that they spent nine to 10 hours per week.

Participants not only felt constrained by time but also by the stereotypes about women in STEM. Celaena was most explicit about the stereotypes, stating that there is a "stereotype on girls that you are not supposed to be interested." Talking about her shift to math becoming her strongest subject, she said that previously she heard "you're not supposed to be interested," and she believed that STEM "was sitting in a classroom doing math equations all day." If not for her parents' support and push to go to a STEM school, she may never have come to see herself as an inventor. Chelly did not state the stereotypes as a constraint explicitly, but, in describing her experience, she indicated that prior to the afterschool leader's invitation, she had not considered coding or STEM as a pathway for her future. The participants had to overcome stereotypes about females in STEM in order to see themselves as leaders, innovators, inventors, and important members of InvenTeams.

While time and stereotypes were significant constraints, the constraints that the participants described the most were lack of knowledge, exposure, understanding, and engagement. We have grouped these constraints into one since they all signaled the need to engage females in pathways toward STEM from an earlier age and in multiple ways. Chelly talked about two types of knowledge she lacked. First, she said she "was never told or given any direction as to how to get there [to college]," and second, she talked about her lack of technical knowledge needed to complete the work on the InvenTeam. She was involved in working on a solar panel and doing coding on her InvenTeam, but her lack of knowledge and prior experience was "frustrating," as she "just couldn't get it [coding]" and was "stressing out over it." She also shared, "I really didn't know anything about engineering. Before inventing, I had absolutely no idea what STEM was … that's why I didn't really have an interest in it. So, I never looked into robotics teams." This lack of exposure to science and engineering became a challenge for Chelly; she and her teammates had to learn most of what they needed on their own, utilizing online resources such as YouTube.

Magdalena and Celaena had more exposure to STEM in their school, yet they also talked about the lack of knowledge, understanding, and exposure to fields, tools, and ideas that would have helped them in their InvenTeams. Celaena stated that she "didn't have exposure to the type of STEM that I would have liked. That creative part." Magdalena also talked about her lack of exposure to different ways of engaging in invention work. She said it was a "hard transition due to the fact that it is different. Different grading system. Some people don't make it." Magdalena said that InvenTeams involved "a lot of technical work and not as many technical members to take that on," so they needed to add a member from a robotics team to bring in the needed expertise. Despite exposing the knowledge and skills Celaena, Magdalena, and their team members lacked in InvenTeams, both young women did give credit to their school and its supports. Celaena credited its "three pillars of critical thinking, innovation, and collaboration," while Magdalena said that the project-based learning and experience with doing presentations from the 9th grade were significant in helping them succeed in InvenTeams.

Celaena's and Magdalena's experiences make visible that the constraints of time, stereotyping, and lack of exposure or knowledge can be mitigated by engaging young women in STEM and project-based learning within the school day and from the beginning of the high school years. The participants' accounts of their InvenTeam experiences provide ways of thinking about policies that could extend opportunities for women's participation in invention and might contribute to narrowing the gender gap in invention and awarded patents.

CONCLUSIONS AND POLICY IMPLICATIONS

Celaena, Magdalena, and Chelly's interview accounts of their InvenTeam experiences, along with results of the survey, offer ways of thinking about factors that support and constrain women's participation in STEM and their work as inventors. They made visible that, despite challenges and constraints, engagement in invention supported views of themselves as STEM-capable and as inventors or innovators. Magdalena and Celaena, who had longer exposure to and more support in STEM, self-identified as inventors and expressed an intent to continue inventing. Chelly, for whom the InvenTeam experience was the first exposure to deep STEM work through inventing, began considering a future in STEM, saw herself as an innovator, and developed a deeper commitment to create work that benefits the community. These findings suggest that students' engagement in the act of inventing (not just exposure to innovation) is a significant factor that can foster the development of future inventors. Our findings are consistent with Bell et al.'s argument that young people's exposure to innovators and innovation can influence their choices to pursue careers that are more likely to lead to invention and patenting (2). Our participant accounts show that the changes in their thinking were, in part, "driven by differences in environment and human capital accumulation, not intrinsic traits," as suggested by Bell et al. (2).

Factors identified in this study that affected the young women's development signal a need for policies and practices intentionally designed to increase the number of female patent holders. The first factor or design consideration relates to people and includes teamwork, public critique, guidance by knowledgeable educators and STEM professionals, and parent support. Students' engagement and experiences were enhanced by their work with teachers and peers in teams. A team-based approach to inventing aligns with findings that teamwork is critical to inventors (2,20). The distributed leadership approach promoted in InvenTeams enables team members to contribute in significant ways from their differential roles. Student accounts of the value and impact of public engagement and critique suggests that opportunities to present and receive feedback on invention projects as they unfold would also be an important component of an invention-focused education policy initiative. The supportive role of parents mentioned by study participants suggests that policies should also have a parent education and outreach component. The parent component should include information about how young women's negative views of STEM and inventing can shift through engagement in STEM-rich environments and project-based learning experiences. Parents, teachers, community members, and students themselves could be provided more information about the vast diversity of skills, experiences, and personal qualities that are important within invention-oriented teams.

The second group of factors relates to environments and places, and the experiences that schools and after-school program sites can make available to young women. Students' citations of project-based learning and multi-year experiences in a STEM-rich school as important preparations for InvenTeam work suggest that the educational model of a STEM school may contribute to creating and supporting the cultural conditions needed to prepare young women to invent. Expectations that all students at the school will engage in STEM projects, and ultimately in a project that produces an invention, may create a school culture that is more conducive to generating female inventors. Other school models that produce young inventors may exist and should be examined in order to create a range of models that can be utilized to address the various needs and local conditions found across the U.S. Our study suggests that afterschool programs may also foster the development of young women as inventors. However, a multi-year afterschool program may be needed to help young women not only to see possibilities in STEM and identify as innovators but also to foster skills and dispositions toward their development as inventors. Given that different places and environments can support women's development as inventors, policymakers should consider invention education policies for both in-school and after-school programs, as well as the length of time young women need to be engaged in inventing experiences to provide the learning opportunities that support shifts in identities.

The third group of factors relates to resources, including online resources and prior experiences. As the participants from the afterschool InvenTeam demonstrated, online repositories that include "how to" videos and other STEM-related instructions and materials can be important in leveraging access to the information needed for females to succeed in invention projects. Videos and other online resources can bridge the gap between what young women need to know and their lack of prior experiences. Background experiences and skills that lead to invention pathways can be developed in STEM-related curriculum as well as in other subjects, such as humanities and art, that foster critical thinking, creativity, and communication skills. All students, including females, need to develop the understanding that invention requires more than STEM skills, thus any person has a potential to take an active role on an invention team and become an inventor.

An additional resource that is often taken for granted, but needs to be considered in making policies about STEM and invention education, is time. Time constraints identified by our study participants could be mitigated by policies surrounding the school day. The young women's descriptions of their challenges to find time in the week to work on their InvenTeam projects suggests that competing demands to participate in multiple projects may need to be adjusted in order to enable young inventors to focus on one project at a time, deepening the engagement and fostering the development of a working prototype that can serve the community.

Other factors impacting invention education and female participation in invention not discussed in this paper include funding, geographic location, educator experiences, and administrative and program staff support, among others. This paper focused on the InvenTeam experiences of three young women whose insights provide a starting point for considering ways STEM and invention education can be accessed by all students. Our analyses indicate that a variety of people, environments, and resources can be utilized to enhance young women's access to and participation in invention education. When local and national policies and practices empower females to find and create opportunities to engage in STEM and inventing from an earlier age, the gender gap in STEM and patent acquisition may decrease over time.

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