TELLING CASES THAT INFORM AN UNDERSTANDING OF FACTORS IMPACTING THE DEVELOPMENT OF INVENTORS FROM DIVERSE BACKGROUNDS

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The lack of diversity among patent holders in the United States (1-3) is a topic that is being discussed by federal policymakers. Available data suggests that prolific patent holders and leading technology innovators are 88.3% male and nearly 94.3% Asian, Pacific Islander, or White, and half of the diversity that does exist is among those who are foreign born (3). The data shows that there is a need for greater diversity among patent holders. Few studies, however, are available to guide the work of educators creating learning opportunities to help young people from diverse backgrounds learn to invent. Educators must navigate issues that have complex sociocultural and historical dimensions (4), which shape the ideas of those surrounding them regarding who can invent, with whom, under what conditions, and for what purposes. In this paper, we report the results of an ongoing multimethod study of an invention education program that has worked with teachers and students in Grades 6 through 12 for the past 16 years. Findings stem from an analysis of end-of-year experience surveys and interview transcripts of six students (three young men and three young women) who participated in high school InvenTeams®. The data were used to investigate three topics: 1) ways high school students who have participated on an InvenTeam conceptualize the term "failure" and what it means to "learn from failure," 2) what supported and constrained the work of the three young women during their InvenTeams experience and the implications for policy makers concerned about the gender gap in patenting, and 3) ways the young men and young women took up (or didn't take up) the identity of "inventor" after working on a team that developed a working prototype of an invention during the previous school year.

Key words: Invention education; Ethnographic perspective; Multi-method research; Gender gap; Young inventors; Inventor identity; STEM

INTRODUCTION

The lack of diversity among patent holders in the United States (1-3,5) is a topic that has gained the attention of researchers and federal policymakers. Available data suggests that prolific patent holders and leading technology innovators are 88.3% male and nearly 94.3% Asian, Pacific Islander, or White, and half of the diversity that does exist is among those who are foreign born (3). The challenge of diverse representation in patenting is related to the lack of diversity within particular science, technology, engineering, and mathematics (STEM) disciplines, namely engineering (4) and technology (6), which are among the fields with the highest volume of patent

generation. Cook (4) found that in the engineering fields, women represented 22.8% of doctoral degrees awarded in 2014, and the share awarded to African Americans was 1.7%. Sanders and Ashcraft (6) found that "only 19 percent of all software developers" were female and that 88% of the teams who patented were all-male compared to 2% that were all-female invention teams.

Addressing diversity and gender gaps in innovation and invention requires concerted and continuous efforts through policies and programs enacted by educators in formal and informal educational settings (5). Few research studies, however, are available to inform educators' efforts to help young people from diverse backgrounds learn to invent. Educators must navigate issues that have complex sociocultural and historical dimensions (4), which shape the ideas of who can invent, with whom, under what conditions, and for what purposes. Despite challenges, many educators and educational programs are providing opportunities for young people to learn to work as inventors during their early years of schooling (5). In this paper, we report the results of an ongoing study of an invention education program, known as InvenTeams, offered by the Lemelson-MIT (LMIT) Program. The program is situated within the School of Engineering at the Massachusetts Institute of Technology (MIT). Staff within the program administer a national grants initiative that awards $10,000 to each of 15 teams of teachers and students in Grades 9 to 12 each year. Each grant recipient teacher and their team of students build a working prototype of a technological solution to a problem the student team identifies in their local community. The InvenTeams program has been in existence for 16 years.

The staff of the LMIT Program, in their dual roles as program administrators and as education researchers, are engaged in a series of investigations, grounded in an ethnographic logic-of-inquiry (7,8), to determine what can be learned about the development of young inventors from students' and teachers' experiences with the national InvenTeams grant initiative. A multimethod, ethnographically-informed (9) program of research has been developed in collaboration with external researchers and consultants. LMIT staff act as embedded ethnographers (10) and co-researchers to raise program and invention education-relevant questions that external researchers help investigate (11). This creates a collaboration and partnership between LMIT staff and external ethnographers. Research team members, working together, learn from and with each other, generating deeper insights into invention education and the InvenTeam program's impact on students, teachers, and other stakeholders.

The ongoing research collaboration began with our first study (12), in which the internal ethnographers examined if students who had worked as inventors across an entire school year perceived that they had learned how to learn from failure. If so, investigators wanted to know what meaning the students were attaching to 'learned' and the meaning students were attributing to 'failure.' The program of research began with the first study focused on student learning from failure because it was one of the main topics InvenTeam students emphasized on the post experience surveys and in conversations with LMIT staff. The insider-driven focus on learning from failure also related to one of the key thinking skills the Committee for the Study of Invention (13) identified as needed by inventors. The study connected student and educator insider perspectives within the InvenTeams program to the larger conceptual and policy dialogues about invention education and failure as part of a learning process.

The second study (14) focused on three young women who had participated in the InvenTeams grant initiative. It explored what could be learned from the young women's experiences in the InvenTeam program in order to inform understandings about the gender gap in patenting. The third study (15) compared the experiences and perspectives of the three young women to three young men who had participated in InvenTeams during the same year. The contrastive analysis of the young women's and the young men's experiences enabled us to identify personal and contextual factors that impacted students' development of inventor identities. Findings from the two most recent research papers were presented at the Eighth Annual Meeting of the National Academy of Inventors and are revisited in this paper.

InvenTeams as a Site of Study

The LMIT Program serves as a site of study for

the ongoing multimethod, ethnographically driven program of research. InvenTeams grants have been awarded to 243 teams of students in Grades 9 to 12 between 2003 and 2019. A total of 2,750 students have participated on the teams, and 35% of those student participants were identified as female. Eight of the teams were awarded U.S. patents for their work, though patenting is not a requirement for the InvenTeams program. Women comprised 24% of the members of the teams awarded patents. These numbers are higher than the average of 18.8% of women engaged in invention and patenting (16).

End-of-year experience surveys conducted by LMIT staff consistently showed that participating students learned from failure and to persist; developed confidence in solving problems; learned to work within a team environment; and discovered interests and capabilities in the fields of STEM and/or in social science or humanities disciplines such as economics/finance, communication, management, or psychology. The end-of-year surveys administered by InvenTeams staff revealed that each year, on average, 31% of the student participants identified themselves as inventors at the conclusion of their InvenTeams experience.

Building on the initial examinations of survey responses, our research program has expanded over the past three years to include a variety of records and research methodologies that inform understandings of the processes, practices, and interactions among a variety of actors that make the InvenTeams and related LMIT programs work. Driven by an ethnographic epistemology, over the past three years, we have conducted interviews with InvenTeams program staff, teachers, students, LMIT prize winners, and others to understand their experiences and pathways to invention. We are also engaged in collecting video, audio, textual, and other artifacts to explore how the program works and what impact it makes in the moment and over time in the lives of students, teachers, community members, and many others. Expanding the program of research to explore the actions and interactions of the varied actors that make the programs work helps us generate insights into invention education so that we can inform educational policies and practices. The work on new policies and practices, in turn, creates possibilities

for expanding opportunities for diverse youth to engage in invention and innovation.

RESEARCH APPROACH AND PARTICIPANTS

The overall program of research utilizes a variety of data collection methods—ranging from surveys to informal conversations, participant observations, document analyses, and video and audio capture by researchers and by participants. The research is guided by an ethnographic perspective, and its goal is to understand people's practices, processes, and perspectives from their points of view, within situated groups and events embedded in the larger socio-cultural contexts (17,18). Our study of invention education draws on scholarship that conceptualizes ethnography as epistemology (19-21) and a way of thinking (22,23), rather than a method or a set of techniques (24-26). This epistemology enables researchers to conduct full-scale ethnographies or to develop smaller-range studies that adopt an ethnographic perspective to investigate particular phenomena and areas of interest (17,27,28). Our program of research is a multimethod research design driven by an ethnographic epistemology but is not a full-scale longitudinal ethnography of one particular site where invention education takes place. A study that utilizes an ethnographic perspective, like full-scale ethnographies, can draw on a variety of methods and tools to explore the complex in-time and over time processes, practices, and consequential progressions (29) of human activity and interaction (21,23,30). For the studies synthesized in this paper, we drew on survey, interview, program document, and informal conversation records in order to construct understandings of the factors that impacted young people's potential development as inventors and innovators.

Research Questions

The two studies on young women's and men's experiences in invention education focused on the factors impacting student conceptualizations of themselves as inventors (14,15). The first study explored the experiences and perspectives of three young women who had engaged as inventors; our study questions were:

- How and in what ways do high school students

who have conceptualized, designed, and built an invention as InvenTeams members represent their experiences on the end-of-year surveys?

- Are there differences in the self-reported experiences of young women and young men?
- 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?
- What supported and/or constrained the young women's participation in STEM and/or their work as inventors on an InvenTeam?

The second study complemented the first and sought to understand the similarities and differences between young women's and young men's experiences in invention education and their self-identifications as inventors. The questions guiding the second study included:

- Do high school students identify themselves as inventors after participating on an InvenTeam?
- How do they explain their choice of identity descriptions?
- What prior experiences with STEM do students have that may influence their take-up of an "inventor" identity?

The main emphases in both studies revolved around student identification with inventor identities and the experiences that influenced student engagement and pathways in invention and STEM.

Participants and Data

The corpus of data that was utilized for both studies included LMIT program documents and end-of-year experience surveys collected from all InvenTeams student participants in 2017 (n = 147). In addition, one-on-one hour-long interviews were conducted in person with six students (three young men and three young women). A stratified purposeful maximum variation sampling approach (31) was used to select the six students from the post-experience survey respondents. One student attended a private high school, four students attended traditional public high schools (two of whom were in a special magnet program within their traditional public high school), and one attended a public charter school. The students' race and ethnicity were diverse and included those underrepresented in STEM. Interviews were

conducted at MIT during the culminating event for InvenTeams known as EurekaFest. The interviews were then transcribed by an outside agency and analyzed by the researchers.

All three women in the sample 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, enabling the researchers to conduct both inter-team and cross-team comparisons of individual students' experiences. Their team consisted of both males and females, and the team's work was supported by two male teachers at the school. 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.

All three men in the sample started similarly with their InvenTeams as did the women. They participated in InvenTeams throughout the 2016-2017 school year and attended the culminating event at MIT in June of 2017. The three participants were from different schools. Jacob attended a public charter school that is named for a prominent African American surgeon and medical researcher. The school has a focus on STEAM, which is STEM plus the arts. Jacob was in the school's co-curricular engineering design program. George, a second participant, was in an Engineering Career Academy in a public school. The career academy utilized Project Lead the Way curriculum. The third student, Alec, attended an independent college preparatory secondary day school. The day school had an established robotics program in which Alec had participated since the ninth grade. All three men had extensive technical backgrounds and participated on co-ed InvenTeams.

Data from the semi-structured interviews with the six focus students was supplemented by InvenTeams program records in order to make connections between students' statements in the interviews and activities that had occurred during the InvenTeams year in the students' schools and communities. Survey, interview, and program records enabled us

to explore individual and social factors that students identified as impacting their views of themselves as inventors. The use of multiple sources of data was part of an intentional multimethod research design driven by an ethnographic perspective and its goals to uncover insider perspectives, locating them in the academic, social, and other contexts that support and constrain student opportunities for learning and identity development.

ANALYSES

The two studies focusing on student inventor identities and factors that influenced inventor identity development utilized the 2017 end-of-year survey data. We examined how InvenTeams members represented their experiences and whether there were differences between young women's and young men's self-reported experiences.

Student Accounts of Learning from Failure

The 2017 survey, in which 73% of the students responded, showed that 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." Differences between female and male "strongly agree" responses to three questions became apparent. Findings, discussed in Couch et al. (14), are reprinted in Table 1.

Table 1. Significant Differences in Male and Female Students' Agreement

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

In addition to rating the level of agreement on Likert scale items, the end-of-year survey asked students to define failure in their own words. All six students responded to this open-ended question. Magdalena defined failure as "something that you were unable to accomplish THAT time, but also something you can learn from to accomplish next time." Calaena similarly marked the iterative nature of failure and learning from failure, explaining failure as "a success without the sugar coating, it's something that needs to always be redefined and learned from." Chelly, on the other hand, focused on the negative aspects of failure and stated, "Failure is allowing something to stop you from pursuing and accomplishing something great. In essence, giving up and not persisting." Of the three young men, George and Alec conceptualized failure as an opportunity for learning. George defined it as a "setback that can be learned from," while Alec named it "an educational opportunity." Jacob defined failure as a situation in which "you give up on something important without putting forth the effort to fix the change needed for you to be successful." All six students noted the potential of failure to lead to new learnings and accomplishment. They also made visible their deeper understandings that learning from failure involves taking action, trying again another time, and persisting.

After noting the survey responses of the importance students attributed to learning from failure and persistence, we sought to understand the processes of InvenTeams' work that may have impacted the ways students defined failure. The next phase of our analysis involved examining the transcripts of in-person interviews with the six students and focusing on their accounts of high and low points in their efforts to develop a prototype. The interviewer had asked students to describe high points, low points, and experiences with failure. A domain analysis (32) of interview transcripts demonstrated that all but one of the students described failure as a technical error, a time when things did not work and new ideas needed to be generated to find a solution to the technical failure. Magdalena was the exception to the technical focus on failure and instead described failure from a human interaction perspective. Failure, from her perspective, occurred when she "didn't feel as though I was pulling my team together the way I needed to be."

In the next phase of our effort to generate emic understandings of how InvenTeam students think about learning from failure, we selected Magdalena and Chelly as tracer units. The type of failure Chelly described was typical of four other students and

related to learning from a technical failure. Magdalena was selected because she was the only student to describe failure from a human interaction perspective. Analyzing the discourse of how the two young women talked about failure made visible the differences in what was learned from failure and the ways learning was constructed through dialogue and interactions with other individuals. Chelly saw failure as a low point and gave two examples of "hitting a road block" when trying to code. When asked what was learned from failure, Chelly emphasized learning to work as a team. Chelly and the four other telling case students saw failure as an inability to get something done, a technical matter that could be resolved through team work and various resources.

Magdalena, on the other hand, saw failure as a relational encounter when she "butted heads" with a teammate and struggled to bring the team together in her role as a lead of the management sub-team. For Magdalena, learning from failure involved finding ways of communicating and understanding another person and being understood. Magdalena made visible not only the relational, but also the contextual, nature of failure and learning from failure. She emphasized her role as a leader as the context in which she needed to learn to act and communicate differently.

Student Identification with Inventor and Other Descriptors

Magdalena's emphasis on her role as a leader as a context for understanding her learning from failure prompted our analysis of another section of the survey. One of the survey questions administered to all InvenTeam students at the end of the InvenTeam grant year offered students a set of descriptors, and students were asked to mark all terms with which they identified. There was no significant gender-based difference in who identified as inventors, as 21 females (34.4%) identified as inventors, compared to 26 males (32.9%). We found, however, a gender-based discrepancy in InvenTeams participants' selections of other types of self-descriptors. Table 2, reprinted from the original study (14), 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.

Table 2. Self-Descriptors Selected by 2017 InvenTeams Participants

Female InvenTeams members		Male InvenTeams 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	Total	288

To examine the meanings of these self-descriptors for the students and to explore shifts in how the students saw themselves in relation to these descriptors, we returned to the interview transcripts. In Study 2, we presented analyses of the ways the three young women experienced identity shifts and envisioned new roles and possibilities for themselves as a result of participation in an InvenTeams. "Shifts" referred to changes in ways of thinking, knowing, or being that each young woman articulated in the interview. Findings, documented in detail in Study 2, described the shifts articulated by all three young women and connections to elements of the InvenTeam program. Celaena, for example, provided accounts of the 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.

Magdalena also 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. Chelly's shift focused on 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 in the end 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.

Collectively, the three young women made visible 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 built in and developed within the InvenTeams program; 2) resources; 3) people; and 4) personal qualities, values, and beliefs. The three factors constraining the work of InvenTeams included 1) time; 2) stereotypes; and 3) lack of knowledge, exposure, understanding, and engagement. People and teamwork, environments and spaces, and resources could be supports or constraints depending on the context, time, situation, and design of activities and interactions in particular locations.

Factors that Impact Student Identity Developments

Having identified the supporting and constraining factors based on the experiences of the three young women, we returned to the larger dataset and, in the third study (15), explored factors that may account for differences in self-identifications between the female and male members of high school InvenTeams. We built on the three telling cases of the young women and compared their responses with those of the three young men from the same InvenTeams year. Information uncovered during this study revealed the importance of relationships between prior STEM experiences and three self-descriptors of identity: inventor (common to one male and two females),

engineer (common to all three males), and innovator (common to all three females). The self-descriptors selected by the students and their prior STEM experiences are shown in Table 3.

Table 3. Students' Self-Descriptors of Identity and Prior STEM Experiences

Student	Identity: Inventor	Identity: Innovator	Identity: Engineer	STEM @ Home	STEM @ School	STEM in Out-of-School
Alec			X	X	X	X
Jacob	X		X	X	X	X
George			X	X	X	X
Chelly		X				
Magdalena	X	X			X	X
Celaena	X	X		X	X	

Analysis of male and female interviewees' accounts of STEM experiences in out-of-school settings revealed that the three men engaged in numerous STEM learning opportunities in informal education settings from a young age. Their exposure and participation in STEM activities, described in more detail in Study 3 (15), continued throughout their lives into the high school years. Unlike the three young men, who all had multiple and continuous exposures to STEM activities and innovation, only one of the three women, Magdalena, talked about being engaged in a STEM program in an out-of-school setting prior to InvenTeams. Chelly mentioned that she "never really looked into robotics teams" or other science activities as a possibility for out-of-school engagement. Celaena did not mention any out-of-school STEM experiences at all.

Even though the three young men had more STEM-oriented experiences in their homes, schools, and out-of-school activities, they did not show a higher propensity for self-identifying as an inventor. All three men self-identified as engineers, a descriptor that aligned with their prior experiences in engineering and robotics activities. The one young man (Jacob) who did take up the inventor identity described several experiences in which he engaged with community members around his problem solving and invention efforts. His account, along with research findings about the importance of continuous exposure to invention and engagement with community (5,14), makes visible that inventiveness is a situated and communal, rather than a sole person, activity.

Of the three young men, only Jacob saw himself

as an inventor. In contrast, two of the three young women took up the identity of inventor despite their limited experiences in STEM at home and after school. Celaena and Magdalena, the two young women who chose inventor as a relevant self-descriptor, had attended a STEM school for two years or more and had multiple opportunities to engage in various invention-related activities in high school. The third young woman, Chelly, cited the InvenTeams experience in an out-of-school program in her senior year as her main STEM-related experience.

The differences in the young men's and young women's self-identifier choices and the young women's willingness to choose inventor as a self-descriptor makes visible the importance of exposure to invention education and STEM opportunities. Bell et al. (33) and scholars who study the gender gap in invention (14) suggest that exposure to invention at a young age—as well as support along the way—is needed to create opportunities for more women and students from diverse backgrounds to explore and choose careers that may lead to invention, entrepreneurship, and patenting (5).

DISCUSSION

Findings generated from these complementary studies about InvenTeams participants' experiences and views of themselves as inventors-in-the-making demonstrate the potential for invention education offerings to interest and engage young women and students from diverse backgrounds in STEM and to help them envision themselves as inventors even when they have not been engaged in prior STEM programs. The findings also suggest that young women with limited STEM experiences may choose to rate what they have learned from the experience higher than young men do, as young men may already have had several opportunities for STEM learning related to the topics being measured. This difference may be attributable to the novelty of the learning experiences for the young women and the types of subjects and ways of working that they had not already had an opportunity to learn.

Our findings related to the prior STEM and other invention-related experiences of the young men and, conversely, the lack of experiences of the young women, can be considered alongside the broader array of experiences that students have available to inform their understandings and decisions about their preferred college and career pathways. Data published by the U.S. Department of Education suggests that many students rely on their own judgment as they think about education after high school, and 49% rely on advice from family members (34). Those relying on their families may be guided by people who are unfamiliar with the importance of STEM experiences and inventive capabilities for the future of the student and society (34). Our studies of the InvenTeams experiences have shown that young people's work as inventors—and experiences of learning both to use and to create technological solutions—offer opportunities for students of all genders to develop in ways that are needed, whether one chooses to continue to invent or not. Ways educators can learn how to support this type of learning for all is the focus of future studies.

ACKNOWLEDGMENTS

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