Lemelson-MIT Student Prize Retrospective:

Inventor Developmental Pathways

LEMELSON-MIT

Dear Colleagues,

This report, along with the companion piece *Student Prize Winners and Their Impacts*, highlights collegiate students recognized for their creativity and inventiveness through the receipt of the Lemelson-MIT Student Prize. We hope these inspirational role models who are making a significant difference in the world get you thinking about what you could invent. As you read about these students, the problems they chose to address, and their technological solutions, you will learn that:

- Invention is everywhere. Prize winners come from urban, rural, and suburban areas across the United States.
- Invention is often a team sport. Prize winners in the last eight years of the program were undergraduate students who worked as a team. The team approach brought different expertise to bear on the problem being addressed.
- Invention is for everyone. Prize winners represent a variety of majors, gender identities, races/ethnicities, and socioeconomic backgrounds.

There is no shortage of problems in the world that need new and novel, useful, unique, and non-obvious solutions. We welcome you to apply your unique skills and expertise to finding and solving problems that matter through ways of thinking common to inventors. It is never too early or too late to get on the pathway to invention. As you get started, please remember: inventing is just plain fun!

In closing, we wish to thank the Lemelson family and The Lemelson Foundation for their support of the Lemelson-MIT Student Prize program. Their dedication to the next generation of inventors and entrepreneurs has made our work possible. We look forward to the continued joint work of helping more women; young people from low-income families; and Black, Latinx, Indigenous, and other people of color get on the pathway to invention.

Sincerely,

Michael J. Cima
Faculty Director
Lemelson-MIT Program

Stephanie R. Couch
Executive Director
Lemelson-MIT Program

Invention, Inventors, and Leading Innovators

WHAT ARE "INVENTION" AND "INNOVATION"?

The Lemelson-MIT Program differentiates between invention and innovation, although the terms are often used synonymously in popular press. An invention is an idea that is useful, unique, reduced to practice, and not obvious to one skilled in the arts. Once reduced to practice and the value to society is realized, the invention can be considered an innovation.

> **…there was a recognition for best inventor, top 10 inventors, I think, from a popular magazine… And our invention was in there and you see your name and you're called an inventor. Then you're like, oh, I guess I'm an inventor."** — David Moinina Sengeh

WHO IS AN INVENTOR?

The Student Prize winners we surveyed and interviewed indicated that they did not identify as inventors when they started their journey down the developmental pathway of inventing. The students' inventor identity emerged when: (a) a recognized institution or person named them as an "inventor" (such as through winning the Lemelson-MIT Student Prize), (b) they received one or more patents, and/or (c) they founded a startup company based on the invention.

BARRIERS TO SELF-IDENTIFYING AS AN INVENTOR

There are several significant barriers to self-identifying as an inventor.

1. "Inventor" is not considered a traditional profession, so it is not recognized by students as a career option in the same way as "doctor," "policeman," or "teacher." Professions have pre-determined pathways through formal education, accreditation, and/or professional organizations that regulate membership. Invention, however, has:
   - No clear disciplinary path (interdisciplinary, transdisciplinary, STEM, humanities, ANY discipline),
   - No accrediting process, and
   - No organization that regulates membership.

Acquiring a patent is not even an absolute requirement. In Uganda, for example, an inventor would not submit a patent for their invention because there is no expectation that intellectual property would be protected (interview with Paige Balcom).

2. Another significant barrier to self-identifying as an inventor is a reluctance to identify with the common inventor or scientist stereotype of the "geek in a lab coat" who is impersonal and self-absorbed. This stereotype is in fact so culturally entrenched that even after winning the Student Prize, one winner does not call himself an inventor because of this "egocentric" connotation. Instead, he self-identifies as a "maker" or "problem solver." The white male inventor/scientist stereotype may be especially problematic for women and people of color. One female Student Prize winner shared, "I thought scientists were all these nerdy men who wore their shorts up to here and had a pocket protector and a little calculator in it. And that was not me."

3. Even with winning invention competitions, some inventors are reluctant to identify as an inventor because of imposter syndrome. Katherine Jin shares this perspective:

"We started winning some student competitions, like the Lemelson-MIT Program [Student Prize], that all helped build my confidence as an inventor, but it also made me feel a lot of imposter syndrome in the sense that I didn't feel like I was smart enough or good enough to be given that title. And I think that's been probably one of my biggest personal struggles in general, which is connecting the reality of 'I'm an inventor.'"

Purpose and Structure of the Lemelson-MIT Student Prize Retrospective

As shown in the other major section of the retrospective, Student Prize Winners and Their Impacts (accessible from the back of this booklet), invention and innovation fuels social and economic advances in society to address some of the world's most daunting challenges of our time. There is a need to prepare the next generation of inventors and innovators to address the many challenges. Students must acquire knowledge, skills, and practices from those within our educational institutions through deliberate exposure to invention in ways that support individuals' developmental pathways as inventors. The purpose of this section of the Lemelson-MIT Student Prize Retrospective, Inventor Developmental Pathways, is to share Student Prize winners' perspectives about their own invention journeys as developmental processes. The insights are being shared with the goal of informing ways educators and education administrators design opportunities for learning/doing invention in local contexts.

A majority of the data used in this retrospective analysis came from the following sources:

1. Survey data of annual student applicants and winners from 2017–2021 (n=269).
2. 2018 Report: Study of Lemelson-MIT Student Prize Winners: Factors that Support Winners' Development as Inventors (3Jan2019).
3. Transcripts from Student Prize winner focus group interviews (2018) [n(undergraduates)=7, n(graduates)=4].
4. Survey data from all previous student winners (2022): of 119 surveys mailed, 38 were completed and returned.
5. Video interviews of 12 Student Prize winners from 2009–2021 representing the diversity of winner backgrounds. Interviews were conducted and provided by Maaia Mark Productions (2022).

Student Prize Winner In-Depth

A LEADING INNOVATOR...

Geoffrey von Maltzahn, MIT

2009 GRADUATE WINNER

Geoffrey von Maltzahn is the 2009 Graduate Lemelson-MIT Student Prize winner for developing a new class of therapeutics that target cancer. Geoff traces his invention roots to his childhood love of art and a sense of adventure from when his mother read exploration stories to him. He explains how these fostered an enchantment with the "thrill and terror of a blank canvas staring at you [as you] try to image what could be" and the element of adventure when one is "audacious enough to believe that you can come up with a new idea and that that idea might make a difference in other people's lives or your own." His interests in art and exploration merged with math in high school, where "math provided this language where you could start describing things in new ways." These led him to exploring at the intersections of engineering and biology in college:

"Engineering is a realm where you can mathematically describe the way things work. And when things are really engineerable, you can describe how all things work.... Biology just felt like this world where we don't know how anything works and, and it's gonna take incredible advances to know how some, many, or all things work and connecting the dots between where we were then,

> **...that team of people is gonna challenge themselves and challenge each other to try to do something that they just don't know is possible.**" — Geoff von Maltzahn

where we are now, and what's to be.... It was obvious it was gonna require a lot of imagination and almost artistry to do justice to the extraordinary world that we call life."

Geoff credits his undergraduate research mentor with getting him "hooked on the creativity of the scientific process" by giving him the freedom to "kind of run wild." He said his mentor offered "enough rope to mess up a whole bunch of times" in the laboratory as they were studying ways to make biomolecules programmable. His research advisor in graduate school also "provided a ton of creative freedom to explore crazy ideas" in thinking about "technologies within biology as a system and not just individual parts." It was during this time that Geoff was involved in starting two companies:

"I just loved it … the rate of learning was incredible. The extreme partnership with other people was amazing … the fact that it felt like the whole thing was gonna die every Tuesday was an advantage as opposed to a disadvantage, in that it forced you to solve problems really quickly."

Geoff began to envision new possibilities through these experiences:

"I started to imagine that if it's true, that biology has one of these epic jumps of becoming an area where we can predictively succeed in creating extraordinary technologies, it's almost certainly the case that many of the most impactful life science companies haven't been started yet, and maybe they all haven't been started yet. And that led me to start contemplating places to be inventing."

Geoff has been the most prolific inventor of the 119 Student Prize winners, holding 26 patents and being listed on over 200. His inventions and influence have extended across disciplinary fields and led to his founding or co-founding 14 companies.

Reflecting on the significance of winning the Student Prize, Geoff shares:

"The [Lemelson] Foundation created a spotlight for … recognizing the accomplishments of young people at a moment where it opens a lot of doors to them. And hopefully that same spotlight, as it did for me, inspires other people to realize that this big trampoline of MIT, [and] the other institutions that the prizes were awarded, is a place where you can jump really high, and you can go and try to, try to build some extraordinary things."

Reflecting on his own extraordinary developmental path for invention, Geoff also shares some insights for developing the next generation of inventors:

"For our kids, I think a lot about trying to create an environment where they feel loved, we believe in them, and where they realize that some of the most fulfilling moments in all of life come from challenges, from challenging themselves, from believing themselves, from trying something new, from doing something that's frightening or uncomfortable. And I hope that somewhere in that environment of imagination and grit … are the seeds of them … seeing themselves as a next generation of inventors."

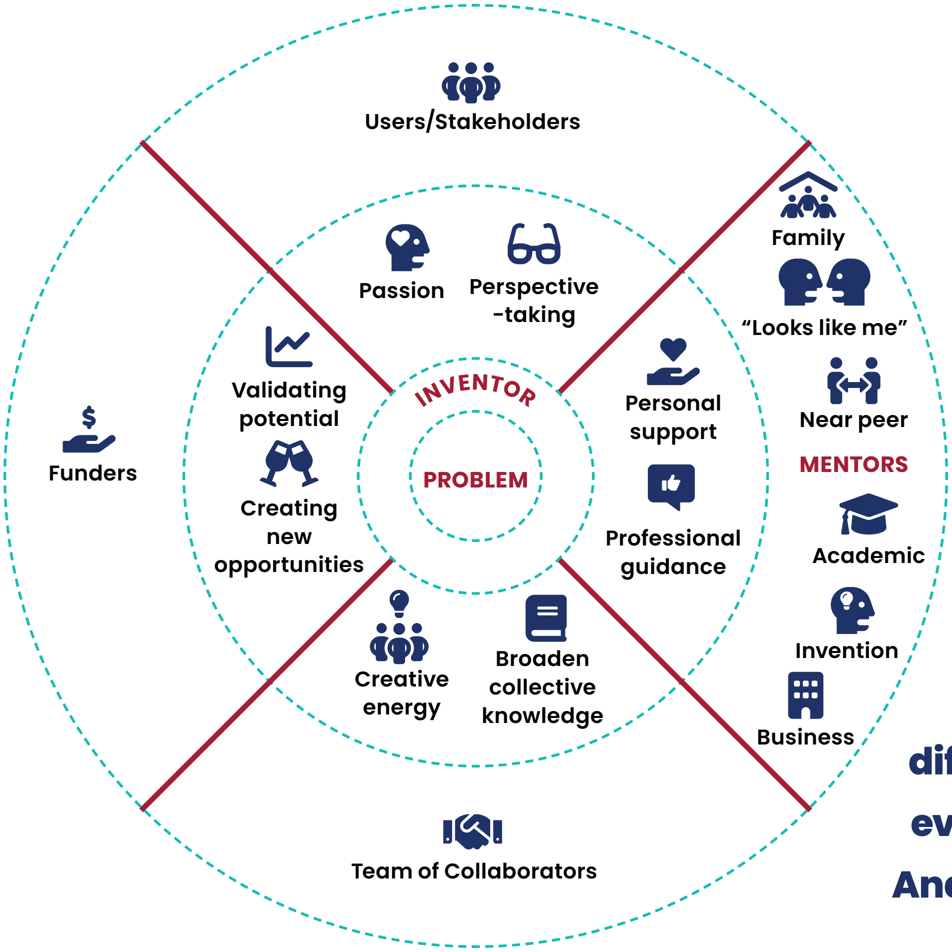
Photo credit: Maaia Mark Productions

An Inventor's Ecosystem of Resources

A team of collaborators: Paige Balcom (center)
Photo credit: Maaia Mark Productions

OVERVIEW

The diagram below represents an inventor's ecosystem of resources in terms of roles and the enabling factors that each role brings to Student Prize winners and inventors more generally. Through surveys and interviews, Student Prize winners identified four significant roles: users, mentors, collaborators, and funders, shown in the outermost ring of the diagram. These roles are critical because each one contributes to the ways, means, and perspectives that an inventor draws on to engage in the invention and innovation endeavor of creative problem solving. This section takes a deeper dive into each role and the significance of the enabling factors that support inventors.



> **Inventors see the future different. Yeah. They see it even though it's not there. And they believe it as if it is, and that is powerful.”**
>
> — Matthew Rooda

USERS

When Tomás Vega and his team needed to understand the challenges that his visually-impaired friend faced in navigating his wheelchair, they moved into his friend's home to begin to see the world from his perspective. At the height of the COVID-19 pandemic, when Katherine Jin spoke with a hospital janitor who contextualized the problem of identifying areas in a hospital room that were not yet

Testing with a user: Daniel Stickney (L) and Corten Singer (R)
Photo credit: Roland Saekow

decontaminated, she similarly recognized how her invention was significant in promoting social equity for these janitors. Winners stressed this need to engage with users in both the problem and solution spaces of the invention process. Users must be involved and share their perspectives to inform how an inventor shapes their problem. Users should be involved during the prototype phase in providing feedback to inform the iterative solution process and confirm that the prototype is indeed working toward addressing the right problem.

COLLABORATORS/TEAM

Every Student Prize winner who was interviewed acknowledged how their successes were part of a larger team effort. Team interactions forged strong relationships for Geoff von Maltzahn and drove collective creativity and learning. Abraham Espinoza and Matthew Rooda needed additional expertise on their team to broaden their collective knowledge and skills to develop the technology that would identify nuances in piglet squeals. Winners are in consensus that their teammates and collaborators are an essential part of the invention journey to both broaden their collective knowledge base and fuel creative synergies.

FUNDERS

Winners acknowledge the challenge and necessity of obtaining funding to realize the impact of their invention in society. Persuading funding agencies and investors to take a chance on a new idea at the onset of beginning a startup company is uncommon. Most winners instead participated in pitch competitions to raise seed funding for their startup that could be used for filing patent applications, initiating manufacturing, and conducting third-party testing. Obtaining funding validates the potential of an invention to create value and often opens the door to new opportunities.

MENTORS

The largely unseen facet of an inventor's journey is their support system of mentors. Winners shared examples of their experience with many types of mentors who influenced them both professionally and personally. Some mentors guided winners through the particulars of invention and business. Disciplinary mentors, largely research advisors, gave them independence in pursuing research and modeled risk-taking and engaging in the nature of scientific endeavors. Mentors that "look like me" helped lower the barrier to identifying as a scientist and fostered self-confidence. The support of near peers helped winners, especially women and people of color, deal with imposter syndrome. The most cited type of mentor, however, was family members who fostered creative mindsets, provided personal support, and allowed time for play when these winners were young. Mira Moufarrej acknowledges the role of her support system of family, friends, and peers as significant in this process of inventing:

"Of course, you need a really important support system where they make sure that when you're in those low moments, that you're reminded of other things in one's life and how it's not that big of a deal [to fail] … cuz it's hard not to take failure personally, especially if you've been working on something [an invention] for a really long time."

As shown in the next section, early personal and schooling experiences largely facilitated through winners' mentors may be the most significant influence on their longer-term development as inventors.

Paige Balcom (L) and her mentor Dr. Ashok Gadgil (R)
Photo credit: Maaia Mark Productions

Invention as a Creative Process

OVERVIEW

Invention is a creative process. The figure below shows the four components of the non-linear invention cycle (center) and how Student Prize winners describe the motivations, mindsets, and actions required to invent. The most common themes from winners about the invention process, as shown in the figure, are: passion, curiosity, perspective-taking, creativity, "failing forward", learning, and resilience.

Tomás Vega (L) and Corten Singer (R)

Photo credit: Maaia Mark Productions

FACETS OF THE INVENTION PROCESS

There are many facets that contextualize the invention process, as shared by Lemelson-MIT Student Prize winners. Winners are motivated to identify and solve problems through invention because of the potential impact of their work on the lives of others in terms of equity, justice, and/or making the world a better place. In order to realize this impact, it is important that the user perspective drives the process of identifying and understanding the problem through inquiry and research. Stepping back to take an outside perspective requires curiosity, extreme open-mindedness, and the willingness to see things as if one is seeing them for the first time. To invent by developing a novel and unique solution to a problem, one must be willing to break away from what may be considered "normal" because, as explained by Mira Moufarrej, "nothing is really normal because 'normal' is different in different places." This idea is central to perspective-taking.

> **...there are aspects of invention that embed a combination of extreme humility and extreme open-mindedness or belief in what is possible. And the extreme humility is that you realize that of the many ideas that we all have and could have...the number of those that are really worthwhile, wow, is really, really small. And, particularly in biology, there's error bars on everything. You're surrounded by uncertainty. And I think you need to know that failure is around every corner in order to navigate towards something that could be awesome."**
> — Geoff von Maltzahn

The potential solution to a problem is creatively addressed during the building and testing phase through a non-linear decision-making process of prototyping that is both iterative and abductive. The process is iterative, in that inventors will build successive prototypes, improving their model of the solution in each iteration. Inventors also ensure within each iteration that the developing prototype is answering the right question. The invention process is also abductive, in that inventors make the next decision (step) about how to improve their developing prototype, based on what they have learned up to that point in time rather than following a predetermined process. Inventors learn from each "failed" prototype, which informs the next version of the prototype. The process of iteratively developing a prototype requires taking a step back from what the inventor thinks they know, so their mind may be open to seeing the situation in a new way. The winners stressed that "failing" during the prototyping phase is a necessary part of the invention process, offering "an opportunity to do things again." We have therefore reframed this nuanced meaning of "failing" as "failing forward" in the figure.

INTER- AND TRANSDISCIPLINARITY: AFFORDING OPPORTUNITIES FOR THINKING CREATIVELY

Today's real-world problems are complex, inherently uncertain, and dynamically emerging. It should not be surprising, then, that the problem and solution spaces of the invention process are also riddled with inherent complexity and uncertainty. The nature of this complexity and uncertainty of real-world problems is, in part, made visible in the figure (see previous page) that depicts invention as a creative process.

> **...if you're passionate about a problem... finding a solution to a problem, just start doing something, just start talking to people, start prototyping and doing...my first prototype [of a small-scale plastic recycling process for PET] was melting some plastic milk jugs in my apartment kitchen oven... you learn a lot from just getting your feet wet, just learning about the [problem/solution] space and those first initial failures... You're gonna make so many failures, but you learn a lot from those and...just don't be afraid to fail."** — Paige Balcom

At the center of the figure are prototyping solutions. Prototyping a technical "solution" to a complex real-world problem requires engaging at the edge of what is "known" by integrating bodies of knowledge between disciplines to develop an interdisciplinary solution and/or generating new knowledge that may have roots from multiple perspectives. The latter may be known as a transdisciplinary solution in some academic circles.

There is much more to this process, however, than the "solution," as shown in the figure, which leads us to consider a more nuanced definition to describe invention as a creative process for solving real-world problems. The process begins with an inventor seeking to understand a problem within the complexity and uncertainty of its social context. The first steps in inventing, therefore, are not about a technological device at all. Considerations that significantly impact the creative nature of an invention process are, rather, continuously informed through knowledge gained from interactions with, and exposure to, the social world.

We therefore draw on a "transdisciplinary" perspective as modeled by the Swiss Academy of Sciences,[1] which acknowledges the significance of integrating both disciplinary-based and "non-scientific" bodies of knowledge in creating solutions to real-world problems. This conception of transdisciplinarity mirrors what was offered by Student Prize winners as they described their invention process (see figure). This perspective is further supported by winners' accounts of what drives them to invent: social impact (for more information, please refer to *Student Prize Winners and Their Impacts*). The implications of bringing both bodies of knowledge to the forefront are at the center of invention and innovation: inventors' technical solutions must uniquely address the particularities of the social aspects of the problem in order to have the desired social impact. "Extreme open-mindedness" (and others as shown in the figure) is therefore required to position inventors to see new potentials or the emergent "adjacent possibilities"[2] as the fertile environment for and of creativity.

If a goal is to prepare the minds of student-learners for thinking creatively to identify and solve the world's most pressing and challenging problems, then the question remains: how and in what ways should we build institutional capacity in order to afford student-learners opportunities to develop the capabilities required for inventing and innovating? In the next section, we look again to the personal experiences and developmental pathways of our Student Prize winners to gain insight into this question.

to be able to solve the, the big problems in the world requires interdisciplinary solutions and collaboration across different fields." — Paige Balcom

[1]Hirsh-Hadorn, G., Pohl, C., & Bammer, G. (2010). Solving problems through transdisciplinary research. In R. Frodeman, J. Klein, & C. Mitcham (Eds.), The Oxford handbook of interdisciplinarity. Oxford University Press.

[2]Kaufmann, S. A. (2016). Humanity in a creative universe. Oxford University Press.

Developmental Pathways: Building Capability for Inventing and Innovating

Student Prize winners' developmental pathways are as diverse as the nature of their inventions. Although some elements of their pathways are common, their interests, disciplinary backgrounds, and personal backgrounds show how inventing is accessible and attainable to anyone with a passion to solve a problem.

This representation of Student Prize Winner Developmental Pathways (across these three pages) was constructed from what winners said influenced them in their pathways to inventing from early experiences through self-identifying as an inventor and innovator. As shown in ***Student Prize Winners and Their Impacts***, these winners come from diverse social, economic, linguistic, academic, and ethnic backgrounds, which bring diverse perspectives to identifying and solving problems; that is, inter- and transdisciplinary perspectives that will foster creative and unique solutions. Problems were identified and the unique solutions emerged from the inventors' creation of their own pathways for solving problems that they were passionate about.

Their development as inventors started with EARLY EXPERIENCES in family life where they were afforded opportunities to explore, create, and fail. Many winners also grew up between and across cultures that fostered their ability to approach problems from different perspectives. These early experiences contributed to an open mindset for their engagement with the world and positioned them to pursue creative opportunities in their SCHOOLING AND EXTRACURRICULAR activities, such as taking makerspace classes and participating in "hack-a-thons." Most winners arrived in these ways for their university studies with prepared mindsets as fertile ground for inventing and innovating. Most winners pursued inter- and transdisciplinary interests that guided their POSTSECONDARY LEARNING EXPERIENCES through undergraduate and graduate research opportunities as well as participation in university innovation programs. Building capability for INVENTING AND INNOVATING clearly is a developmental process that hinges on students' early exposure to creative endeavors.

EARLY EXPERIENCES:

- Seeing family as mentors and role models for resilience, taking risks, creativity, independence
- Having a desire to build: LEGOs, breaking/making things
- Having creative outlets: father was a painter
- Normalizing failure: observing entrepreneurial family—"they failed a bunch"
- Tinkering with cars with grandfather
- Always building, creating, woodworking, doing carpentry
- Repairing garage sale and trash finds
- Participating in elementary school-level "Camp Invention"
- Inventing games "more complicated than rock-paper-scissors"
- Observing inventions and innovations used in NASCAR racing to improve strategy
- Playing video games
- Being given the space for independence and being creative
- Having the opportunity to work as a kid
- Being given opportunities to explore
- Experimenting with a science kit
- Trying to fix things that were broken
- Living within and across cultures
- Creating a pulley system to carry toys up to a treehouse
- Creating a pulley system to control the light switch from the bed
- Creating Pokemon cards—Tomás Vega
- Creating and selling Pokemon cards—Abraham Espinoza

I loved watching NASCAR and every single week, all I would be focused on is what are the innovations or inventions that are going to become a part of this team's strategy to get better... another thing that made me think a little differently is video games. And I think kids get a really bad rap sometimes... but they constantly force you to solve problems and be creative and work as a team.”

— Matthew Rooda

SCHOOLING AND EXTRACURRICULARS:

- Having teachers and extracurricular team coaches as mentors
- Being exposed to more of the world and what is possible
- Participating in:
  - Hack-a-thons and Science Olympiad
  - Makerspace classes
  - Robotics team competitions
  - Hands-on machining classes
- Identifying as a “hacker”: breaking code and seeing how it works
- Problem-solving policy-based conversations: participating in youth parliament to address malaria in communities in Africa
- Being mentored on the robotics team by engineers from Ford Motor Company

POSTSECONDARY LEARNING EXPERIENCES:

- Studying in more than one discipline
- Having research interests across disciplines: inter- and transdisciplinarity
- Having research advisors as mentors for inventing
- Being exposed to more of the world and what is possible
- Recognizing inequity and injustice in the world
- Participating in:
  - Hack-a-thons
  - Makerspaces
  - Opportunities to mentor others
  - University innovation centers: accelerators/incubators
- Having space to play in the laboratory
- Being mentored: undergraduate and graduate advisors
- Seeing people who “look like me”

I can navigate in these different circles [of Lebanese and US cultural identities]. And maybe that's a superpower. Maybe it doesn't have to be something where I have to be in both and understand both completely. The fact that I can navigate both, even if I'm not totally deep in one specifically, in and of itself, is important. And I think that's also true in interdisciplinary work [where] you have to speak different [academic] languages.”

— Mira Moufarrej

> **...my first love as a kid was art and then during high school, I got really interested in math. Math provided this language where you could start describing things in a new way. I thought that was really amazing. I decided to go to MIT because it seemed like a really interesting place to see where art and math might join. And I ended up falling in love with engineering and biology for similar reasons.”**
>
> — Geoff von Maltzahn

INVENTING AND INNOVATING:

- Winning the Lemelson-MIT Student Prize and other competitions
- Identifying problems and having the particular knowledge and skills to solve them
- Being motivated to help people and society
- Identifying and solving a problem in a novel and useful way
- Building a team of collaborators
- Starting companies
- Mentoring others
- Creating new connections across disciplines
- Infusing creativity and innovation into education curricula

> **...I really can’t emphasize enough how much representation matters...”**
>
> — Katherine Jin

A LEADING INNOVATOR...

David Moinina Sengeh, MIT

2014 "CURE IT!" GRADUATE WINNER

David Moinina Sengeh is the 2014 "Cure it!" Lemelson-MIT Student Prize winner for his work on developing next-generation wearable mechanical interfaces (prosthetic sockets) that improve comfort for amputees. David's invention developmental pathway has prepared him to infuse creativity and innovation in school curricula as the Minister of Basic and Senior Secondary Education and the Chief Innovation Officer for the Government of Sierra Leone.

David loved to fix new gadgets from a young age growing up in Sierra Leone. He says, "I loved reading new languages and pretending like I understood the French directions or the Spanish directions, but really it was that I could put together stuff and I could create different connections."

David credits his family and mentors for developing him as an innovator:

"My parents allowed me to play, and I had mentors who gave me the opportunity to learn at scale, to implement at scale, to do stuff that had impact on people's lives. [These were] definitely crucial to my own growth as an innovator."

David pursued bioengineering in college because he believed it would enable him to have the largest impact on society. After winning the Lemelson-MIT Student Prize and working as a data scientist, David created a new government entity, the Directorate of Science, Technology, and Innovation, where over 100 officials and staff are digitally transforming governance. David is now leveraging his knowledge and experience in invention to guide the new curriculum as a minister of education:

"I said [that] we need to focus on the five C's: computational thinking, not just literacy; comprehension and not just literacy; civics, so the work that we do has an impact; creativity, our kids need to learn how to problem solve; and critical thinking, [students] have to think outside the box. And that is embedded now in our curriculum."

Photo credit: Maaia Mark Productions

...I said [that] we need to focus on the five C's: computational thinking, not just literacy; comprehension and not just literacy; civics, so the work that we do has an impact; creativity, our kids need to learn how to problem solve; and critical thinking, [students] have to think outside the box. And that is embedded now in our curriculum."

Key Themes Supporting Development as an Inventor/Innovator

EXPOSURE TO DIFFERENT IDEAS, PEOPLE, PERSPECTIVES, TEAMWORK, AND SOCIAL CHALLENGES

> …the concept of exposure to working on solutions that bring to light this entire world [of the challenges faced by people with disabilities] that a lot of people just don't understand, I think is another huge social impact …not necessarily specific to [our invention], …just working on problems that, you know, people oftentimes are unaware of…that is only gonna help people become more empathetic and understanding… and hopefully more driven to solve these problems."
>
> **— Corten Singer**

> **…expose the next generation to the idea of inventing and problem solving…teach them about design thinking and thinking creatively, out of the box, …and prototyping and making things, and just giving them a teamwork environment to be able to collaborate together and learn from each other and solve these problems together."**
>
> — Paige Balcom

SEEING ONESELF REPRESENTED IN ROLE MODELS

> I remember at the time, the head of the USPTO was an Asian woman, and she came over specifically to talk to me and I really can't emphasize enough how much representation matters and how even just seeing someone who looks like you in a role that you want to be in, can give you that motivation and can also give you that confidence. You [say], yeah, I can do that. I've seen someone like me who can run this."
>
> **— Katherine Jin**

LIVING AND SEEING THE WORLD THROUGH AN INTER- OR TRANSDISCIPLINARY LENS

...it was even kind of frustrating for me in college because I was looking for computational biology courses or bio-robotics courses, but they're not always offered because interdisciplinary work isn't always emphasized... And even now, I would argue that at the end of the day here at Kinnos, the skills you need to succeed as a researcher would be either as a mechanical engineer or as a chemist. And those are two things that I'm not... and those are two things that I've had to learn after school. And so, I do think school can sometimes have that negative effect of pigeonholing you into just one area, but that's not actually how the real-world works. The real world has problems that touch all different kinds of disciplines."

— Katherine Jin

...my interests have always been pretty interdisciplinary. I would say I've struggled with that as an identity crisis throughout my life...And I have never fit into one bucket."

— Mira Moufarrej

BEING AFFORDED OPPORTUNITIES FOR THINKING CREATIVELY (IN CREATIVE SPACES)

In high school I had people who allowed me to create and to learn and to be part of solutions that were bigger than myself."

— Katherine Jin

...but I was supposed to be a hyperactive kid. So I was sent to a special school for hyperactive kids and it was very much a free form... creative space. And I think that really helped me channel the hyper-activeness into being creative and just creating things. And I think that opportunity had a really good impact in my life and beyond."

— Mercy Asiedu

Key Themes Supporting Development as an Inventor/Innovator

REINFORCING THAT ANYONE CAN BE AN INVENTOR

> Everybody thinks the sexy idea is the one that's gonna win...we'd go to these competitions and there'd be Stanford and Harvard and MIT and Georgia Tech...and here we are from Iowa, grew up a pig farmer...you didn't ever feel like you were as good, ever. And then when you'd win, it just felt that much better. Because it...reinforced, like, no, I do belong. I do belong here."
>
> **— Matthew Rooda**

What Resources Do You Wish You Had?

"Invention programs for younger kids.... If I could have worked with a team with other people to develop things, um, additionally, what I would've also really loved was a specific space for women or minorities to learn about invention because especially at a young age society tells girls from very young that you're not gonna be maybe that good at math and science.... And so, think about how that impacts women from a young age, if they enter in all their STEM classes and think 'I don't have a math brain or a physics brain.' And so often what happens in these classes is, you can have them be dominated by people who are traditionally assumed to do well.... And so by creating spaces, just for people that are already underrepresented in this space, you kind of make a safe area for people to learn and get interested in it without necessarily having the societal pressure or comparison to people that you think could do it better." — Katherine Jin

"I wish they let you fail as kids. Yeah. Like you have the kid who comes up and says math isn't important. All right. Well, as a teacher, I'm gonna go give you all an assignment. And I know you're going to fail because you do not know the math equations that you're gonna [need] to do this well. Well now, after everybody falls on their face, let's step back and say, okay, now if we would've used algebra and you would've approached this problem differently, you see how easy and fast and simple this really is. Oh, wow. I get it. I understand now why it's important. I had a physics teacher who actually had us go out there as kids and build all of these, these components and tools that would allow us to try to solve problems. And that helped me see it a different way, but they don't let us fail. They do not let you fail enough." — Matthew Rooda

"...lots of people can be inventors too... and it just takes piecing, piecing things together in a slightly new way to solve problems. And it takes creativity, I think. Invention...you need space to be able to let your mind just kind of wander and ponder and think."

— Paige Balcom

"I really wish I had access to just even a club in school where we could just tinker and build things and really go through mini design projects for fun, make toys, and [that] taught us it was possible to do so." — Mercy Asiedu

"I wish makerspaces were a thing when I was a kid."
— Paige Balcom

"I wish that my schools that I went to growing up focused more on entrepreneurship. Ultimately you go through a school being told these are the resources you have. Now you have to pick a career. Well, I hated the idea of knowing an end, a cap. I wanted something that I could chase for the rest of my life. Something that I could always feel as though there was, there was always something I could go for. And I think as a kid, when you grow up, you realize [in] almost every industry there's no ceiling, but as kid, it feels like they are. It feels like, 'oh, I'm gonna go be this, or I'm gonna be that, and then I'm done.' Well, I didn't want that. And I think that the idea that [Lemelson-]MIT really promotes going out there and creating your job, which is something they often say, 'go out there and create your future, build your job, become your own boss.' That was nothing that was taught to me growing up by my school. And I really wish they would've focused on that." — Matthew Rooda

"One of the things that I wish I would have access to, or been able to experience when I was growing up in school, is the teachers being able to walk me through the why, why do I need to learn things? Why math is important? Why science is important?"
— Abraham Espinoza

Current State of Affairs

What we have learned from our Lemelson-MIT Student Prize winners about their own developmental journeys further validates a key finding from a 2018 study (Bell, Chetty, Jaravel, Petkova, & Van Reenan, 2018): Exposure to innovation in childhood affects the type and level of innovation children pursue in adult years. Their data showed that the movement of students from commuter zones that have low rates of patenting to zones with high rates can account for 37% of the difference in who earns a patent. The authors note that this data suggests that human capital, mentoring, and networks of support, beyond simply what is afforded within the school itself, matter. This data also suggests that there is significant human potential for inventing and innovating that is being systematically unrecognized and untapped. This is especially significant for underrepresented minorities in invention.

> **"What Jerry Lemelson and Dolly Lemelson have articulated so well is that all of us grow up with heroes that play basketball or play baseball or are [TV/movie] actors and [they are] accessible… whereas we, inventors, are kind of like ostriches with our heads underground, really focused on the things that… we're passionate about, but [inventors are] largely inaccessible, or even seemingly aloof, nerdy, [and] uninteresting. And part of what we try to expose our kids to is a belief that they can create technology."**
>
> — Geoff von Maltzahn

WHAT IS THE EXTENT OF THE PROBLEM?

The Gender Gap

While a foundational study (Nager et al., 2016) found that 97% of people in their study of inventors and leading inventors had at least a four-year college degree and given that 57% of college graduates are female (and still accounting for the increase of female college graduates over time), the inventor-innovator gender gap is striking:

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).

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).

It will take 118 years to reach gender parity at the current rate of change. If girls were exposed to female inventors in childhood commute zones as boys are to male inventors, the rate of female innovators would rise by 164% and the gender gap in innovation would fall by 55% (Bell et al., 2018).

The Ethnicity Gap

"Technological innovation remains a largely white, male enterprise" (Wisnioski, 2019; Nager et al., 2016).

Exploration of ethnicity and country of origin in the Bell et al. (2018) study showed that minorities born in the United States had low rates of patenting and representation among R&D 100 recipients, and that rates were higher for those born outside the United States.

"One reason for the low rates of Blacks and Hispanics among U.S. innovators is their low rate of STEM doctorates. Among total doctoral recipients, Hispanics represent 3 percent of working PhD recipients in STEM fields.... However, Hispanics represent 17.4 percent of the U.S. population and earn 6.1 percent of PhDs. Blacks represent just 2.2 percent of the working scientists and engineers with STEM doctorates ... but represent 13.2 percent of the population and 8 percent of total doctorates" (Bell et al., 2018).

The Economic Gap

Students from high income families are ten times more likely to patent than students from below-median income families (Bell et al., 2018).

Why is closing the gender, disciplinary, ethnic, and economic disparities in the inventor population important?

An overly represented portion of social problems that have the potential to be addressed through innovation and invention will be identified, framed, and solved through inventions from the perspectives of inventors from particular gender, ethnic, disciplinary, and economic backgrounds that are overly represented in the inventor population when compared to their representation in the general population. This is a much larger issue than "who gets a patent?" Rather, it is an issue of "what and whose problems get recognized and solved?"

Making Invention and Innovation Accessible to All Learners

Developing learners to address the societal and global challenges of today and the uncertainties of tomorrow requires preparing them for creative problem-solving, beginning early in their educational journeys. Given this goal of preparing students to meet the uncertainties of tomorrow, the Lemelson-MIT Program has identified six challenges that high school and community college graduates face in entering the workforce, and we have developed strategies for providing opportunities at the K–12 levels through invention education to overcome these barriers:

- **Challenge 1:** Providing learners with advanced technological skills for rapidly evolving technologies in fields that are also evolving rapidly and require knowledge from different disciplines.

  - **Approach:** The approach requires student inventors to select current technologies that can contribute to the development of their invention—technologies that change over time in tandem with whatever technologies are emerging and widely available across the United States, such as sensing devices related to the Internet of Things (Estabrooks, Zhang, Perry, Chung, & Couch, 2019).

- **Challenge 2:** Preparing learners for jobs in industry growth sectors that require employees to apply STEM knowledge and skills to problems that are unpredictable and emerging.

  - **Approach**: The approaches to problem solving used by inventors directly align with what employers need. These skills also include working in teams and engaging with people from different social, cultural, linguistic, economic, and academic backgrounds.

- **Challenge 3**: Continuously adapting instructional offerings in ways that keep pace with the rate of technological change.

  - **Approach:** The approaches to problem identification and creative problem solving available in LMIT invention education content allow for applying different ideas from different disciplines and different technologies (those currently understood that solve the problem at hand). This creates a constant frame that can be applied to teaching and learning processes and that readily adapts to changing knowledge, technologies, and industries.

- **Challenge 4:** Overcoming the tradition of courses and course sequences planned within the context of singular disciplines.

  - **Approach:** Invention education provides an opportunity to reconceptualize the work of educators as integrators of bodies of knowledge and as designers of learning for interdisciplinary STEM and transdisciplinary approaches to real-world problem solving.

- **Challenge 5:** Providing resources that prepare learners to create their own jobs because of a lack of employers and jobs that pay a living wage in many communities.

  - **Approach:** The intellectual property awareness, protection, and entrepreneurship elements of LMIT offerings empower learners to create their own jobs. Small businesses are a major source of employment for the vast majority of Americans. Those with intellectual property knowledge, including those with patents, are more likely to attract venture capital (Couch & Estabrooks, 2020; Fechner & Shapanka, 2018; Milli et al., 2016).

- **Challenge 6:** Addressing needs of BIPOC students and women underrepresented in STEM fields and disciplines.
  - **Approach:** Invention education also responds to this unique moment when the country is reflecting on ways "racist scripts" have inhibited the formal recognition of creators and the need to decolonize (Vats, 2020) what counts as STEM. Learner ability to exercise self-efficacy by self-selecting the problem and the solution creates a situation in which the educator must bring people with the requisite STEM knowledge to the student as opposed to predefining the knowledge students should be motivated to learn (because the educator and institution have deemed the information to be important). This also empowers learners who already possess STEM knowledge or technical skills to demonstrate their capabilities that have not yet been recognized.

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The remaining pages of this publication take a more personal and detailed look at Lemelson-MIT Student Prize winners through surveys and personal interviews to show the impacts of their inventions on society. To explore this further, move to the "back" of this retrospective, which is the cover page for *Student Prize Winners and Their Impacts*.