



RESEARCHING INVENTION EDUCATION

A White Paper

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EXECUTIVE SUMMARY

Invention Education (IvE) is a term that refers to deliberate efforts to teach people how to approach problem finding and problem solving in ways that reflect the processes and practices employed by accomplished inventors. The term has been used by individuals and organizations to describe educational programs that date back more than a decade.

Research studies of IvE in the United States that examine what is being accomplished, by whom, under what conditions, and with what outcomes, are limited. Formal and informal educators who recognize the importance of invention and entrepreneurship in America and want to support the growth and development of young inventors, therefore, have a limited evidence base available to inform their work. Members of the growing IvE community believe that it is important to document and critically examine IvE practices to accelerate the growth of high-quality learning opportunities afforded to young people. With the rapid pace of technological change, the future of collaborative work environments, and the many global challenges that are in need of solutions, every child deserves to grow up with the invention mindset, skills, and knowledge to be an inventor and a future problem solver.

Considerable progress has been made in the past decade in the expansion of science, technology, engineering, and mathematics (STEM) learning opportunities to students from diverse backgrounds. Women and students from underrepresented communities (by race, ethnicity, income, or geography), however, still face significant barriers to becoming inventors, entrepreneurs, and part of the innovation economy. Individuals—especially females, minorities, low-income, and rural youth—may be held back by limited opportunities for learning and development. Barriers may include a lack of access to IvE curriculum facilitated by prepared instructors, limited mentorship opportunities, constrictive policies placed on school curricula, and instruction and assessment practices. The lack of research highlighting the impact of IvE on student outcomes and invention pathways may also contribute to challenges with the take-up of IvE by educators, as well as challenges with recruiting and preparing students from underrepresented backgrounds to see the relevance of pursuing STEM college and career pathways to their lives and to what they aim to accomplish in their adult years.

This white paper (WP) is a synthesis of work conducted by researchers interested in IvE who participated in a yearlong collaborative effort supported by the Lemelson Foundation. The Lemelson Foundation’s mission is to inspire youth to solve problems through invention and provide young entrepreneurs the tools to create sustainable solutions and commercial opportunities (<https://www.lemelson.org>). Working across the year, the IvE research group’s goal was to consolidate the existing knowledge base informing the IvE efforts of individual researchers, educators, funders, non-profit organizations, and government agencies. Working together, the group aimed to create a document that reflects the research base, values, and principles guiding the work in this emerging field of study.

The initial IvE research group included 39 members. The number of researchers participating in the group has continued to grow, signaling that there is significant interest in this emerging field of study. The original group was drawn primarily from research universities (76%), was predominantly female (71%), and participants were primarily from the east and west coasts of the United States (72%). Regular monthly meetings began in August 2018 to promote collaboration between researchers, identify conferences and publications amenable to IvE, explore research interests, and determine the current state of IvE research and practice. The group engaged in honest and open dialogue about our individual work and sought ways to collaborate across institutions. Of central interest was the breaking of barriers between programs and forging new collaborative pathways to ensure all youth have access to IvE. The group met at the Lemelson Invention Education Convening in November 2018 and spent a day in a research meeting at the American Educational Research Association in April 2019. The IvE research community was invited to contribute to this WP by sharing their research findings and the studies that inform their writing about IvE. Monthly online meetings, conference gatherings, and individual conversations between group members facilitated the structure and writing of this WP.

Of central interest was the breaking of barriers between programs and forging new collaborative pathways to ensure all youth have access to IvE.

IvE is an emerging and transdisciplinary field of study. The transdisciplinary nature of the work creates challenges for researchers asked to examine program offerings in accordance with the norms and expectations of a singular discipline. Next Generation Science Standards (NGSS) promoted for use in K–12 schooling in the United States, for example, are relevant to IvE projects. The problem investigated and solutions being developed by young inventors will typically address disciplinary core ideas, practices, and cross cutting concepts specified by NGSS. The particular ideas, practices and concepts, however, may not align with those specified for the students' particular grade level since the focus will depend on the problem or solution being developed by the student(s). In addition, students may be learning and displaying concepts and practices from a variety of fields and disciplines such as the arts, mathematics, computer science and entrepreneurship. Similar challenges confront computer science educators given the interdisciplinary nature of computer science. The computer science education framework—and the positive reception it has received among educators for the ways in which the ideas can be integrated across multiple disciplines and grade levels—was posited as an exemplar during the discussions among the IvE research group (Association for Computing Machinery, Code.org, Computer Science Teachers Association, Cyber Innovation Center, & National Math and Science Initiative, 2016). IvE researchers, as a result of these discussions, determined that the organization of the WP should reflect the sections of the computer science framework to the fullest extent possible. This approach has the added benefit of supporting future studies that may examine the ways in which the teaching of computer science and IvE converge and diverge.

This WP includes the following eight sections:

- 1. Equity and Access in Invention Education** illustrates how participation in IvE is not equally distributed across gender, race, socio-economic status, or geographic locales. Providing IvE opportunities during the school day may increase the number of underrepresented groups who enter and persist in IvE and career pathways.
- 2. Integrating and Making Explicit the Connections to Other Disciplines** discusses the transdisciplinary nature of the knowledge, skills, and mindsets employed by inventors and how the current rigid separation between disciplines in school does not support the complex problem solving involved in the invention process.
- 3. Invention Education Throughout a Life Span** explores the need for early and continuous exposure to invention opportunities in a variety of formal and informal community settings—including home, school, museums, libraries, camps, and/or makerspaces—in order for youths to develop as inventors.
- 4. Facilitating and Teaching Invention Education** identifies the knowledge, support, and experiences educators need to facilitate student engagement in invention; the challenges they face; and the reasons they choose to incorporate IvE into their practice.
- 5. Programs and Assessments of Invention Education** documents current efforts to engage K–20 students in IvE and discusses assessment tools to document student outcomes and impact.
- 6. Theories and Methodologies Used to Study Invention Education** outlines the diverse set of current theoretical and methodological frameworks employed by the IvE research community.
- 7. Policy Implications: Suggestions From Testimonies** Provided to the United States Patent and Trademark Office (USPTO) includes excerpts from IvE members who commented during public hearings conducted in response to federal legislation known as the Study of Underrepresented Classes Chasing Engineering and Science Success (SUCCESS) Act of 2018 (Public Law 115-273 of the 115th Congress).
- 8. Gaps in Invention Education Research** identifies incomplete areas of research and opportunities for future research and collaboration.

This WP draws on the research conducted by the IvE research group and the work of others frequently cited by research group members. The section topics and research included here are not meant to be an exhaustive review of existing research; rather, this is the work currently informing the IvE researchers' agendas, theoretical frameworks, and methodological approaches. Because IvE is a relatively new field, there are many gaps in understanding how IvE impacts all phases of a student's development (cradle to career) and the promising practices across both formal and informal learning environments. We invite you to become an active contributor within the IvE research community and to bring your research base to the group in ways that can inform future updates to this document.

INTRODUCTION

Invention education (IvE) is a developing field of study in both K–12 and higher education. Entities and individuals who associate their work with IvE offer young people opportunities to develop ways of thinking, capabilities, and dispositions identified as being common to inventors.

The contributors to this paper adopted a working definition of IvE as the facilitation of educational engagement in which people find and define problems and design and build new, novel, useful, and unique solutions that contribute to the betterment of society (Committee for the Study of Invention, 2004; Couch, Skukauskaite, & Green, 2019). The Lemelson Foundation identifies IvE as “a pedagogical approach focused on problem identification through empathy and collaborative problem solving that results in novel solutions by integrating the process of invention into teaching and learning” (The Lemelson Foundation & Coy, in press).

Those working in this field, however, have yet to agree on a single definition of the term “invention education.” Definitions, characteristics, mindsets, skills, or descriptions of IvE offered by practitioners, program providers, policy makers, and researchers vary, given the newness of the field and the significant diversity in the theoretical and practice-oriented perspectives individuals bring to their work. Educators who have deep knowledge of science, for example, may approach the teaching of how to invent through a constructivist, constructionist, inquiry, or scientific practices lens as they guide students in proposing solutions to problems involving the environment, water, physical health, or biomimicry. Educators who work in the engineering fields may approach inventing through an engineering design framework and focus on creating new materials, advances in the automotive sector, or solutions that advance fire and life safety. Educators with an arts background may emphasize arts and design practices while creating a new artistic process or product. A background in social sciences may focus on community ethnography, cultural aspects of problems and problem solving (anthropology) or the nature of what problems exist from the perspective of particular populations or individuals (sociology and psychology). Entrepreneurship educators may facilitate invention by employing a lean startup methodology through hypothesis-driven experimentation, design thinking, iterative prototype testing releases, and customer-driven validated learning. They may focus on outcomes of reduced product development cycles and sustainable or revenue-generating inventions for their customers.

The groups working in this new field also frame ways of thinking like an inventor and discuss required capabilities in different ways. References in the literature to ways of thinking as an inventor include the need to integrate conceptual knowledge from different disciplines and to look at problems from different perspectives in order to find new and novel solutions. This is sometimes referred to as “boundary crossing,” as one needs to go beyond ways of knowing employed by scientists, mathematicians, or any other singular discipline or field of study (National Academies of Sciences, Engineering, & Medicine, 2018, 2019; Perez-Breva, 2016; Root-Bernstein & Root-Bernstein, 1999). *Capabilities* often refers to skills such as the use of a particular type of equipment or

software, or practices including effective oral and written communication, providing evidence to support claims, and problem identification. Capabilities can also refer to the traits, mindsets, attributes, or dispositions of an inventor, such as resilience, self-direction, and critical thinking (Flynn, 2016a, 2018). A preliminary framework for IVE commissioned by the Lemelson Foundation (The Lemelson Foundation & Coy, in press) identifies and defines several attributes:

- **Empathy:** Listens to viewpoints other than just their own, understands a variety of perspectives, and is able to understand the challenges or needs of others;
- **Creativity:** Ability to pair things in an unanticipated way to reveal untapped potential;
- **Curiosity:** Alertness to practical problems and opportunities. Also, intentional focus on both large overarching systems and small micro-components;
- **Resilience:** Embraces failure as a learning experience, ability to work toward delayed gratification, and a critical stance toward their own work;
- **Calculated Risk-Taking:** Conservation of energy where possible, in order to minimize necessary exposures;
- **Passion:** Optimistic commitment to vision, coupled with flexibility to contemplate novel ways to achieve the desired end result;
- **Resourcefulness:** Seeks solutions with available resources and ways to increase available resources; and
- **Tolerance for Ambiguity and Complexity:** Comfort with working on the margins of established knowledge and willingness to become immersed in a multi-layered problem set.

Invention educators represent one of many groups working in education that recognize the importance of providing students with opportunities to engage in, acquire, and demonstrate competencies in the practices, skills, mindsets, dispositions, attributes, and traits attributed to leading innovators. The content and focus of teaching practices associated with invention and innovation are represented in the knowledge, core concepts, and practices reflected in particular disciplinary areas including K–12 national education standards in English language arts (National Governors Association, 2010), science and engineering (National Research Council, 2013), mathematics (National Governors Association, 2010), 21st Century Learning (Trilling & Fadel, 2009), and technology (K12 Computer Science Framework, 2016). Invention education researchers and practitioners support the need for multidisciplinary approaches to teaching and learning, and the alignment of IVE pedagogical practices to the relevant

the importance of providing students with opportunities to engage in, acquire, and demonstrate competencies in the practices, skills, mindsets, dispositions, attributes, and traits attributed to leading innovators

standards articulated as important to the different disciplines. Flexibility in the sequencing of when the concepts or practices are taught, and the configuration of the standards that are addressed within particular course offerings, are key to the transdisciplinary work common within IvE programs.

Some groups within the IvE community offer learning opportunities that support the development of individual inventors. Others offer programs for team-based invention so that knowledge and expertise from a diverse array of disciplines and cultures possessed by individual students can inform the team members' understandings of a problem as well as their efforts to design and create a solution to a problem. Awareness of the need for knowledge, skills, and mindsets found in different disciplines or fields of study contributes to the notion that the work of inventors is transdisciplinary. Information, concepts, and practices from many different disciplines need to be brought together in ways that allow students to develop an understanding of the problems people face. Diverse knowledge and skills are also needed for the development, testing and efforts to bring solutions forward in ways that contribute to the betterment of society and the lives of others.

Published research related to particular IvE programs or practices, whether designed to serve individuals or those seeking team-based learning opportunities, is limited. The work within the existing programs, however, is often guided by research findings that relate to the many component parts of IvE. Research studies pertaining to such areas as design thinking, systems thinking, maker education, computer science education and computational thinking, science and engineering education, project- and problem-based learning, and entrepreneurship are all relevant to designing and implementing effective IvE offerings. Program providers informing the development of this WP could articulate the research base that guides their work, even if their own program offerings had not been researched.

This WP represents a first step toward bringing together the body of research that the contributing authors and members of the larger IvE community have produced to date and/or used to guide the work they identify as invention education. The process for constructing the WP involved:

- Calls to contribute and Invention Education Research (IER) online group meetings (monthly starting August 2018);
- Meeting at the American Educational Research Association's annual conference, brainstorming and sharing in small groups (April 2019);
- Reviewing two IvE focused issues of the National Academy of Inventors' *Technology and Innovation* journal (May–June 2019);
- Constructing an extended outline with citations (May 2019);
- IER community feedback on the WP extended outline (May–June 2019);
- Writing of the WP with IER community contributions (June 2019)

- Sharing the WP draft with the IER community (July 2019)
- IER Community review and feedback on the draft (July 2019)
- Finalizing the draft (August 2019)
- Professional editorial review and formatting (September 2019)
- WP Publication (October 2019)
- Presentation of WP at Lemelson IvE Convening (November 2019)

The WP includes eight sections that mirror the Computer Science (CS) framework (Association for Computing Machinery et al., 2016). The CS framework served as a guide for topic identification because CS, like IvE, is an emergent interdisciplinary field that also addresses knowledge and skills that are critical to students' preparation for their future work. The CS framework acknowledged that learners can enter computer science at any age or level of education; the same holds true for learning how to invent. CS is a field that is distinct, yet intertwined with IvE since inventors must work with existing technologies as they find and refine understandings of problems, and design and build new technological solutions.

The eight sections of the WP include overviews of IvE research focusing on 1) what is known about equity and access, 2) interdisciplinarity of the field, 3) learning of invention (student focus), 3) educating for invention (teacher focus), 5) models and assessments of IvE implementation, 6) theories and methodologies utilized in researching IvE, 7) policy dialogues and implications, and 8) gaps in research.



1

EQUITY AND
ACCESS IN
INVENTION
EDUCATION

1 EQUITY AND ACCESS IN INVENTION EDUCATION

Invention, inventiveness, creativity, and innovation are recognized as key drivers of societal development and economic growth worldwide (Committee for the Study of Invention, 2004; Novy-Hildesley, 2010; Perez-Breva, 2016; Villa, 1990). Inventors are celebrated in books, social media, and curricula in science, engineering, technology, and related fields such as entrepreneurship or design. Historical accounts of inventors demonstrate tremendous variety in their personal backgrounds and the funds of knowledge that they drew upon while envisioning their breakthrough, though documentation of the contributions of women, people of color, immigrants, and minorities are not as visible as those of white men (Milli, Williams-Baron, Berlan, Xia, & Gault, 2016; Nager, Hart, Ezell, & Atkinson, 2016; Shaw & Hess, 2018). Recent research that examines who is inventing, patenting and driving innovation in the United States has revealed major gaps in who participates in patenting and inventing (Bell, Chetty, Jaravel, Petkova, & Van Reenen, 2018; Fechner & Shapanka, 2018; Haseltine, 2018; Hosler, 2018; Hunt, Garant, Herman, & Munroe, 2013). One of the most visible gaps is the underrepresentation of women and minorities in patenting and STEM disciplines (Bell et al., 2018; Comedy & Dougherty, 2018; Cook, 2011, 2019; Couch, Estabrooks, & Skukauskaite, 2019; Gottlieb, 2018; King & Pringle, 2018; Landivar, 2013; Milli et al., 2016; Ong, Smith, & Ko, 2018; Sanders & Ashcraft, 2019).

One of the most visible gaps is the underrepresentation of women and minorities in patenting and STEM disciplines

The lack of diversity among inventors and patent holders in the United States has been gaining more attention in education and policy circles in recent years (Haseltine, 2018; Lost Einsteins, 2019; Sluby, 2004; Wisnioski, Hintz, & Kleine, 2019). Available data suggests that prolific patent holders and leading technology innovators are 90% male and nearly 95% Asian or White, with much of the diversity that does exist being attributable to those who are foreign born (Nager et al., 2016). Researchers examining the gaps in patenting frequently associate it with the lack of diversity within particular STEM disciplines, namely engineering (Cook, 2019) and technology (Sanders & Ashcraft, 2019), which are among the fields most prone to patent generation. Cook (2019) found that, in the engineering fields, women represented 22.8% of doctoral degrees awarded in 2014, and the share of doctoral degrees in engineering awarded to African Americans was 1.7%. Sanders and Ashcraft (2019) found “only 19 percent of all software developers” were female (p. 323) and 88% of the teams who patented were all-male, compared to 2% that were all-female invention teams.

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There have been numerous initiatives to train and cultivate innovators. Women and African Americans, however, continue to participate at each stage of the innovation process—from education to patent activity, and then to

start-ups—at lower rates than their (respectively) male and white counterparts (Cook, 2019). The lack of diversity in innovation pathways limits the scope of problems being investigated and solutions being generated to address the challenges faced by these underrepresented groups. Negative repercussions for society have been linked to the persistent demographic gaps. Koning, Samila, and Ferguson (2019), for example, analyzed historical patent data in biomedical fields and found teams with women inventors were more likely to target issues that predominantly affect women, and this effect is larger when a woman is the lead inventor on a patent. This evidence suggests that addressing the gaps in patenting among women is a strategy that can lead to inventions that benefit a broader sector of society. Conceptually, this argument highlighting the importance of gender diversity might also be applied to the underrepresentation of particular demographic groups in the patenting process. Analysis of who is and is not represented among patent holders is challenging, however, since the United States Patent and Trademark Office (USPTO) does not collect demographic data from patent applicants.

IvE as a way to bridge the innovation access gaps and to create opportunities for students from underrepresented backgrounds to enter, persist, and thrive in STEM and innovation education pathways and careers.

Two other gaps reflected in the literature are the divide across income lines (Bell et al., 2018; Fechner & Shapanka, 2018) and the effect of geographical concentrations of invention in particular areas and cities (Aghion, Akcigit, Hyytinen, & Toivanen, 2017; Agrawal, Cockburn, & Rosell, 2010; Bell et al., 2018; Ejeremo & Hansen, 2015; Feldman, 2019).

Research indicates an uneven access to innovation negatively impacts not only the development of local communities, but also U.S. social and economic well-being and competitiveness. Therefore, many propose IvE as a way to bridge the innovation access gaps and to create opportunities for students from underrepresented backgrounds to enter, persist, and thrive in STEM and innovation education pathways and careers.

Addressing Inequities Through Invention Education in Communities and Schools

Exposure to innovation, invention, engineering, and STEM in school can benefit students of all ages, from kindergarten and preschool (Aguirre-Munoz & Pantoya, 2016) to elementary (Cunningham, 2018; Kim & Park, 2012) to middle (Calabrese Barton & Tan, 2019; Tan, Calabrese Barton, & Benavides, 2019; Zhang, Estabrooks, & Perry, 2019) and high school levels (Couch, Estabrooks, & Skukauskaite, 2018; Couch, Skukauskaite, & Estabrooks, 2019; Estabrooks & Couch, 2018; Flynn, 2016b; Kort, 2016; Maaia, 2019; Moore, Newton, & Baskett, 2017) and beyond. The importance of early exposure to science and innovation as a predictor for patenting activity was made visible in the often-cited “Lost Einsteins” report on the life cycles of inventors (Bell et al., 2018). Bell and colleagues, at the Opportunity Insights group at Harvard University (Bell et al., 2018), linked U.S. inventor demographic information on patents to tax records and New York city school district records for 1989–2009. Their analysis across the three data sources showed that children’s opportunities to become inventors were

influenced by their race, gender, socioeconomics, and the environment in which they grew up. The authors argued that exposure to innovation during childhood is “a critical factor that determines who becomes an inventor and the types of innovations they pursue” (p. 33). Their findings align with other studies documenting intergenerational links between the patenting activity of parents and children in the United States (Bell et al., 2018; Link & Ruhm, 2013; Sarada, Andrews, & Ziebarth, 2017). The research suggests the best approach to creating equitable access and generating interest in inventing and STEM pathways for diverse learners is student engagement in IvE learning that begins at an early age and continues across their years of schooling.

Empowering Youth Through Community-Driven Engagement

Inequities in access to IvE learning opportunities have been made visible by research studies that disaggregated data about participation in STEM careers and patent authorship according to income, race, gender, and geographic location (Hunt et al., 2013; Nager et al., 2016). Researchers have argued that one way to increase youth participation in STEM is to create more opportunities within the communities where diverse youth live. Calabrese Barton & Tan (2018a) conducted a four-year longitudinal study of youth makers in two different urban, community-based STEM-rich makerspaces, demonstrating the impact of community-embedded maker activities for diverse youth. Using ethnography, they documented the culture of these two makerspaces and how the spaces supported (and didn't) the development of 41 youth maker projects/inventions. The study illustrated the ways that making with and in the community opened up opportunities for youth to employ their communities' rich cultural knowledge and wisdom as part of their making activities, while also questioning and negotiating the historicized injustices they experienced. For the youth makers in this study, “interest” in invention/STEM-rich making was a complex phenomenon that involved not just curiosity or a desire to learn more, but a commitment to addressing needs in one's community. This is important because this stance-taking approach positions youth with the power and agency needed to take action with both STEM and cultural knowledge and practice(s), and distributes among all the actors the intergenerational teaching, learning, and expertise present in STEM-rich making.

Community engagement efforts in IvE can be fostered through schools in ways that increase opportunities for all students. A study by Dunkhase & Flynn (2013) identified K–12 administrators who took advantage of avenues to engage students in authentic STEM problem-based learning, invention, and entrepreneurial ventures in partnership with community stakeholders. Administrators described community members as individuals who brought unique cultural understandings, knowledge of current problems facing the community, and expertise in how to create solutions. Administrators identified increased pressure from industry, parents, and an emerging STEM education movement to prepare students to be workforce ready. Community members were identified as a resource to facilitate workforce-development skills and mindsets, many of which align with those of inventors, such as grit, communication, adaptability, collaboration, critical thinking, and creativity. The skills and mindsets were made visible to students as students collaborated with the community

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members on advancing solutions to community problems. The connection between invention and work-force-readiness skills and mindsets may serve as an argument for IvE integration into the K–12 curriculum.

Community spaces have a potential to provide opportunities for intergenerational engagement and learning through multiple exposures to varied projects and ongoing discussions with mentors across time and events. Multiple instances of exposure to inventing opportunities and people who support invention have been shown to be significant in helping youth to develop interests in STEM and to begin envisioning themselves as inventors, innovators, engineers, and leaders, among other developing identities (Calabrese Barton & Tan, 2018b; Couch, Skukauskaite, & Estabrooks, 2019; Couch, Skukauskaite, & Estabrooks, in press; Nazar, Calabrese Barton, Morris, & Tan, 2019; Small, 2018).

Leveraging Inequities Through Embedding Invention Education in School

One of the ways to make IvE opportunities accessible to a broad range of diverse students is to embed IvE in the regular school day so the learning opportunities are available to all students, as opposed to only those who have access to and choose to participate in community-driven activities after school. This approach is informed by Bell et al.'s (2018) study of the over-time effects of the lack of exposure to innovation. The researchers found that limited exposure to innovation was a key factor contributing to “lost Einsteins” (i.e., girls and low-income and minority children who are underrepresented in STEM and who might have the potential to become inventors if provided the opportunities). Researchers and practitioners have argued that IvE, when integrated into school curricula and fostered in the regular school environment, has the potential to increase diverse students’ opportunities for exposure and engagement in invention, engineering, and integrated STEM processes and practices (Committee for the Study of Invention, 2004; Couch et al., 2018; National Academies of Sciences, Engineering, & Medicine, 2019, Perusek & Shlesinger, 1987).

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Studies of Lemelson-MIT’s InvenTeams high school program, for example, have demonstrated how the capacity for invention and participation in STEM careers can be equalized for diverse students when all students are provided the resources and support needed to engage in multidisciplinary, team-focused invention projects conducted over time (Couch et al., 2018; Couch et al., 2019; Estabrooks & Couch, 2018). Case studies of three young women who participated in a team-based IvE program in 2017 indicated that one of the young women who had identified as having very few STEM experiences prior to participation in InvenTeams was interested in pursuing a STEM college/career path at the end of her year in the IvE program (Couch et al., 2018). Through follow-up contact, the researchers learned that she went on to enroll in an introductory computer science course in her freshman year of college. Continuing efforts to document the impact of the InvenTeams program have demonstrated that IvE helps young women develop their capacity to learn from failure (59.3% strongly

agree) and to persist (55.6% strongly agree). The experience also helps young women develop confidence in their ability to solve problems (49.1% strongly agree; Couch et al., 2018).

Comparing the data of young women with the young men participating on the InvenTeams in the same year, Lemelson-MIT researchers discovered that young men were less likely to cite learning from failure, persistence, and self-confidence in their ability to solve problems as a benefit derived from participation on an InvenTeam, with 34.7% strongly agreeing that they developed their capacity to learn from failure, 31.9% strongly agreeing that they developed their capacity to persist, and 29.6% strongly agreeing that they developed confidence in their ability to solve problems (Couch et al., 2018). The gender-based differences in self-reported benefits from program participation may be attributable to young men's experiences with developing these capabilities through ongoing STEM-focused experiences across time in prior years. Case studies of three young women and three young men who participated on InvenTeams in 2017 revealed that the young men were found to have had consistent experiences with STEM in school, outside school, and at home starting at an early age and continuing through their high school years. The young women, in contrast, had few prior experiences with STEM (Couch et al., 2019). The studies of IvE within schools, therefore, make visible the potential of school-based programs to provide women and underrepresented youth with access to STEM experiences and potential STEM college and career pathways.

Exploring the impacts of an IvE STEM Innovator program, researchers at The University of Iowa conducted a three-year longitudinal case study with over 700 high school students and their teachers from four U.S. states (MN, IA, NJ, MS) to identify how the integration of IvE embedded into classes during the traditional school day impacted high school students' invention and entrepreneurial skills, mindsets, and knowledge (Flynn, 2018b). The required classes (85% of models) exposed all students, regardless of gender (47% female), race (28% minority), or socio-economic status (43% free and reduced meals) to an authentic invention and entrepreneurial experience. Students collaborated in teams to advance solutions by working with community partners. Results indicate females and minorities significantly increased ($p < 0.001$) their IvE skills and mindsets at growth rates equal to their male and white non-Hispanic peers. The model stemmed from educators' engagement in 60–100 hours of professional development with multidisciplinary teams, and was presented to industry, students, parents, and administrators. Feedback was used to create a unique, multidisciplinary teaching approach for K–12 that included community engagement. Educational programs, tailored to local contexts and designed to be embedded within school curricula, increase the likelihood that all students will have the opportunity to gain access to IvE and community mentorship across multiple years of school and within and across academic subject areas.

Persistent inequities in representation in STEM careers and among patent holders suggest the need to integrate IvE and STEM-related learning opportunities into the regular school day, where they can reach all K–12 students beginning at a young age (Bell et al., 2018; Hira, Joslyn, & Hynes, 2014). Given the social inequalities in American society (Bell et al., 2018; Hunt et al., 2013), schools have the potential to become places where invention can be taught to all and

schools have the potential to become places where invention can be taught to all

1. Equity and Access in Invention Education

where young people can gain hands-on experiences with the processes, practices, and potentials of inventing (Couch et al., 2018; Magee, Sheppard, & Cutcher-Gershenfeld, 2004). More research is needed, though, to understand the components of the learning methodologies and environments that are key to fostering inventiveness in order to integrate IvE in school curricula.



2

INTEGRATING AND
MAKING EXPLICIT THE
CONNECTIONS TO
OTHER DISCIPLINES

② INTEGRATING AND MAKING EXPLICIT THE CONNECTIONS TO OTHER DISCIPLINES

Invention Education has been described as being transdisciplinary. Students and teachers working on invention projects and inventors-at-large engage with knowledge and skills from different disciplines and fields of study as part of their effort to develop an invention. Students and teachers may not possess the specific prior knowledge or skills in areas that are needed for the particular problem or potential solution being developed, and therefore may need to engage with others in the larger community to access knowledge and skills that are missing within the immediate group (Calabrese Barton & Tan, 2018b; Couch et al., 2019).

Disciplines that are integrated or explicitly linked through IvE differ according to the problem being addressed, and/or according to the aims of the course or program being offered. A sequence of courses found in the College of Design at the University of Oregon, for example, teaches students ways of thinking and working as an inventor through studies that include a focus on human physiology, journalism, business, engineering, and design (Sokolowski, 2019). A senior design capstone course at the University of California, Irvine includes a focus on biomedical engineering, medicine, and entrepreneurship (King, Hoo, Tang, & Khine, 2019). Students in a high school maker education course engaged with computer science, engineering, and art (music) as they developed ways of thinking and working as an inventor (Maaia, 2019). High school students with an interest in entrepreneurship, graphic design, computer coding, and engineering work on teams to develop solutions for clients and the community (Kort, 2016). Particular types of art, crafts, and design activities have also been shown to be highly correlated to those who have received patents for their inventions (Root-Bernstein et al., 2019), which supports the hypothesis that knowledge from these fields and disciplines is activated during the development of an invention.

The act of drawing on multiple disciplines to find and define problems and to design solutions has been referred to as “boundary crossing,” which is an expertise inventors need to synthesize and employ information beyond a single field or discipline in order to imagine something in a new way (Committee for the Study of Invention, 2004; National Academies of Sciences, Engineering, & Medicine, 2019). The notion that inventors must engage with ideas and practices from many disciplines is far from new. Root-Bernstein and colleagues (Root-Bernstein et al., 2019) argued in a 2019 article in the National Academy of Inventors’ *Technology & Innovation* journal that “building what might be called ‘integrated networks of enterprise,’ connecting skills and knowledge from across different disciplines, is a valuable way to enhance creative potential, a conclusion that is consistent with a long and varied set of studies beginning with John Dewey in 1934” (p. 210). Root-Bernstein et al. cited Charles Steinmetz, “the innovator behind many of General Electric’s early successes and one of the elite members of the Inventors Hall of Fame” (p. 210), who already in the 1940s taught his students that knowledge of math and engineering needed to be integrated with studies in the liberal arts to be able to design inventions that address human needs and contribute to society in positive ways.

2. Integrating and Making Explicit the Connections to Other Disciplines

Examinations of the words and practices of early inventors such as Steinmetz, Da Vinci (Pollman, 2017), Wiener (1954), Tesla (Carlson, 2019), and others emphasize the importance of working across disciplines and drawing on varied human and physical resources to develop innovative ideas and solutions (Dyer, Gregersen, & Christensen, 2011; Koning et al., 2019; Root-Bernstein & Root-Bernstein, 1999). The need to integrate varied disciplinary and experiential knowledge has gained more ground and visibility in education over the past 20 years, resulting in reports that speak to the limits of preparation in a single discipline and the need for knowledge from multiple disciplines to converge as innovative solutions to problems are developed and assessed (National Research Council, 2014; Roco, Bainbridge, Tonn, & Whitesides, 2013) and change in educational programs and policies (Committee for the Study of Invention, 2004; National Academies of Sciences, Engineering, & Medicine, 2019; National Academy of Engineering & National Research Council, 2014).

Prolific inventors, STEM professors, and leaders in creativity research produced a report in 2004 recommending transformations in K–12 schooling to enhance inventiveness for quality of life, competitiveness, and sustainability (Committee for the Study of Invention, 2004). The recommendations would resolve a number of challenges that they identified, including the “rigid separation between disciplines” and “inadequate balance between building a body of knowledge and the creative use of knowledge (e.g., insufficient use of open-ended problems)” (p. 56). Many K–12 schools in the United States continue to exhibit instructionist notions of learning characterized as “straightforward internalization or acquisition of information that is delivered by the instructor” (Sawyer, 2015, p. 20). National education standards and state frameworks setting forth what students should know and be able to do in science, engineering, and other subjects have continued to be discipline specific. The Next Generation Science Standards (National Research Council, 2013) and the Science and Engineering for Grades 6–12 report (National Academies of Sciences, Engineering, & Medicine, 2019) have opened doors for more integrated teaching and learning of science in recent years (National Research Council, 2014), including integrating invention into the high school science classroom through the engineering design practices (Perry & Estabrooks, 2019). Few examples exist, however, of interdisciplinary curricula in which innovative techniques and ways of thinking have been brought together across different disciplines (Wineburg & Grossman, 2012). Instruction in schools rarely resembles the types of creative and inventive open-ended problem solving students must tackle to solve more complex challenges in the world, thus leaving learners without the supports needed to learn how to integrate information across disciplines and apply knowledge to real-world problem solving (Weis et al., 2015; Wineburg & Grossman, 2012).

Published research on the programs and outcomes of exposure to innovation and invention are more prevalent at the university level (Chang, Sharkness, Hurtado, & Newman, 2014; King et al., 2019; Sokolowski, 2019). Many studies at the higher education level emphasize the importance of interdisciplinary learning and preparation of diverse students for careers in STEM, entrepreneurship, and invention fields. Studies of invention efforts in higher education frequently mention collaboration, partnerships, and interdisciplinary connections that involve community partners. Some courses and programs described in the research literature are designed intentionally to address the needs of specific industries so that students develop the diverse expertise needed for those industries (Balos, Napoli, & Green, 2019; King et al., 2019; Sokolowski, 2019). The engagement allows the students

to leverage the knowledge, resources, support, and development of skills and dispositions needed for inventing (Balos et al., 2019; Couch et al., 2019; King et al., 2019). University technology transfer offices and/or intellectual property lawyers, in some instances, collaborate with inventors to help them understand and navigate the patenting or intellectual property protection processes (King et al., 2019; Mercier, Ranjit, & Reardon, 2018).

Invention education programs in Grades K–12 are often the result of partnerships between schools and higher education institutions or between multiple kinds of higher education institutions (Balos et al., 2019; Couch et al., 2019; Flynn, 2016a; Kim, Cho, Couch, & Barnett, 2019; Moore, Newton, & Alemdar, 2019; Newton, Alemdar, Moore, & Cappelli, 2018; Zhang et al., 2019). K–12 IvE initiatives may also be integrated with resources and spaces in the community, such as makerspaces (Calabrese Barton & Tan, 2018b; Maaia, 2019), industry (Balos et al., 2019; Sokolowski, 2019), clinical settings (King et al., 2019), and libraries (Small, 2018). One vision for IvE programs, seen from the perspective of higher education faculty members, was expressed in the words of Magee, Sheppard, and Cutcher-Gershenfeld (2004) in a paper contained within the Committee on the Study of Invention report. Magee et al. envisioned education in which technological inventiveness is widely valued, is integrated into curricula, and is developed through the balancing of individual and group activity, learning within academic disciplines, and engagement of creativity. The vision also included “appropriate attention to initiative, expression, and pace” (p. 57), incentives and infrastructures of support for educators, and “no barriers to entry in the profession” (p. 58) for people of diverse backgrounds. Magee et al. argued that the educational system was far from where it needed to be to foster technological creativity and inventiveness, but schools, universities, policy makers, funders, and other stakeholders can take action to create opportunities. After all, as the third finding of the report stated, “The best way to learn to invent is to invent” (Committee for the Study of Invention, 2004, p. 28).

Another vision for K–12 IvE programs, presented at a 2019 symposium hosted by the National Association of Research on Science Teaching, was put forth by higher education faculty and graduate students (Barnett et al., 2019). The presentation shared research findings generated by an invention-oriented program offered to middle school students as part of their science class. The curriculum for an existing IvE program was modified in ways that addressed the needs of English language learners and incorporated experiential activities to connect the students’ learning to their home cultures. The researchers presented evidence that the modified invention-oriented project-based learning motivated English language learners to comprehend science concepts better, helped them retain content knowledge in science, inspired excitement about their own inventions, and improved science knowledge and science literacy while also valuing their cultural backgrounds. The researchers also noted that classroom teachers realized they needed to shift to a facilitator role and highlight the relations between invention and the underlying science concepts when teaching with the invention-oriented project-based learning curriculum.

The potential benefits of integrating instruction in ways that address multiple disciplines simultaneously through open-ended problem solving, which can happen through IvE, have been acknowledged in the Science and Engineering for Grades 6–12 report (National Academies of Sciences, Engineering, & Medicine, 2019). Instruction

2. Integrating and Making Explicit the Connections to Other Disciplines

in schools, however, rarely resembles the types of creative and inventive open-ended problem-solving students must tackle to solve more complex challenges in the world. This leaves learners without the supports needed to learn how to integrate information across disciplines and apply knowledge to real-world problem solving (Weis et al., 2015; Wineburg & Grossman, 2012).

There is a lack of evidence explicitly connecting the practices of IvE to existing teaching and learning frameworks (e.g., NGSS, ISTE, or ITEEA) or educational movements (e.g., Maker Education, Computer Science for All, or Project-Based Learning). Furthermore, there is no evidence (causal or descriptive) of the impact IvE has on traditional measures of student achievement in STEM (or other) disciplines that rely on standardized testing. This evidence, coupled with further documentation of the emerging evidence of IvE's impact on non-cognitive constructs—such as self-efficacy and identity formation—which can predict persistence along innovation pathways over a lifetime, is necessary to make a case as to why IvE should be taken up as part of the regular school day curriculum.



3

INVENTION
EDUCATION
THROUGHOUT
A LIFE SPAN

③ INVENTION EDUCATION THROUGHOUT A LIFE SPAN

Research shows today's leading innovators are an average of 47 years of age with roughly equal proportions below the age of 40 and above the age of 50. Typically leading innovators were in their early 30s at the time of their first patent filing (Nager et al., 2016). Little research exists to understand the developmental milestones between birth and attainment of an inventor's first patent. Researchers studying IvE, however, agree on the need for early and continuous exposure as well as for specific support and programming that can bridge gender, racial, socioeconomic, and geographic divides in invention pathways. Awareness of inequities in STEM, innovation, and invention pathways is the first step to developing opportunities and programs for women and other groups underrepresented in STEM and invention (Demiralp, Morrison, & Zayed, 2018; Mercier et al., 2018; Shaw & Hess, 2018).

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Early Exposure and Explicit Connections With Community Funds of Knowledge

Several studies support our hypothesis that those who become inventors have been exposed to innovation and have had opportunities to engage in IvE from an early age. In a study that examined 253 successful STEMM (STEM+Medicine) professionals' early experiences, Root-Bernstein and colleagues (Root-Bernstein et al., 2019) found that art, craft, and design (ACD) activities in early childhood and adolescence were instrumental in helping these professionals develop knowledge, skills, and dispositions that impacted their inventiveness in later life. These early activities included private lessons, self-learning, mentoring, and school classes. The authors argued that "the impact of ACD on STEMM practices begins in childhood and involves persistent practice through adolescence/young adulthood into maturity" (p. 211). They also made visible that supporting such ACD practices "depends on a diversified, distributed network of cultural activity and access involving intellectual and economic support for formal and informal types of education; workshops, ateliers, and studios for ACD practice; businesses that supply equipment and materials; arts and crafts museums and galleries for the display and dissemination of products; and communities that value and support ACD" (p. 211).

The role of community support for inventiveness is similarly emphasized in the work of Calabrese Barton and Tan (2018b) who argue that partnering with community clubs helps to situate making/invention "on youths' and community's turf" from the start (p. 159). Opportunities to engage in making/invention situated at the community club, where youth already spend significant time and where most have a personal history and connection with the place (understanding its norms and practices, being positioned as cherished youth members of the club), opens up opportunities for youth to construct identities as inventors and makers in ways that center or amplify their cultural knowledge and wisdom, as well as the relationships that they value in their lives. This can make engaging in STEM-rich inventions/making less threatening or distancing from their everyday lives. For

3. Invention Education Throughout a Life Span

example, Calabrese Barton and Tan (2018a) show how a regular practice at one community-based makerspace, in which youth move their inventions from their makerspace into common areas at the center, created sustained opportunities for younger peers to learn from the youth inventors. In this example, youth moved their geodesic dome and other play items they created to more broadly shared recreational spaces, reconfiguring their community makerspaces for more engaging interactions with the inventions in place-based ways. Youth inventor/makers were acknowledged as Community STEM experts who knew and cared about their community, and who could utilize STEM toward solving their problems.

Wilson-Lopez and colleagues (Wilson-Lopez, Mejia, Hasbun, & Kasun, 2016) similarly argued that community, home, and everyday practices can be utilized and connected to the skills and dispositions guiding IVE and STEMM pathways. They reiterated the issue of observed gaps in patenting and underrepresentation of women, African American, and Latinx people. Wilson et al. argued that the underrepresentation, however, does not mean that young people in underrepresented communities are not already inventing or inventive. Wilson-Lopez et al. (2016) used the funds of knowledge framework (Gonzalez, Moll, & Amanti, 2005) to make visible that Latinx students' everyday practices and knowledge map on to what is known about the skills and dispositions of inventors and engineers.

Basu and Calabrese Barton (2007) also investigated the connections between the funds of knowledge that urban, high-poverty students brought to science learning and the development of a sustained interest in science when participating in an after-school program focused on scientific inventions. This study showed that youth developed a sustained interest in science and invention design when: (1) their science experiences connected with how they envisioned their own futures; (2) learning environments supported the kinds of social relationships students valued; and (3) science activities supported students' sense of agency for enacting their views on the purpose of science. Like Wilson-Lopez et al. (2016), Basu and Calabrese Barton (2007) and other researchers studying early and sustaining exposure to invention in home and community spaces have argued for a need to make more explicit connections with community funds of knowledge as sources and supports for youths' inventiveness.

Sustaining Support in Educational Settings

Invention education researchers agree that inventiveness refers to knowledge, traits, and dispositions that are developed, as opposed to capabilities that people are born with (Bell et al., 2018; Committee for the Study of Invention, 2004; Couch, Skukauskaite, & Estabrooks, 2019; Link & Ruhm, 2013; Novy-Hildesley, 2010). Research demonstrates that exposure to innovation and development of inventiveness can begin and develop at any age (Couch, Skukauskaite, and Green, 2019), and that sustained exposure over time makes the most lasting impact (Calabrese Barton & Tan, 2018b; Couch, Skukauskaite, & Estabrooks, 2019; Flynn, 2018; Root-Bernstein et al., 2019). Early exposure to innovation in childhood, sustaining support, and intergenerational

inventiveness refers to knowledge, traits, and dispositions that are developed

linkages have a strong association with the chances of growing up to be an inventor (Bell et al., 2018; Link & Ruhm, 2013; Sarada et al., 2017).

Exposure to innovation at an early age and sustaining support for inventiveness can happen through opportunities for learning in both formal and informal education and community settings, including libraries (Small, 2018), museums (Shaby, Ben-Zvi Assaraf, & Tal, 2019), makerspaces (Calabrese Barton & Tan, 2018a), camps (Jackson & Asante, 2018), and varied spaces for arts, crafts, and design activities (Root-Bernstein et al., 2019). Ways of thinking and working as an inventor develop through interactions with others in various settings, including home (Wilson-Lopez et al., 2016), school and/or public libraries (Small, 2018), community and/or maker spaces (Bell et al., 2018; Calabrese Barton & Tan, 2018a; Couch, Estabrooks, & Skukauskaite, 2018; Maaia, 2019), and museums and summer programs (Jackson & Asante, 2018; Plucker & Gorman, 1999). For example, Jackson and Asante (2018) employed a design-based approach to examine middle schoolers' access, participation, and collaboration in a vacation camp for creating shoe soles based on a curriculum from the Lemelson-MIT JV InvenTeams program. Analyzing data generated from campers' interview responses and participant-observers' field notes, researchers identified a need for the camp's scope-and-sequence to move more quickly to hands-on, problem-specific activities to foster student engagement. Jackson (2018) and Jackson and Semerjian (2019), in related presentations, found that the middle-school-aged youth participating in invention projects experienced shifts in self-efficacy ratings throughout the camp period. Students cycled through a wide range of emotions throughout the multi-day camp, including initial confidence and optimism to frustration and anxiety, and then success and pride at the culmination of the activities. Jackson and colleagues found no statistically significant difference between the self-efficacy ratings of students who self-identified as female and those who self-identified as male, demonstrating that exposure to invention in the camp setting can be equally beneficial to all students.

Exposure to invention in school settings can benefit youths just as informal settings such as camps, makerspaces, and libraries do. Researchers have demonstrated that in-school and after-school educational opportunities in middle school (Calabrese Barton & Tan, 2019; Tan, Calabrese Barton, & Benavides, 2019; Zhang et al., 2019) and high school (Couch, Estabrooks, & Skukauskaite, 2018; Couch, Skukauskaite, & Estabrooks, 2019; Maaia, 2019) help students participate in IvE in more systematic and sustaining ways. Middle school IvE research, for example, has demonstrated the opportunities and challenges teachers face in introducing IvE (Zhang et al., 2019) and in adapting the curricula to meet the needs of linguistically and culturally diverse learners (Kim et al., 2019). Calabrese Barton and Tan's (2019) study of youth inventions in middle grades engineering showed that opportunities to engage with invention in consequential ways through engineering design are shaped by the historicized injustices students encounter in relation to participation in STEM and schooling. Findings described students' practices as they engaged in engineering design toward inventions intended to be a part of the classroom community that supported them in the robust STEM-rich design work, while also engaging their lived lives and community wisdom. The authors discuss how these practices support moments of rightful presence in STEM classrooms by

Exposure to invention in school settings can benefit youths just as informal settings such as camps, makerspaces, and libraries do

3. Invention Education Throughout a Life Span

inscribing youths' marginalizing school experiences as a part of classroom science discourse and co-opting engineering design as a tool to expose, critique, and transform these unjust experiences.

Despite all the benefits, IvE remains relatively scarce in school settings, particularly middle school classrooms. Zhang, Estabrooks, and Perry (2019) analyzed middle school science teachers' experiences of teaching with a widely used IvE curriculum and found that those teachers valued the benefits of IvE, yet struggled with incorporating it in their curriculum. Factors such as limited instruction time; lack of confidence, support, and experience in facilitating invention projects; and a dearth of invention curriculum that aligns with district standards significantly hindered the classroom enactment of IvE at the middle school level.

Invention educators emphasize the potential benefits and contributions to improving the lives of others that can be realized as students invent solutions to real problems found within the community (Couch, Skukauskaite, & Estabrooks, 2019; The Lemelson Foundation & Coy, in press). Many middle school program offerings teach students through both semi-structured and open-ended problem-solving activities. Programs at the high school level may engage students in actively seeking problems within their communities, conducting research and working with beneficiaries to understand a problem, and engaging in iterative design and testing processes that help them develop solutions that they then present to the beneficiaries and the public (e.g., Lemelson-MIT's InvenTeams program; Georgia Tech's InVenture Prize program; University of Iowa's STEM Innovator program). Through such open-ended problem-based learning, students develop technical and social skills that boost their confidence and open doors to pathways and college aspirations they may not have considered previously. The impact of IvE is particularly significant to women and students who have not had previous sustaining opportunities to engage in STEM and collaborative problem solving (Couch et al., in press).

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Schools can be key places where opportunities to engage in inventing processes and practices are introduced and made available to diverse students across grade levels. The dispositions and skills of inventiveness developed in home, community, and formal educational settings can then be carried forward, introduced, or further developed in universities (Balos et al., 2019; King et al., 2019; Moore et al., 2019). Unfortunately, few students have continuous pathways to inventing from early years through the university and beyond, but lasting effects of exposure to IvE and innovation can begin at any age and in any space, and can shape diverse youths' pathways into the future (Committee for the Study of Invention, 2004; Couch, Skukauskaite, & Green, 2019; Moore, Newton, Alemdar, & Holcomb, 2017; Root-Bernstein et al., 2019). Research has demonstrated that early exposure to STEM fields shapes the decisions and pathways of diverse students in higher education and beyond. Researchers have also argued that it is never too late to introduce students to opportunities to invent, and that providing opportunities to engage in invention and STEM at the university level can encourage historically underrepresented students to take up STEM and engineering pathways even if they have not had early exposure (Chang et al., 2014; Ong et al., 2018).



4

FACILITATING
AND TEACHING
INVENTION
EDUCATION

④ FACILITATING AND TEACHING INVENTION EDUCATION

Few studies are available to guide educators' efforts to help young people learn to invent, including but not limited to those from diverse backgrounds. Educators must navigate issues that have complex sociocultural and historical dimensions (Cook, 2019), which shape the ideas of those surrounding them regarding who can invent, with whom, under what conditions, and for what purposes. Although challenging, many educators are providing opportunities for young people to learn to work as inventors during their early years.

Researchers have begun, over the past few years, investigating what knowledge, support, and experiences teachers need to facilitate student engagement in invention. They identified that teachers need knowledge and experience in guiding students in open-ended, problem-based inquiry (Estabrooks & Couch, 2018; Maaia, 2019; Small, 2018), scaffolding instruction (Zhang et al., 2019), and integrating student backgrounds and home funds of knowledge (Kim et al., 2019; Wilson-Lopez et al., 2016) to make such inquiry possible for diverse students. Since IvE integrates knowledge and skills from varied disciplines, teachers also need to know how to utilize knowledge, people, and resources across disciplines and industries (King et al., 2019; Sokolowski, 2019) and how to integrate STEM and STEAM subjects (Balos et al., 2019; Maaia, 2019; National Academies of Sciences, Engineering, & Medicine, 2019). Assessing integrated instruction and open-ended inquiry that involves students participating in different ways and at different paces also calls for teacher experiences and knowledge of varied forms of formative and summative assessments and feedback (National Academies of Sciences, Engineering, & Medicine, 2019; Zhang et al., 2019).

Few studies are available to guide educators' efforts to help young people learn to invent, including but not limited to those from diverse backgrounds.

Researchers also demonstrated the importance of teaching research and inquiry skills to support students in the problem-finding and research phases of invention processes. Conducting studies of student engagement in invention within library settings, Small (2014) argued that invention is a highly information-based activity, requiring a range of inquiry skills and information resources that support youth invention activities. These capabilities and the navigation and evaluation of the varied information resources are critical to 21st-century skills learning, often taught by school librarians. In a study by Small (2014) that surveyed and interviewed 84 young inventors (Grades 4–8), researchers queried students about inquiry skills that the students perceived as being most important to their success as an inventor. The three most frequently chosen responses were “choosing the best idea” (90%), “asking good questions” (88%), and “finding needed information” (87%). Student reliance on websites (cited by 75% of respondents as valuable for sparking new ideas), checking the originality of their ideas, and/or exploring ways to make their ideas even better highlight the importance of educator capacity to teach students information-literacy skills. As Small (2014, 2018) argued, collaborating with librarians can help educators leverage their own and their colleagues' knowledge and skills to support students in the invention processes.

4. Facilitating and Teaching Invention Education

Collaboration with educators and others within and beyond the school is another resource teachers need to draw on to expand their own knowledge and to support student inventing. When working with students to invent technological solutions to real-world problems (Couch & Skukauskaite, 2019), teachers often need to have technical knowledge and skills such as CAD modeling, electronics, or mechanical engineering. This type of knowledge can be key to engaging students in conceptualizing, designing, building, and testing physical prototypes of solutions to the problems students had identified in their community (Balos et al., 2019; King et al., 2019). Knowledge and experience in innovation, entrepreneurship, invention, and design are also assets that invention educators with careers prior to teaching often bring to learning environments to support student inventiveness (Maaia, 2019; Moore et al., 2019; Moore, Newton, Alemdar, & Holcomb, 2017). Few teacher education programs prepare teachers for such instruction (National Academies of Sciences, Engineering, & Medicine, 2015; National Academy of Engineering & National Research Council, 2014); therefore, the key to teaching IvE is the teacher's willingness to learn and fail alongside students, to be comfortable not knowing all the answers, and to embrace ambiguities and uncertainty of the processes of invention (Estabrooks & Couch, 2018; Maaia, 2019; National Academies of Sciences, Engineering, & Medicine, 2019; Zhang et al., 2019).

Knowledge and experience in innovation, entrepreneurship, invention, and design are also assets that invention educators with careers prior to teaching often bring to learning environments to support student inventiveness

Teachers' Reasons for Engaging in Invention Education

Participating in invention and integrated, interdisciplinary, problem-based teaching of STEM requires teachers to change and embrace new, more uncertain ways of teaching and learning (Maaia, 2019; National Academies of Sciences, Engineering, & Medicine, 2015, 2019). The complexity of teaching IvE led researchers to investigate factors that motivate teachers to do it and factors that present teachers with challenges as they help students learn to invent. Research on IvE educators, including their reasons for taking up IvE and their self-efficacy and learning, is being developed within the IvE research community. Moore and colleagues (Moore et al., 2019), in surveys of teachers engaging students in the K–12 InVenture Prize program run by Georgia Tech University, found that participating teachers had high engineering and entrepreneurship self-efficacy scores, with the highest scores attributed to elementary teachers. Lemelson-MIT Program researchers discovered that 67% of the teachers who had submitted the initial application for the InvenTeams grant, and were selected to participate in a professional learning opportunity at MIT in June 2018, were second-career teachers (Couch & Skukauskaite, 2019; Skukauskaite, Couch, & Lemelson-MIT Program staff, 2018). This finding was unexpected and led the staff

Participating in invention and integrated, interdisciplinary, problem-based teaching of STEM requires teachers to change and embrace new, more uncertain ways of teaching and learning

of the Lemelson-MIT Program to conduct further research exploring what second-career teachers bring to their willingness and capacity to facilitate IvE in their high schools. Preliminary interview results indicate that second-career teachers bring real-world experiences and examples, varied support networks, and higher tolerance for risk-taking, not-knowing, and open-ended learning, among other dispositions and capabilities that help them facilitate IvE with their students.

Teacher motivations for facilitating IvE focus on their students and student learning (Moore, Newton, Alemdar & Holcomb, 2017; Skukauskaite et al., 2018; Zhang et al., 2019). Teachers appreciate the integration of knowledge acquisition and application through invention, reinforced learning of STEM concepts through multiple channels (hands-on and minds-on activities), enrichment of student understanding through real-world applications, and the excitement invention brings to classrooms (Zhang et al., 2019). They are motivated to share their knowledge and experiences (King et al., 2019; Sokolowski, 2019) and to help students develop knowledge, skills, and dispositions that can aid in the development of future innovators capable of addressing and solving real societal (Couch & Skukauskaite, 2019) and/or industry problems (Balos et al., 2019; King et al., 2019). Connecting with the community, university, and other partners (Calabrese Barton & Tan, 2018b; Moore, Newton, Alemdar, & Holcomb, 2017; Skukauskaite et al., 2018) to solve real societal and/or industry problems (Balos et al., 2019; King et al., 2019) also fosters teachers' interest in engaging their students in IvE. Teachers are driven by equity and social justice reasons and want to help diverse students develop capacities for—and envision pathways in—innovation, entrepreneurship, and STEM fields (Calabrese Barton & Tan, 2018b; King et al., 2019; Moore, Newton, Alemdar & Holcomb, 2017; Small, 2018; Sokolowski, 2019) that traditionally have been dominated by white male inventors (Milli et al., 2016; National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2011; Sanders & Ashcraft, 2019). Ultimately, teachers undertake IvE projects with their students because they enjoy the processes and learning opportunities created in invention learning environments (Couch & Skukauskaite, 2019; Zhang et al., 2019).

Challenges in Facilitating Invention Education

Creating environments for IvE comes with challenges that stem from three primary aspects of the nature of invention and its historical association with particular privileged groups, locations, and images of inventors as gifted individuals rather than as teams of regular people “pooling” diverse knowledge and skills. The first aspect, transdisciplinary nature of IvE, poses the challenges of boundary crossing (to connect diverse knowledge of science, arts, and social science disciplines) and engaging with groups of practitioners drawn from different disciplines. Second, the open-ended and collaborative inquiry process of invention creates challenges for teachers who are often trained to know, teach, and transmit knowledge in a singular discipline rather than guide and learn alongside students working in teams. The third involves the physical and environmental aspects of IvE and the need for space, physical and human resources, tools, and the technical and applied knowledge needed to develop technological solutions to real-world problems.

4. Facilitating and Teaching Invention Education

Teachers, especially those teaching at the secondary level, are often trained in single disciplines (National Academy of Engineering & National Research Council, 2014); therefore, the transdisciplinary nature of IvE creates a challenge for teachers to learn how to bridge disciplinary knowledge and help students connect and apply their prior learning in different fields. Zhang and colleagues (2019), in a case study that examined one teacher's experience in implementing a Junior Varsity (JV) InvenTeams curriculum developed for middle school grades by the Lemelson-MIT Program, noted the challenges the teacher faced with integration in a science classroom. Among the main challenges were the requirements to teach specific content within specific time frames and to address content standards while engaging students in activities that foster student creativity, engagement, and deeper learning.

A related challenge stemmed from the open-ended inquiry processes of IvE. While the teacher in Zhang et al.'s study talked about his enjoyment of inventing processes and the enthusiasm of his students as a driver for his continued commitment to foster IvE, he also highlighted the challenge of managing the dynamics of IvE learning processes. Balancing guiding students and teaching versus allowing for student freedom and open-ended exploration in inventing was not always comfortable. The teacher also talked about the challenge of understanding and addressing the ways students' prior experiences with more traditional curricula—in which students were in a more passive receiver role—impacted students' approaches to and engagement in more active IvE processes and practices (Zhang et al., 2019). Addressing the varied needs of diverse students and modifying curricula and teaching processes based on students' different learning needs, preferences, and processes; reading, writing, technical, and/or language abilities; pacing; and cultural backgrounds are additional challenges teachers face (Kim et al., 2019; Zhang et al., 2019).

Despite the challenges, the teacher in Zhang et al.'s study, as well as other invention educators and researchers (Estabrooks & Couch, 2018; Maaia, 2019; Magee et al., 2004; Moore et al., 2019), emphasize the importance of creating safe learning environments in which failure is seen as an opportunity for learning and where students own their invention processes and work at different paces, in different configurations of teams, over time to solve real-world problems. Teachers often share, in interviews and informal conversations (only some of which are captured as research data), that taking “a back seat” and letting students lead may be hard at first; however, seeing the ways students individually and collectively take up the invention learning opportunities and engage in deeper learning brings its own rewards to the teacher.

The third set of challenges invention educators face relates to the environmental factors, including human and physical resources, funding, administrative supports, and technical knowledge and tools needed to design, build, and test a prototype for a solution to a real-world problem (Couch et al., 2018). There is little research documenting these challenges or ways of addressing them. A number of researchers call for creating partnerships among schools, universities, industry partners and communities to leverage the resources and the knowledge needed for IvE (Balos et al., 2019; National Research Council, 2000; Sokolowski, 2019). Others advocate starting with the people who “have migrated to the edges and can act as bridges back to the core experts of a given domain” (McManus & MacDonald, 2019, p. 58). Such champions of IvE can help teachers, students, and

community resources interconnect to build the sustaining resources and communities for inventing. Other ways to overcome challenges in fostering IvE include integrating IvE within a school day, creating more STEM schools that engage girls and underrepresented minorities in STEM learning, and creating policies that support IvE in financial and other ways (Couch et al., 2018; Couch & Skukauskaite, 2019).

Scholars have argued that “it takes a village” to grow an inventor (Calabrese Barton & Tan, 2018b; Committee for the Study of Invention, 2004; Couch et al., 2018; King & Pringle, 2018; Lynch et al., 2018; McManus & MacDonald, 2019; Ong et al., 2018; Samuelson & Litzler, 2016; Schmidt, Rosenberg, & Beymer, 2018; Wilson-Lopez, Sias, Smithee, & Hasbún, 2018). Researchers within the IvE research community have identified the following kinds of actors who support diverse youth in invention processes and practices.

The “village” of IvE participants includes:

- Teachers/educators as guides (Maaia, 2019; Skukauskaite et al., 2018; Small, 2018; Zhang et al., 2019);
- Adult and peer mentors and members of the community (Calabrese Barton & Tan, 2018b; Couch et al., 2018; Small, 2018; Wagner, 2012);
- Industry mentors (Balos et al., 2019; King et al., 2019; Sokolowski, 2019);
- Technical mentors (Couch et al., 2018; Couch, Skukauskaite, & Estabrooks, 2019; King et al., 2019; Sokolowski, 2019);
- Business, entrepreneurship community (Flynn, 2016a; King et al., 2019; Sokolowski, 2019)
- IP lawyers (Demiralp et al., 2018; Sokolowski, 2019);
- University faculty or partners (Balos et al., 2019; King et al., 2019); and
- Program designers and supporters (see Table 1).

Drawing on the varied human, physical, and environmental resources, these varied actors can create and support IvE and diverse youths’ engagement in inventiveness. The next two sections of this WP make visible the efforts that are underway to create programs, assessments, people networks, and research evidence that can communicate to and impact policy making at state and national levels.



5

PROGRAMS AND
ASSESSMENTS
OF INVENTION
EDUCATION
PROGRAMS

5 PROGRAMS AND ASSESSMENTS OF INVENTION EDUCATION

Invention Education Programs

There is no one IVE model, nor one way of creating opportunities for people from the various ages and stages of development to grow their inventiveness, creativity, entrepreneurial talents, and success in STEM careers (Committee for the Study of Invention, 2004; Couch, Skukauskaite, & Green, 2019). Various programs found across the United States address and foster inventiveness. Programs in which members of the growing Invention Education Research community participate demonstrate initiatives that span a wide range of age groups and formal and informal learning contexts. Table 1 provides examples of programs by age or grade level, with brief descriptions of each program’s focus.

Table 1: Invention Education Programs by Age/Grade Level

Program	Location	Program Focus	Research on the Program
<i>Across age groups and grade spans (including educator training for leading invention or innovation projects)</i>			
InVenture prize	GA	From problem identification to prototyping, K–12 students develop inventions in small groups over the course of multiple months. Students iterate their designs based on feedback, and top inventions compete in a statewide competition at Georgia Tech	Moore et al. (2019)
STEM Innovator	National	Educator professional development facilitates creation of tailored community-engagement models to infuse innovation, invention and entrepreneurship into classroom practice. Access to curricular resources and online STEM Innovator assessment portfolio to measure change in skills, mindsets, and knowledge over time. Attributes mapped to workforce, college readiness skills, and national K–12 standards.	Flynn (2016a) www.steminnovator.org
Libraries as innovation spaces	National	Libraries that create innovative spaces may be learning commons, makerspaces, collaboration rooms, 3D printing stations, etc., and are generally designed to foster creative productivity through technology and collaboration.	Small (2018)

5. Programs and Assessments of Invention Education Programs

Program	Location	Program Focus	Research on the Program
Science fairs administered by the Society for Science and the Public	International	Society-affiliated fairs are competitions for 9th–12th graders that exist in most U. S. states as well as abroad. Winning an honor through a fair allows students to compete internationally.	https://findafair.societyforscience.org/
Invention Convention Worldwide powered by The Henry Ford	International	The Henry Ford Invention Convention Worldwide offers IVE programs for K–12 students globally. The Invention Convention program is deployed to more than 120,000 students across the United States and thousands more across eight countries. Invention Convention Worldwide is powered by a coalition of global affiliates who elevate STEMIE (STEM+Invention+Entrepreneurship) education through competitions, events, and a flexible, project-based curriculum aligned to education standards. The Invention Convention Coalition affiliates share a vision of a world in which all learners have access to innovation, invention, and entrepreneurial learning to gain the confidence and skills to control their own destiny. Invention Convention is part of The Henry Ford’s suite of Innovation Learning products.	http://inventionconvention.org/about/invention-convention-worldwide/ https://www.thehenryford.org/education/teaching-innovation/ https://www.theinnovationproject.org/
Elementary			
Engineering is Elementary	MA, PA, National	Engineering is Elementary is a project of the National Center for Technological Literacy at the Museum of Science, Boston. Their goal is to address effective STEM education by serving children and educators in Grades K–8 via curriculum development and dissemination, professional development for teachers and teacher educators, and educational research and evaluation.	Cunningham (2009, 2018); Engineering is Elementary (2011) https://eie.org/about-us
Middle School			
JV InvenTeams–Lemelson-MIT	National	Through the use of hands-on invention-based design activities, Lemelson-MIT’s JV InvenTeams enriches the STEM education of students in Grades 6–10.	Zhang et al. (2019) https://lemelson.mit.edu/jv-inventteams

5. Programs and Assessments of Invention Education Programs

Program	Location	Program Focus	Research on the Program
I-Engineering	MI, NC	Middle school engineering curriculum focused on engineering for sustainable communities and productive identity work.	Calabrese Barton & Tan (2019); Tan, Calabrese Barton & Benavides (2019) http://engineeriam.org/
High School			
InvenTeams—Lemelson-MIT	National	The Lemelson-MIT InvenTeams are groups of high school students, educators, and mentors that invent technological solutions to real-world problems of their own choosing. High School students are thusly given a unique opportunity to experience invention and cultivate creativity.	Couch, Skukauskaite & Estabrooks (2019); Lemelson-MIT Program (2019); Skukauskaite, Couch, Green, & Lemelson-MIT Program staff (2017) https://lemelson.mit.edu/inventeams
Maker problem-based learning	National	Community-based, collaborative learning environments that permit learners to explore and tinker while encouraging their creative growth have been associated with maker education. A maker-based STEM culture allows high schools to evolve activities that incorporate elements of the STEAM movement.	Calabrese Barton & Tan (2018a); Maaia (2019)
BizInnovator	National	Youth entrepreneurship curriculum that enables high school business and marketing educators to engage students in the entrepreneurial mindset as they explore the skills and mindsets necessary to launch a successful startup company.	Brown, Bowlus, & Siebert (2011) https://bizinnovator.com/
University and beyond			
Interdisciplinary, industry-specific curricula	CA	The convergence of various fields of study with large areas of industry transforms innovation by giving rise to interdisciplinary innovation programs with novel applications in industry, albeit stemming from an academic-based origin. Students in academic programs engage in solving real problems of the industry.	Sokolowski (2019)—sports design industry; King et al. (2019)—bio-medical engineering; Balos et al. (2019)—Navy engineering

5. Programs and Assessments of Invention Education Programs

Program	Location	Program Focus	Research on the Program
The United States Patent and Trademark Office (USPTO)	National	Information and support for patenting. USPTO promotes the progress of science by securing for inventors their products; the protection of new ideas and investments in innovation is paramount not just for the vitality of inventors, but the U.S. economy as well.	Hosler (2018)
American Association for the Advancement of Science—Lemelson Invention Ambassadors program	National	The AAAS-Lemelson Invention Ambassadors program showcases the work of contemporary figures and voices in invention that address the grand challenges facing humanity. One such example involves the gender gaps faced by women, especially in the case of invention; the AAAS-Lemelson Invention Ambassadors program focuses on the achievements of women inventors within their program in the hopes of inspiring others around the world to provide more opportunities for women to participate in solving global problems.	Comedy & Dougherty (2018) https://www.aaas.org/programs/invention-ambassadors
NSF I-Corps program	National	The National Science Foundation (NSF) I-Corps program accelerates societal benefits of NSF-funded research projects ready to move toward commercialization. This is accomplished by preparing scientists and engineers to extend their focus beyond the university laboratory and learn to identify valuable product opportunities that can emerge from academic research, while gaining skills in entrepreneurship.	Nnakwe, Cooch, & Huang-Saad (2018)

The sampling of programs in Table 1 makes visible the broad range of initiatives available for people of all ages to engage in IVE. Invention education programs differ in their focus, population served, and emphasis, but most of them include the following elements:

- A problem-finding or defining stage;
- A real-world problem arising from the needs of others;
- Teamwork and collaboration within and beyond the team;
- Mentors and others from the larger community beyond the school or classroom;

- Iterative and recursive learning and design cycles;
- Open-ended inquiry to solve real-world problems;
- Embracing learning from failure and uncertainty;
- Milestones along the way;
- Prototyping and creating a potential solution to the real-world problem;
- Considerations of Intellectual Property and Patenting or marketability processes and practices; and
- Educators as guides, mentors, or coaches who learn alongside students.

Researchers have argued that early and sustaining exposure to invention, STEM, arts, and medicine-related (STEAMM) experiences have the most lasting impact on young people’s trajectories and careers in invention and related fields (Bell et al., 2018; Committee for the Study of Invention, 2004; Root-Bernstein et al., 2019); however, engagement in IvE at any age and in any type of program can also impact one’s interests, college and career pathways, and, more generally, can awaken one’s creativity, “can-do attitude,” and self-confidence in problem solving as well as empathy and understanding of the social world through a problem-seeking and problem-solving lens (Couch, Estabrooks, & Skukauskaite, 2018; Moore, Newton, Alemdar, & Holcomb, 2017; Perez-Breva, 2016; Root-Bernstein & Root-Bernstein, 1999).

Assessing IvE Impacts

We have found little research to date that addresses ways of assessing the impacts of IvE programs. Most of the assessment models available in the literature are program specific. For example, in describing the Biomedical Engineering-focused invention program at the University of California, Irvine, King and colleagues (King et al., 2019) assess student success based on student surveys and evaluation of students’ attainment of stated course objectives. Program success is also measured by collecting records about the number of new technologies and/or intellectual property licenses generated and the number of start-up companies created.

Another example of IvE impact assessment is the Lemelson-MIT Program’s efforts to collect multiple forms of data to understand the complexities of IvE processes and outcomes. The successes of the Lemelson-MIT InvenTeams initiative are assessed through student end-of-year experience surveys and teacher surveys. Recently, outside researchers collaborated with the program staff to document and understand the processes and impacts of the program from multiple points of view, including program and observation records, teacher and student interviews, conversations, and surveys, as well as linking of the multiple datasets (Couch et al., 2018; Couch, Skukauskaite, & Estabrooks, in press). In 2019, the Lemelson-MIT Program piloted a student historian role in two teams, enabling high school students to become co-researchers (Skukauskaite, Estabrooks, Morales Rodriguez, & Hull, 2019) and to generate video, audio, and documentary data that allows both the insiders on the InvenTeam and outside researchers to examine and present the multilayered ecosystem of IvE in high schools.

5. Programs and Assessments of Invention Education Programs

A third example is the longitudinal, multifaceted approach to middle and high school students' attainment, demonstration, and assessment of invention, innovation, and entrepreneurship skills, mindsets, and knowledge competencies that has been developed by the STEM Innovator program at the University of Iowa. The STEM Innovator Portfolio tool was created and piloted over 2 years by leveraging the multidisciplinary expertise of over 50 state and national leaders across multiple disciplines. For this assessment, students create portfolios to document individual and team competencies across time, from one semester to several years, as they create solutions to problems of interest to them and their community. Students receive peer, self, educator, and community partner feedback through an online STEM Innovator portal a minimum of three times across the innovation process as they develop a prototype solution. Students reflect on the feedback reports and propose next steps with their peers, community partner, and educators to keep moving forward. The portfolio includes six components collected a minimum of three times across the course of prototype development and assessing specific aspects of the invention/innovation learning process. The six components are: Innovator Profile (assesses skills, mindset, knowledge), Community Pitch (team management and progress, communication skills, value propositions, research and development), STEM Innovator Canvas (start-up innovation process, team and individual progress), Team Value Rubric (individuals' contributions to team advancement), Videography (capture innovation process, prototype, and team progress), and STEM Innovator Proficiency Exam (knowledge and practices innovation and entrepreneurship). Students have an option to submit the STEM Innovator Portfolio to the University of Iowa to be reviewed by industry experts to gain STEM Innovator certification. The portfolio may be used to demonstrate innovation competencies for job interviews, scholarship applications, or post-secondary admission. Students may earn STEM Innovation college credit from The University of Iowa (a Research-1 university), which is transferable to most colleges across the United States.

Multiple forms of assessment are also used to evaluate the impacts of the InVenture prize competition and professional development for teachers. Moore and colleagues, in their 2019 paper, reported results based on a teacher survey that included teaching engineering and entrepreneurship self-efficacy scales as well as a scale that measured teacher motivation. The team's previous work also explored student experiences in the program and they presented results at the 2015 and 2018 American Society for Engineering Education conferences.

The published work on IvE programs makes visible that each of the programs utilizes a variety of data sources at multiple points in time to document the impact of the program to its various participants. Given that each IvE program is unique, no one assessment model can be utilized for all programs. However, the complex over-time portfolio assessment of the STEM Innovator program could potentially become a guide for other IvE program assessments. Efforts by the Lemelson-MIT Program (Couch et al., in press; Skukauskaite et al., 2017; Skukauskaite et al., 2018), a Navy Workforce program led by researchers at the University of California, Santa Barbara (Balos et al., 2019), and the InVenture Prize (Moore et al., 2019) program in which program staff collaborate with external researchers offer another approach to evaluation research. All three examples integrate program evaluation and academic research in ways that address the needs of the program and lead to publications that address the needs of the larger academic community.



**THEORIES AND
METHODOLOGIES
USED TO STUDY
INVENTION
EDUCATION**

6 THEORIES AND METHODOLOGIES USED TO STUDY INVENTION EDUCATION

Research in IvE draws on a broad range of theoretical and methodological frameworks. Table 2 provides an overview of theories utilized in the work of researchers within our IvE community. Table 3 lists methodologies used, and both tables include a sampling of the authors using those theories and methodologies. An in-depth explanation of these theories and methodologies is beyond the scope of this WP and readers may refer to the work cited or may reach out to the authors for further exploration of ways of conceptualizing and studying IvE.

Table 2: Theories Used to Study Invention Education

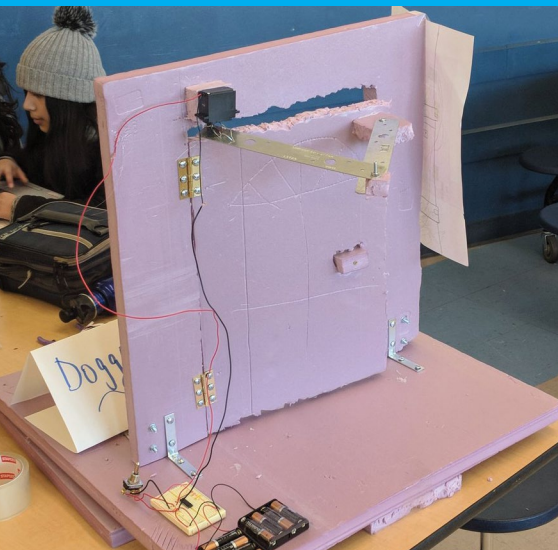
THEORIES UTILIZED	Examples of authors using/citing the theories
Constructivist theories	Maaia; Moore et al.; Flynn
Sociocultural theories of learning	Maaia; Balos et al.; Couch, Skukauskaite & Estabrooks
Social construction of identities	Couch, Skukauskaite & Estabrooks
Culturally and linguistically responsive teaching theories	Kim et al.; Calabrese Barton, & Tan
Motivational and engagement theories	Small
Guskey’s model of teacher change	Zhang et al.
Problem-based learning	Maaia; Balos et al.; Estabrooks & Couch; Flynn

Table 3. Methodologies Utilized in the Study of IvE

METHODOLOGIES UTILIZED	Examples of authors using/citing the theories
Interactional ethnography	Couch et al.; Balos et al.; Maaia
Sociolinguistic discourse analysis	Couch et al.; Maaia; Balos et al.
Case studies	Zhang et al.; Kim et al.
Survey designs	Moore et al.; King et al.; Sokolowski; Flynn; Jackson & Semerjian
Multi-method designs	Moore et al.; Couch et al.; Flynn

6. Theories and Methodologies Used to Study Invention Education

METHODOLOGIES UTILIZED	Examples of authors using/citing the theories
Critical longitudinal ethnography	Calabrese Barton & Tan
Participatory approaches—YPAR, community-engaged research partnerships	Calabrese Barton & Tan
Design-based research	Jackson & Asante
Econometrics	Cook; Bell et al.



**POLICY IMPLICATIONS:
SUGGESTIONS FROM
TESTIMONIES AT USPTO
ON THE SUCCESS ACT**

7 POLICY IMPLICATIONS: SUGGESTIONS FROM TESTIMONIES AT USPTO ON THE SUCCESS ACT

Many people and groups working in IvE embrace the notion that all people can learn to invent if they are afforded access to learning opportunities that demystify the work of inventors (Wisnioski, 2019) and provide support as the newcomer learns to invent. The efforts to date to teach young people how to invent, reviewed in part in this WP, are promising but do not yet reach large percentages of students in the United States. Numerous challenges remain that have hindered efforts to grow and scale IvE offerings. This paper has examined many of the challenges, including the need for students to be taught how to integrate and apply knowledge from different disciplines to problem finding and problem solving. At present, the vast majority of schools are providing instruction that focuses on learning within individual disciplines.

all people can learn to invent if they are afforded access to learning opportunities and provide support as the newcomer learns to invent.

Other challenges and potential policy solutions are captured in testimonies given during public hearings conducted by the United States Patent and Trademark Office (USPTO) in accordance with federal legislation known as the Study of Underrepresented Classes Chasing Engineering and Science Success (SUCCESS) Act of 2018 (Public Law 115-273 of the 115th Congress). Testimonies submitted by Drs. Michael Cima and Stephanie Couch of MIT (June 2019), Mr. Danny Briere from The Henry Ford and Invention Convention Worldwide (June 2019), and Dr. Leslie Flynn from the University of Iowa (May 2019) are summarized in this section of the WP to make visible how members of the larger IvE research community can utilize research on their own programs to construct arguments for policy change at the national level.

Policy Testimonies Grounded in Lemelson-MIT InvenTeams Research as a Telling Case for Understanding Opportunities, Challenges, and Needs for Policy Change

MIT Professor Michael Cima, a prolific inventor, Associate Dean of Innovation in the School of Engineering, and the Co-Director of MIT's Innovation Initiative, and Dr. Stephanie Couch, Executive Director of the Lemelson-MIT Program, provided written and oral testimony. They argued that young people need access to a wide range of learning opportunities that develop their capabilities for engaging and coming to understand the needs of others (empathy); finding and defining problems; finding and/or generating information/data and analyzing it to inform understandings and to engage in hands-on activities in which they design, build, and experiment with different technologies, reflecting on creations; and persisting through iterative cycles of activity. This open-ended playful learning “strand” needs to come alongside the thoughtfully designed linear progression models for individual academic disciplines that are found in today's K-12 schools (Cima & Couch, 2019).

Drs. Cima and Couch argued that it is especially important that students in Grades 10–12 have opportunities to work in teams to apply their knowledge and skills to an open-ended invention project. Ways of starting a business or taking the working prototype forward after graduation (entrepreneurship education) need to be infused within this type of learning experience or capstone course.

especially important that students in Grades 10–12 have opportunities to work in teams to apply their knowledge and skills to an open-ended invention project

In their testimony to the USPTO, Cima and Couch wrote:

elements of these types of opportunities that we refer to as “invention education” can be found in maker education, computer science and coding, entrepreneurship education, invention education, hackathons, and open-ended inquiry-based problem solving or project-based learning activities. Individual constituency groups advocate for learning opportunities in each of these areas. Each word has a distinctive meaning, but all are synergistic and can co-exist within a single school. We are all calling for something similar, but don’t yet have a common language; as philosopher Richard Rorty (1967/1992) said, “It is difficult to say the new in the language of the old.”

They also argued:

The opportunities described above need to be offered as part of the school day so that they are universally available to all students. The learning opportunity should be designed in a manner that aligns with college entrance requirements to help motivate students to complete the course. (Cima & Couch, 2019)

Cima and Couch’s testimony before the USPTO called for “new systems for recruiting, preparing, and supporting educators to lead these types of efforts, with support from others in the surrounding STEM ecosystem. The new systems must be created and sustained through public financing.” They stated that educators need to be taught how to help students learn through open-ended problem finding and problem solving in ways that include using technologies to design and build new and novel technological solutions. Few teacher preparation programs, especially at the secondary level, focus on transdisciplinary teaching. (2019)

They also cited research showing that educators with a career prior to teaching are drawn to facilitating invention projects. Credentialing laws and certain pension rules make it hard to attract such individuals into teaching. All teachers, regardless of the knowledge that they bring to teaching, must have support from people with a wide range of expertise to address team needs. The staffing costs of organizing and managing the ecosystem of support must be financed.

Cima and Couch further emphasized the need for resources to support IvE for all. They stated:

Educators should be provided with resources to assist with the design and implementation of invention education offerings including the spaces needed to design and build, materials and equipment, online resources, and time within an already tight school schedule. (2019)

This portion of the testimony was consistent with findings by Couch, Estabrooks, and Skukauskaite (2018). Their study of factors affecting young women’s development as inventors uncovered evidence of the importance of environments and places for learning. The study highlights the rich and varied 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 InvenTeams work suggested 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 United States.

The study suggested that after-school programs may also foster the development of young women as inventors (Couch et al., 2018). However, a multi-year after-school program may be needed not only to help young women 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 IvE 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.

Another group of factors uncovered in Couch, Estabrooks, and Skukauskaite’s 2018 study related to other resources, including online resources and prior experiences. As the participants from the after-school InvenTeams 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 (Couch et al., 2018). 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 curricula, 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.

Given that different places and environments can support women’s development as inventors, policymakers should consider IvE policies for both in-school and after-school programs

Couch, Estabrooks, and Skukauskaite (2018) argued that an additional resource that is often taken for granted, but needs to be considered in making policies about STEM and IvE, is time. Time constraints identified by the study participants could have been mitigated by policies surrounding the school day. The young women described their challenges to find time in the week to work on their InvenTeams projects; this suggests that competing demands to participate in multiple projects may need to be adjusted in order to enable young

7. Policy Implications: Suggestions From Testimonies at USPTO on the Success Act

inventors to focus on one project at a time, thereby deepening the engagement and fostering the development of a working prototype that can serve the community.

Cima and Couch's testimony to USPTO (2019) also called for support in creating and sustaining networks of people and communities invested in IVE.

They argued:

Students and teachers need to be guided in their problem solving, prototyping, and efforts to bring products to market by faculty and graduate students in colleges and universities, industry mentors, and community informants. Inventing is a team sport, with requirements for training opportunities, thought partners, and assistance with commercializing new technologies (Hintz, 2019). In many geographic regions across the United States, individuals with the requisite knowledge and skills are in limited supply (Feldman, 2019).

This part of the testimony aligned with the study by Couch, Estabrooks, and Skukauskaitė (2018) in which they describe a range of policies and practices needed to increase the number of female patent holders. Couch et al. urged educational program designers to consider the value of teamwork, public critique, guidance by knowledgeable educators and STEM professionals, and parent support. This recommendation stemmed from findings that the students' engagement and experiences were enhanced by their work with teachers and peers in teams. They noted that a team-based approach to inventing aligns with findings that teamwork is critical to inventors (McManus & MacDonald, 2019). 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 suggest that opportunities to present and receive feedback on their invention project as it unfolds would also be an important component of an invention-focused education policy initiative.

The supportive role of parents mentioned by study participants suggested that policies should also have a parent education and outreach component. The parent component should communicate that 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.

Cima and Couch noted in their testimony to the USPTO that

experiences in working with young people across the nation have taught us that K-12 schools, colleges and universities, and local communities must work together in new ways if we are to bring about the conditions that nurture and tap into the knowledge and ideas of those not represented by today's patent system. We [referring to the Lemelson-MIT

Program, which they operate at MIT] have been able to do the work that is necessary, thanks to private funding from a family foundation. Scaling-up the process and practices we have found effective will require new laws and funding for joint efforts between K-12 schools, colleges and universities, local governments, and STEM professionals. Laws, regulations, and finance mechanisms perpetuated by the state and federal governments and agencies must change if we are to provide the learning opportunities young people need to learn to invent. (2019)

Cima and Couch went on to call for federal investment in a handful of centers that, with support from colleges and universities and private-sector partners in patent-intensive technological fields, could foster robust environments to expand on InvenTeams and other successful IVE models and research approaches that would be scalable and sustainable across the United States.

Questions issued by the USPTO in advance of their hearing asked whether there are policies, programs, or other targeted activities shown to be effective at recruiting and retaining women, minorities, and veterans in innovative and entrepreneurial activities.

In their testimony, Cima and Couch reported:

The 2004 report by the Committee for Study of Invention spawned the national grants initiative for high school students and teachers, known as InvenTeams. The InvenTeams national grants initiative has been funded by the Lemelson Foundation for 15 years, and has been allowed to evolve as needed without interference. The past 15 years have seen 243 teams of high school students, teachers, and mentors produce a working prototype of a technological solution to a problem that students have identified in their communities. Eight teams have received patents for their work, and many more applications are pending.

The InvenTeams model is designed so that students' inventions emerge from problems that the students themselves have defined and are passionate about solving. The problems are not given to students, and students are not artificially constrained to study a particular science concept or set of practices called for by national education standards. The composition of the teams (typically 10-15 students per team) is diverse by design. Demographics for the teams over the past eleven years for which data is available show that 35% of team participants have been females. (See Table 4; Cima & Couch, 2019)

Table 4: Gender of InvenTeams Participants for Years 2007-2018

GENDER	# STUDENT PARTICIPANTS	% OF ALL PARTICIPANTS
Male	1,794	65%
Female	956	35%

Note. Data sourced from InvenTeams rosters.

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Cima and Couch also noted that, from year to year, the percentage of InvenTeams students from underrepresented backgrounds varies. The variation in percentages of underrepresented backgrounds among InvenTeams participants is shown in Table 5 for the years 2016–2018.

Table 5: Percentage of InvenTeams Students From Underrepresented Backgrounds for Years 2016–2018

YEAR	% UNDERREPRESENTED
2018	29%
2017	44%
2016	21%

Note. Data sourced from InvenTeams end-of-year surveys.

Couch and colleagues have engaged in research studies through the past three years (Couch et al., 2018; Couch, Skukauskaite, & Estabrooks, 2019, in press; Estabrooks & Couch, 2018) to document the InvenTeams model and to determine the impact of this type of learning opportunity. The researchers assert that they have uncovered evidence of significant benefits for students, especially for young women and students from underrepresented backgrounds. According to the researchers, the InvenTeams approach contributes to STEM interest and identity, and develops confidence in those who may not otherwise be interested in pursuing STEM college and career pathways.

Couch elaborated on this point in her public testimony before the USPTO:

We think that the opportunity for young people to learn to invent is especially helpful if it is in a team-based format with differentiated roles. A lot of times, the young women who come to these teams come because they're going to be the team leader, they're going to be the communications person, the project manager, and along the way, they discover their skills and capabilities in the STEM areas, and at the end of this year-long experience that they have, we can see that their interest, their confidence, their desire to persist in STEM college and career pathways falls out from that team-based experience. (Public Hearing, Cima & Couch, 2019)

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The linkages made between STEM and what participating students care about in their daily lives offer a reason for students to struggle with STEM. Working in teams of mixed abilities allows each student to make a meaningful contribution, regardless of the prior STEM knowledge and experience he or she brings to the team. Interactions with adults reinforce students' commitment to see their project through to completion and to persist through the challenges they encounter. Many students who were previously uninterested in STEM have gone on

to pursue STEM college/career paths.

Findings from the studies of InvenTeams document the potential for increasing STEM interest and engagement by offering students opportunities to engage in transdisciplinary, non-linear, open-ended problem-solving processes. Findings align with other studies cited in national consensus reports issued by the National Academy of Engineering and the National Research Council (National Academies of Sciences, 2018; National Academy of Engineering & National Research Council, 2014), as well as with recommendations in the report *Charting a Course for Success: America's Strategy for STEM Education*, issued by the National Science and Technology Council's Committee on STEM Education (2018).

Question 11 of the USPTO hearing also asked if there are policies or programs that have proven to be ineffective at recruiting and retaining women, minorities, and veterans in innovative and entrepreneurial activities. Cima and Couch noted that, despite their insights into what can work and the consistency of the MIT team's findings with those of others, barriers to implementation remain. Federal education standards in K-12 continue to emphasize instruction that maintains disciplinary silos. School finance mechanisms, K-12 accountability standards, and college entrance requirements reinforce the siloed, linear approach to teaching and learning found in today's schools. These barriers to change create conditions in which we leave it up to those who are least capable—the students themselves—to figure out how to integrate and apply knowledge and ways of thinking from different disciplines to complex real-world challenges. The exceptional work of InvenTeams students shows what can happen when students have access to coaching and guidance from adults (teachers and technical mentors) who have been trained to support their work, as well as other support structures (Hintz, 2019; Lenoir, 1997) such as those offered by Lemelson-MIT Program staff (Cima & Couch, 2019).

Testimony From The Henry Ford as a Telling Case for Intellectual Property Protection in Invention Education Programs

In his testimony on the SUCCESS Act at a June 2019 hearing of the USPTO, Mr. Danny Briere, Chief Entrepreneur Officer of The Henry Ford and Global Director of Invention Convention Worldwide, indicated that more than 120,000 students across the United States participated in the museum's IVE offerings in 2019 (Public Hearing, Briere, 2019). Most of these inventions, he noted, are not protected by patent applications. He reported that some student inventions are “indeed patentable and even ready for market” (or to be commercialized; p.21). Students display logbooks about how their inventions were created and prototyped, with poster boards and pitches explaining the details. Students, therefore, incur a public disclosure risk relative to their inventions. Briere noted that this is true of every “science fair, invention convention, STEM expo, and pitch competition,” as well as other public events in local

think about American competitiveness on the global stage” by considering “the example of Korea, where all K through 12 students are required to have Invention Education before they graduate high school

schools and other venues across America (p. 20). He argued that educators need to protect these students' inventions sooner through the filing of a provisional patent application, and said that many students and their schools or low-income families are not able to pay the \$70 fee required to file a provisional patent, suggesting that the USPTO create an accessible provisional patent process. The current provision for any applicant who is 65 years of age or more to advance the timeframes for the examination of the application constitutes a precedent for treating filers differently based on age, he contended.

Mr. Briere also urged the USPTO to “think about American competitiveness on the global stage” by considering “the example of Korea, where all K through 12 students are required to have Invention Education before they graduate high school” (p. 26). A number of other nations with IVE programs for youth could be added to this list.

Testimony From the University of Iowa’s STEM Innovator Research Team as a Telling Case to Illustrate the Impact of Invention Education on Providing Opportunity to Underrepresented Youth

Dr. Leslie Flynn, professor of innovation and entrepreneurship in the Jacobson Institute at the University of Iowa’s STEM Innovator program, in her May 2019 USPTO SUCCESS Act public testimony, affirmed the importance of access to innovation, invention, and entrepreneurial thinking for all K-12 students.

She stated:

It is a national imperative that all young adults be provided an education that invites them to the innovation table. In order for the United States to progress as a nation, we need a larger pool of citizens engaged in technological advances to fill high-skill jobs. We need to begin workforce development before students leave our K-12 education system. Students in middle school and high school are already making decisions about their ability and interest to pursue degrees in STEM and their position in our U.S. workforce.

Dr. Flynn elaborated that the current education and workplace environment is not providing equal opportunity for all:

As evidenced by recent STEM work force and patent data Undersecretary Peter highlighted this morning, women and other groups are not pursuing opportunities in comparison to their male, white counterparts. The current educational system does not distribute opportunities equally to all K-12 students and, by extension, to all U.S. citizens. (Public Hearing, Flynn, 2019)

In 2013, in collaboration with over 50 industry experts, STEM Innovator was created: an innovation platform to engage middle and high school

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student teams in designing solutions to complex problems while working with business and industry partners. Currently, the program is in 38 U.S. states and serves approximately 45,000 students annually. Students engage in a start-up methodology that takes them from idea generation to possible commercialization. Students engage in authentic practices of innovation, including rapid prototyping, data-driven decision making, agile and lean methodologies, design thinking, collaborative teaming, computational thinking, and utilization of digital platforms for research and development.

Students gain access and exposure to many careers they didn't know exist through multiple interactions with industry experts. Through the experience, students demonstrate a variety of skills, mindsets, and knowledge we seek in post-secondary students and a highly skilled workforce. The goal is to transform the student experience from sit-and-get to generate-and-create. Our current education system does not engage all students in these experiences and therefore is not preparing them for the future.

Dr. Flynn used evidence from a three-year longitudinal study of high school students engaged in the STEM Innovator program to argue that engaging in continuous and authentic invention and entrepreneurship experiences with community partners has a positive impact on student outcomes, especially those underrepresented in STEM.

The STEM Innovator Portfolio, a digital educational technology tool, was used to collect data and artifacts from multiple sources—including virtual community partners—across the student's educational experience. This allowed outcomes to be captured over years. Because the STEM Innovator platform is infused in the student's normal school day and mostly in required classes, all demographic data match those of the communities studied. The population of 2,000 high school students studied identifies as 48% female and 49% male. Thirty-two percent of participants identify as a racial minority and geographically, an equal number of participants are drawn from rural, urban, and suburban areas.

Dr. Flynn explained that the study demonstrated how “the skills and mindsets of innovators, inventors, and entrepreneurs—grit, adaptability, creativity, risk-taking, collaboration, idea generation, critical thinking, and communication—are significantly increasing across time, and students are able to identify why the change is occurring.”

Dr. Flynn presented key findings from the research on engagement among women and underrepresented groups in the innovation, invention, and entrepreneurial ecosystem.

These include:

Finding 1. We know the list of skills, mindsets, and knowledge needed to engage in the innovation and entrepreneurial process. These were identified by industry leaders and benchmarked versus additional national research and federal workforce documents. Examples of these mindsets and skills include risk-taking, adaptability, resilience, initiative, empathy, collaboration, creativity, critical thinking, data-driven decision making, science and engineering practices, and digital fluency.

Finding 2. The STEM Innovator digital platform allows students to identify and reflect on how and why these attributes are changing over time as a result of engagement in the innovation process. Results indicated all high school students significantly increase their innovation and entrepreneurial skills and mindsets. Students provide evidence of what experiences influence their growth; for example, Emily from an East Coast public school states, “I know I don’t have to be a perfectionist. Failing is important and critical. That is what my industry partner taught me, and I believe him.”

Finding 3. When the data is disaggregated by gender, we see significant growth at the same rate for females as for their male counterparts [$p < 0.05$]. There is no difference between males and females. This data provides evidence that young adult women are as capable as male peers to attain and demonstrate competencies in innovation and entrepreneurial skills and mindsets.

Finding 4. When the data is disaggregated by race, students of white, non-Hispanic background and all other underrepresented groups all significantly increase their skills and mindsets, and do so at the same rate [$p < 0.05$]. There is no achievement gap. Again, our white non-Hispanic students and all other races can equally engage in the innovation process and demonstrate these skills when provided the opportunity. (Public Hearing, Flynn, 2019)

Key action items the administration can take to facilitate engagement among women and underrepresented groups in the innovation, invention, and entrepreneurial ecosystem include:

1. Young adults, especially women and underrepresented groups, need to be able to engage in the innovation and entrepreneurial process while still in our K–12 education system so they persist and identify as inventors.
2. To accomplish integration in school, legislation and public policy need to support integration of innovation into all K–12 schools.
3. Research and development funds through interagency government sources need to catalyze development of curriculum, instruction, and assessment in K–12.
4. Call to Action for private-public partnerships needs to occur to invite business and industry partners into the K–12 arena. This includes financial support and employee mentorship of K–12 student teams.
5. In-service teachers need to be provided access to professional development on how to catalyze innovation schools.
6. Teachers identified their ability and capacity to teach the innovation skills and mindsets to their students before engaging in the STEM Innovator professional development program. Although they identify having some of the skills and attributes like resilience, they have no idea how to facilitate these into

their practice. They also indicate they have no capacity to lead teams in bringing an idea [solution] to sustainability and how to work with industry partners. (Public Hearing, Flynn, 2019)

In her written testimony, Flynn provided additional detail on the research findings, implementation strategies, and policy considerations to include more students in the innovation process. Including invention opportunities in the school day is currently a challenge due to lack of educator training.

Our work with educators across the country makes it clear they have no formal training and limited knowledge on how to facilitate invention in their schools. It is imperative to provide in-service professional development and pre-service training. Professional organizations such as NSTA, ACTE, and NCTM need to provide more platforms for this work to advance the conversation and to provide more access for educators. (Flynn, 2019)

U.S. businesses state the next generation of workers must be highly skilled and possess the mindsets to engage in an increasingly complex global market; they need workforce-ready innovators. To accomplish this, industry must make a substantial commitment to engage with K–12 schools in meaningful, authentic, and long-term relationships.

U.S. businesses state the next generation of workers must be highly skilled and possess the mindsets to engage in an increasingly complex global market; they need workforce-ready innovators.

Past engagement strategies—where employees talk to a class about their work, put on a demo show, or provide a tour to a small group of students—are not effective, and only reach a small number of students, mostly those from well-resourced schools where the employees’ children attend school. (Flynn, 2019)

Dr. Flynn highlighted the Iowa Governor’s STEM Council (<https://www.iowastem.gov>) as a model for other states to explore when creating state education policy. Bipartisan legislative support has increased public-private partnerships to fund teacher professional development (Real World Externships, STEM Scale-Up), community partnerships (STEM BEST), incubator capital (Innovation Fund), and networking centers to share resources (STEM Regional Hubs).

Flynn said:

We need multiple opportunities for educators to engage with industry to build and enact public-private partnerships in schools, many educators need a couple years before they feel confident and empowered to do so, and the STEM Council’s programs make the process more effective and allow multiple engagement opportunities. (2019)

Many of the recommendations outlined by Dr. Flynn signal a need for greater federal investment in IvE. Existing federally funded grant programs, such as the National Science Foundation’s I-Corps program, have helped expand learning opportunities focused on innovation and entrepreneurship at the post-secondary level, but regulations are not written in ways that support open-ended team-based invention projects for K–12. New

7. Policy Implications: Suggestions From Testimonies at USPTO on the Success Act

federal program initiatives could be launched to support the growth and expansion of IvE efforts (Arkilic, 2019; Fasihuddin & Britos Cavagnaru, 2019) in ways that address the identified needs. Federal investment in invention is likely to yield benefits that meet or exceed outcomes from federal investment in science and technology—investments that have helped the United States maintain its national leadership role in science, military endeavors, and as an economic engine (Gustetic, 2019).

Securing federal investment in IvE will require champions who will focus on policy changes in education that address the needs we have identified. The bipartisan Congressional Inventions Caucus, formed in 2015 to educate members of Congress and their legislative staffs about invention, intellectual property, commercialization, and other aspects of this vital segment of our economy, is an example of a legislative body that could (and should) focus on the requisite changes needed in the ways schools and universities are funded and held accountable for particular outcomes.



GAPS IN
INVENTION
EDUCATION
RESEARCH

8 GAPS IN INVENTION EDUCATION RESEARCH

The authors and contributors to this WP recognized the need to bring together the body of research that surrounds the newly emerging field of IvE. The group also acknowledges that the existing research has raised many questions that warrant further study. Nine topics in need of further research are described below.

1) Pre-K to Career Pathways to Invention and Entrepreneurship

The WP presents evidence of the importance of children's exposure to and engagement with IvE from the early years, including Pre-K and elementary school. Longitudinal research is needed to track the learning, progress, and pathways of youth involved in IvE programs in order to assess the impacts of exposure to IvE across time and events. Additional findings surrounding the pathways, supports, constraints, and ways of helping young inventors overcome obstacles would help with the development of programs and adaptation of curricula in ways that reflect research-based practices.

2) Contributions of Competitions and Prize Programs to Inventors' Development

More work is needed to understand the role of competitions and prize programs in supporting young inventors' development. The Lemelson-MIT Program's national student prize(s) for collegiate inventors, the Regeneron Science Talent Search, The Henry Ford National Invention Convention, and the Jacobson Institute's Innovator Competition offer potential sites of study.

3) Community Engagement and Invention Education

Research is emerging to indicate the benefits of community partnerships in facilitating students' work and development as inventors. Further studies are needed to inform understandings of the ways teachers and students find and utilize resources in local communities and how the communities interact with the students and educators. Research is also needed to explore the impacts school-community connections around invention education have on the community (i.e., formation and development of the IvE ecosystem), including perspectives of community members who actively engage with the students. In addition, few studies have focused on the beneficiaries of students' inventions.

4) Transdisciplinary Nature of IvE

This WP argues that IvE is transdisciplinary. Future studies could build on what is known to develop a deeper understanding of IvE's transdisciplinary nature. Further studies are needed to make visible the particular

8. Gaps in Invention Education Research

disciplines IvE draws on, when, where, in what ways, for what purposes, and with what learning outcomes both during the program and over time, as students move on to other grades, programs, or educational pathways.

Related to examining the transdisciplinary nature of IvE is the need to understand which disciplines and which aspects of the various disciplines inform IvE practices and are taught and learned in IvE. The developing field of discipline-based STEM education research (Henderson et al., 2017) emphasizes the need for discipline-specific content knowledge, and IvE researchers will need to demonstrate which disciplinary knowledge and practices can (and cannot) be developed and in what ways through the IvE programs. IvE researchers may need to expand collaborations with discipline-based scholars to demonstrate how IvE intersects with varied disciplines and fields, including various subjects in science, technology and computer sciences, engineering, mathematics, arts, medicine, business, humanities, and others.

5) Comparisons of IvE with Other Areas of Focus in Education

Further research is needed to determine how IvE processes, practices, and intended outcomes align with those in other areas with organized constituency groups in education, especially those that promote problem-focused learning and/or community engagement in the development of solutions to real problems identified in communities. Future work, for example, could examine the intersections of IvE with problem-based, project-based, and inquiry-based learning approaches to teaching and learning. Studies could examine the relationship of IvE with the pedagogical practices found in makerspaces and other informal education settings. The potentials of IvE for service learning could also be examined.

6) Research Methodologies and Methods of Assessment

Ways of studying and assessing open-ended, inquiry-based invention efforts that involve teaching and learning multiple subjects simultaneously remains a challenge in K–12 and in higher education. Additional research is needed to inform assessments for team-based efforts as well as those undertaken by individuals. IvE researchers, in addition to studying varied aspects of IvE and its potential for students, educators, and communities, need to start creating methodologically focused literature—such as handbooks, articles, and books—to make visible ways of understanding and assessing IvE and its impacts. An emerging field such as IvE draws on a variety of epistemological and methodological approaches to study IvE processes, practices, and impacts. Outlining the varied ways of studying the field could be helpful for new researchers entering the field and could also help others within the field explore how particular epistemologies and associated methodologies impact which aspects we study and in what ways.

Ways of studying and assessing open-ended, inquiry-based invention efforts that involve teaching and learning multiple subjects simultaneously remains a challenge in K–12 and in higher education.

7) Gender-Related Research

Research has identified a significant gap between women’s and men’s patenting and participation in invention pathways, yet few studies focus on perspectives of the LGBTQ+ communities. Therefore, more research is needed to understand how gender-diverse students engage in invention education.

8) Diversity, Social Relevance, and Socially Relevant Practices in IvE

Socially relevant education, intersectionality, and other theories, as well as indigenous and other epistemologies, need to be brought into the IvE field to examine the perspectives and experiences of diverse groups of students, their educators, and their communities. IvE programs are locally situated, yet researchers need to demonstrate how the specific cases may inform the larger field of study. Another research area that needs more work is analyses of the learning and inventiveness of students with exceptionalities, including gifted or “high ability” students (Plucker & Gorman, 1999), students with special needs (e.g., Blumenfeld & Sotelo, 2017; Ni & Martin, 2017), or other specific characteristics.

9) Roots and Routes to Invention Education As It Is Known Today

A historical study of IvE and its role within and beyond schools could expand the knowledge of the field by helping current researchers understand prior efforts. The study may offer insights into the future of IvE, including but not limited to ways particular approaches to IvE may need to change to address the current needs of diverse students, educators, and society. For example, Colangelo and colleagues (Colangelo, Kerr, Hallowell, Huesman, & Gaeth, 1992; Colangelo, Assouline, Croft, Baldus, & Ihrig, 2003), who had studied a state-wide Invent Iowa competition since its establishment in 1987 within a center for gifted education, have demonstrated not only the program’s effects and change over time but also its impact on the state curriculum when Invent Iowa curriculum guides were made available for all educators.

A historical study of IvE and its role within and beyond schools could expand the knowledge of the field by helping current researchers understand prior efforts.

The nine gaps identified in this WP present an opportunity for the IvE research community to explore their areas of interest and expertise and to work collectively in advancing the field.

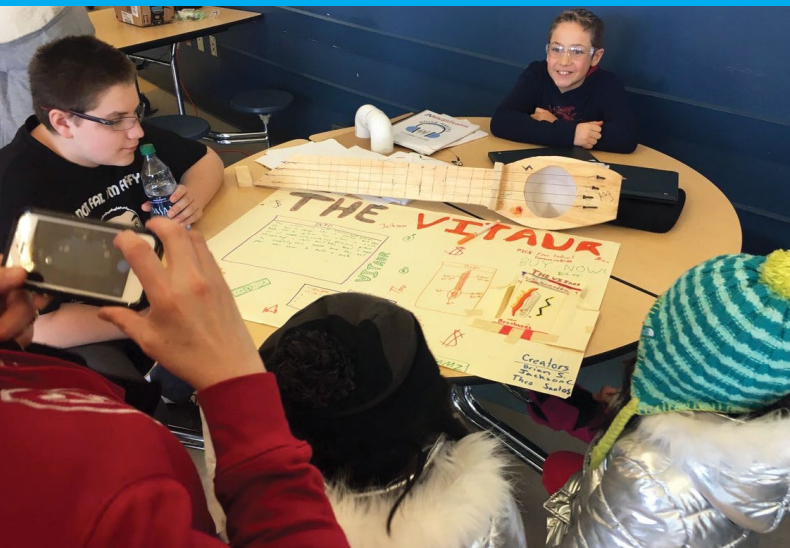


CONCLUSION AND NEXT STEPS

CONCLUSION AND NEXT STEPS

We intentionally drew upon the Computer Science (CS) framework to inform the design of this WP since several of our topics overlap with those in the CS standards. The CS framework was developed to assist K–12 schools with the adoption and implementation of the CS concepts and practices embodied in new standards being taken up in schools across the United States; many schools are working to develop new classes that will afford students opportunities for learning CS across their years of schooling (elementary, middle, and high school). The IvE community sees the need for a similar effort focusing on opportunities to help young people develop the ways of thinking, knowing, and working as a creative problem solvers and inventors. Our ability to make this dream a reality is dependent, in large part, on our ability to continue to grow this emerging field through contributions of researchers, practitioners, policy makers, nonprofits, and public-private partnerships. This paper serves to identify existing research as well as gaps in knowledge, which may guide further development of research-driven IvE.

The IvE research presented cuts across multiple disciplines and demographic sectors and is driven by varied theoretical frameworks and methodological approaches. While this WP presents an overview and builds a foundation of research on invention education in formal and informal learning environments, it also highlights many gaps that still exist in knowledge of IvE processes, practices, outcomes and impacts on diverse students, teachers, and communities. IvE is a growing field and an open research community; therefore, we invite additional researchers to join the IvE research group to share existing research and explore synergies for further collaborations through dialogue, conference meetings, jointly produced journal articles, books, grant applications, and policy forums.



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