RESEARCHING INVENTION EDUCATION: 2019–2025

A White Paper

Prepared for InventEd
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Contents

1. Background

In 2019, a dedicated team of 46 professionals representing the emerging field of Invention Education (IvE) reviewed the corpus of literature about the topic on behalf of The Lemelson Foundation's InventEd consortium. The result was the publication of *Researching Invention Education: A White Paper* (Invention Education Research Group, 2019), which was disseminated by The Lemelson Foundation, practitioners, and researchers. Since then, the field of IvE has continued to develop and expand through a broad, multifaceted ecosystem that has increasingly involved educational research.

The Invention Education Research Group illuminated who was doing research on IvE, where the sites of study were, and which research methodologies were being utilized. The research group sought to "create a document that reflects the research base, values, and principles guiding the work in this emerging field" (p. 1). At that time, there was a focus on reviewing ways in which computer science and IvE teaching were synergistic. Like IvE, computer science was emerging as another boundary-crossing discipline, but with a wider national uptake. The 2019 white paper was divided into eight sections and then summarized in "Gaps in Invention Education Research," which became the starting point for this review. The nine gap topics were (pp. 65–67):

- Pre-K to Career Pathways to Invention and Entrepreneurship
- Contributions of Competitions and Prize Programs to Inventors' Development
- Community Engagement and Invention Education
- Transdisciplinary Nature of Invention Education
- Comparison of Invention Education with Other Areas of Focus in Education
- Research Methodologies and Methods of Assessment
- Gender-Related Research
- Diversity, Social Relevance, and Socially Relevant Practices in Invention Education
- Roots and Routes to Invention Education as It Is Known Today

For this update, educational researchers reviewed journal articles, white papers, conference papers, published technical reports, published government reports and initiatives, and IvE programs. The educational researchers are referred to as reviewers throughout this update. Reviewers focused on IvE research and program evaluation in U.S. formal school settings, out-of-school time settings, and museum contexts if K–12 students or the public were the target audience. Non-English-language publications were excluded. Literature searches of the ERIC database and Google Scholar were conducted in September 2025 for resources between 2019 and 2025 using the keywords

"Invention Education." Unpublished resources known and available to the reviewers are noted as such. Subject matter experts within the field of IvE were contacted for elucidation on some topics. All contributors are acknowledged in this update.

Researching Invention Education: 2019-2025 documents what is now known in the IvE field and identifies opportunities for even greater inclusive impact on K–12 students. It revisits the nine gaps and examines them in the context of what has been published in the past six years. It also identifies strengths and remaining gaps in the scholarly knowledge of invention education. As such, this paper is organized according to the following topics:

- IvE: Related Disciplines and Pedagogies
- Research on Invention Pathways
- Developing Inventiveness
- Community Engagement and Ecosystem Development
- Research and Evaluation Methodologies
- Concluding Remarks

1.1 Revisiting the Importance of Invention and Innovation to the United States

The Committee for the Study of Invention (2004) illuminated that invention and innovation — aspects of human creativity — have raised the living standards in much of the world, making "life longer, more comfortable, more informed, more engaging, for the most part safer from disease and violence, and more productive in innumerable ways" (p. 12). Arguably, over 20 years on from the Committee's report, we face unprecedented opportunities for digital and technological inventions through the recent advancements in artificial intelligence (AI). Indeed, the current federal administration issued America's AI Action Plan (The White House, 2025), which calls for the United States to invent technologies and embrace AI-enhancing productivity. Another current AI initiative supports the next generation of innovators through the pledge of support by 141 patent-intensive corporations and educational organizations that will invest in K–12 students and teachers so they can successfully develop necessary skills and succeed in the changing workforce (The White House, *Pledge to America's Youth*, 2025). Such collaborations could allow exposure for K–12 students and teachers to the newly conceived AI accelerators and incubators that support AI-based technology innovation at scale (Bahoo et al., 2023).

Through the National Science Foundation, the federal government continues to heavily fund the Regional Innovation Engines, commonly referred to as NSF Engines. The multibillion-dollar investment in NSF Engines was "established to advance transdisciplinary, collaborative, use-inspired and translational research and technology development in key technology focus areas" (U.S. National Science Foundation, n.d., *About NSF Engines*, para. 1). The Engines program was introduced in 2022, with the first 10 Engines announced in 2024. The committed funding of $1.6 billion in NSF Engines over 10 years was authorized by the 2022 CHIPS and Science Act, which identified the key technology areas and included educational funding components for teacher scholarships, scaling K–12 innovations in STEM education, and workforce training (U.S. National Science Foundation, n.d., About the "*CHIPS and Science Act*").

1.2 Federal Importance and Recognition of Invention Education

The CHIPS and Science Act was signed into law on August 9, 2022, authorizing federal funding for semiconductor manufacturing in the United States. The law has provisions for workforce development and education to help meet the burgeoning job market demands for a strong STEM workforce to address technological advances. The world is entering a new era — the Intelligent Age — driven by rapid developments in and convergence of AI, quantum computing, and blockchain (World Economic Forum, 2024). Rapid technological developments will impact youth and how they are educated. The World Economic Forum highlighted in its annual meeting that "[e]ducation systems must evolve to prepare future generations for a world of work where many traditional jobs no longer exist and new roles are emerging that require different skill sets" (World Economic Forum, 2024, para. 17).

Two years after the CHIPS and Science Act became law, invention education was included in the *Federal Strategic Plan for Advancing STEM Education and Cultivating Talent* (Committee on STEM, 2024), a five-year strategic plan. The Plan was a product of the White House Office of Science and Technology Policy, The National Science and Technology Council, and the Committee on STEM. The Committee on STEM included 27 government agencies, 23 committee members, and 72 subcommittee members to represent and coordinate efforts toward STEM education in the United States. The Committee on STEM (2024) included IvE in its broad definition of STEM, along with innovation and entrepreneurship topics and skills (p. 49). National imperatives for an inventive and innovative citizenry, advancing technologies that are quickly changing the way we work and live, and the need for a flexibly-skilled workforce offer IvE—an innovation in education—expansion opportunities.

1.3 The Importance of Inclusivity in STEM and Invention Education

The Committee on STEM (2024) called out the need for the United States to inspire, educate, and retain STEM workers throughout the country and asserted that all people should have equitable access to high-quality education and experiences (p. 12). The IvE community advocates this view and affirms that everyone can be an inventor. This is underscored by diversity, equity, and inclusion being foundational core components of IvE. *A Framework for Invention Education* (InventEd, 2020) called upon the growing InventEd community to weave inclusivity throughout all IvE activities. This framework states, "[i]t is incumbent on the Invention Education community of practitioners, funders, and policy makers to ensure that every learner has equitable access, and that historical and systemic disparities are addressed through intentional investments in underrepresented communities" (p. 19). In its *Field Guide* (2022), InventEd called for those within the IvE community to "intentionally design" culturally relevant programs and initiatives (p. 9) to reach and benefit populations of students that have been traditionally left out or left behind, which historically had created a "vast gap in the talent pipeline" (p. 5). Cultural relevance within IvE utilizes students' backgrounds, and lived experiences, and identities — acknowledged as assets — to add personal meaning and empowerment to inventive work. These core components and intentionally designed programs are manifested in many of the reviewed studies. It also highlighted the need to embed IvE within the school day for equitable access. The *Researching Invention Education* white paper (Invention Education Research Group, 2019) highlighted the need to embed IvE within the school day for equitable access. Progress toward inclusive and equitable access will be called out in each section of this white paper.

> ***"Cultural relevance within IvE utilizes students' backgrounds, lived experiences, and identities — acknowledged as assets — to add personal meaning and empowerment to inventive work."***

1.4 Defining Invention Education

The Committee on STEM (2024), in its *Federal Strategic Plan for Advancing STEM Education and Cultivating Talent*, included invention education in a very broad definition of STEM. However, a consensus definition of invention education continues to be elusive. The Invention Education Research Group (2019) described IvE as both a field and a pedagogy. The contributors to the 2019 white 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" (p. 5). This adopted working definition is followed by the identification that IvE is "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" (Invention Education Research Group, 2019, p. 5).

Researchers and practitioners within IvE did not use the definition of invention education in the 2019 white paper, and they have not used a consistent definition since then. Based on the searches, only four publications within the 2019-2025 timeframe explicitly defined invention education (Couch et al., 2024; Skukauskaite & Couch, 2024; Skukauskaite, Saenz, et al., 2023; Talamantes et al., 2022). They referenced the 2019 white paper, but *not* the adopted working definition. Rather, they used a statement from the executive summary, that "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" (Invention Education Research Group, 2019, p. 1) or a combined version. This review does not attempt to clarify or redefine IvE, but acknowledges this as an opportunity for the community to address.

1.5 Orientation to Researching Invention Education: 2019-2025

This review seeks to identify how the knowledge gaps identified in the 2019 white paper have been addressed in the last six years. Undeniably, the complex systems of local, state, and national education have been impacted during these years by major societal shifts. These shifts influence practical concerns of how best to address, scale, and sustain IvE in U.S. schools and enrichment environments. The review moves beyond simply updating the research and extrapolates growth opportunities for IvE. *Researching Invention Education: 2019-2025* concludes with a charge for future research to bolster the existing strong foundation for IvE that has been established by an ecosystem comprised of a multitude of stakeholders.

2. Invention Education: Related Disciplines and Pedagogies

2.1 Evolution of Invention Education

Invention education continues to grow and evolve as a field (Kashuda, 1981; Perusek & Shlesinger, 1987; Plucker & Gorman, 1999). It is important to reflect on recent developments and how the field can benefit from other, similar education initiatives. Among IvE researchers, numerous discussions and publications have focused on where there is overlap and where there is uniqueness in comparing IvE to related fields. IvE can be conceived as a body of knowledge and skills; therefore, as an instructional approach, it is worth identifying related initiatives in both of these areas. Of all the related educational initiatives (i.e., a family of approaches), the reviewers argue that invention education is one that is frequently considered as both a body of disciplinary approaches (content and skills) *and* pedagogical approaches (instructional methods and processes). It is helpful to consider why identifying relations from content and skills, as well as instructional methods and processes, are valuable. Among all the relatives, some are very similar and others are more distant. Maker education may be the closest relative to IvE. It "is closely associated with STEM learning, is an approach to problem-based and project-based learning that relies upon hands-on, often collaborative, learning experiences as a method for solving authentic problems" ("Maker Education," 2025, para. 1). Yet, we consider it to be primarily a pedagogical approach.

Current IvE research has focused on the differences and similarities found within the broader disciplinary and pedagogical approaches illustrated in Figure 1. Gale (2022) described what distinguishes engineering education, a disciplinary approach, from IvE as "[w]hen K–12 students are asked to design a solution to an engineering problem, the design challenges set before them generally originate externally, often as part of engineering curricula adopted by schools or districts" (p. 2). Patel et al. (2024) focused on pedagogy, stating, "Invention education pedagogy empowers children to ideate, create, and solve challenges, including at times, defining their own challenges. It guides students through the practices of innovation. It builds the mindset and skills that support children in the complexities of designing tangible solutions, from concept ideation to product development and business practice" (p. 2).

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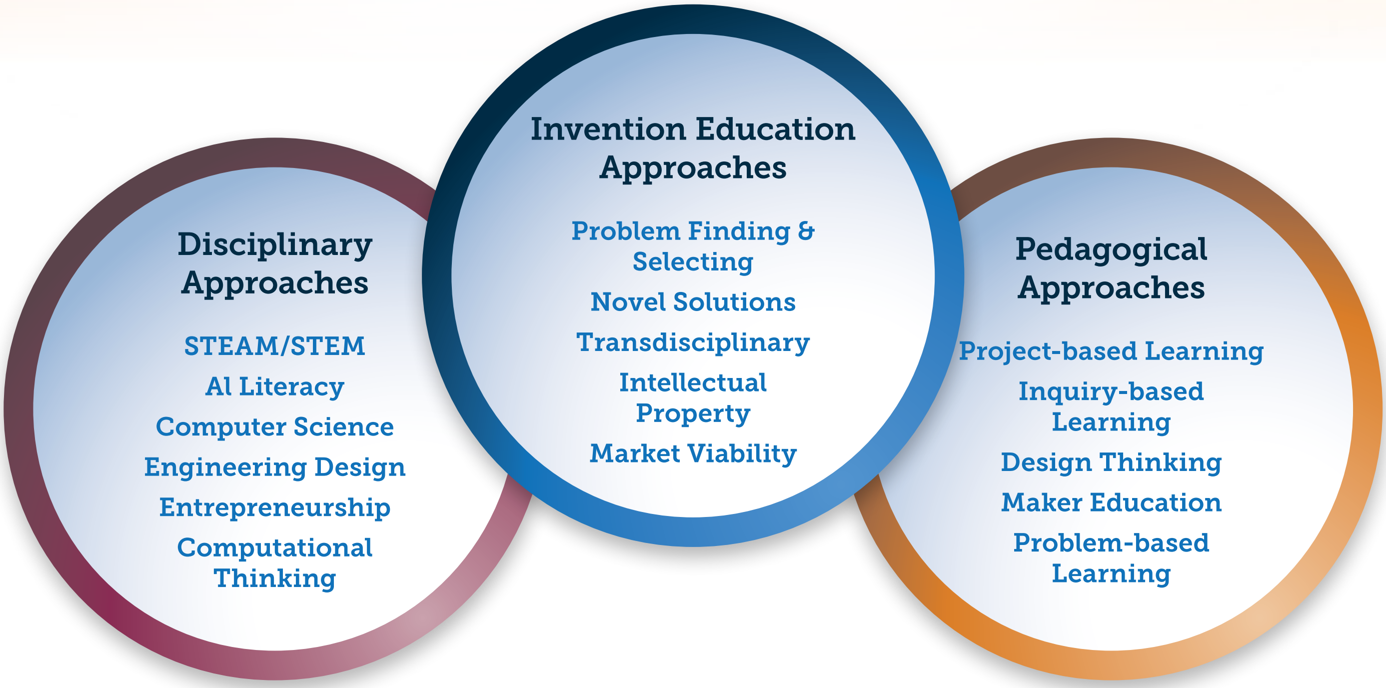
Figure 1

Characteristics of IvE in Relation to Related Disciplinary and Pedagogical Approaches



Keywords and abstracts of current peer-reviewed publications were examined to determine how IvE researchers situated their work. Table 1 illustrates how researchers situated their work within the three approaches—disciplinary (content and skills), invention education, and pedagogy (methods and processes). One team of researchers identified all three approaches in the keywords in their study (Couch et al., 2024).

Table 1

Published Research Examined Through the Lens of Disciplinary, Pedagogical, and IvE Approaches

Approaches	Researchers (Published Year)
Disciplinary approaches	
Science	Zhang et al. (2019)
STEM/STEAM	D. W. Jackson et al. (2024)
STEM	Garner et al. (2021);
	Couch et al. (2020)
Maker	Scharon et al. (2024)
Maker/STEAM	Hernandez-Perez et al. (2024)
STEM/STEAM/Maker	Maaia (2019)
Engineering	Gale (2022); Foss et al. (2019)
Pedagogical approaches	
Problem-based	Skukauskaite, Saenz, et al. (2023)
Problem-based, inquiry-based	Ewell et al. (2022)
Project-based	D. Kim et al. (2019)
Process-based	Rowe et al. (2024)
Design thinking	Skukauskaite, Bridges, et al. (2023)
Design & entrepreneurship thinking	C. R. Jackson, Whittington, et al. (2024)
IvE approaches	
Patents	Fechner et al. (2022);
	Burrage et al. (2022)
Disciplinary, pedagogical, and IvE approaches	
STEM, transdisciplinary, and problem-based	Couch et al. (2024)

Many disciplinary approaches and pedagogies have been well researched and are documented to have long histories of inequity in U.S. education (National Academies of Sciences, Engineering, and Medicine, 2025; Sawyer, 2022). For example, across most science fields—or more broadly, the STEM disciplines—decades-long underrepresentation of women and minorities has persisted (Maltese et al., 2014). The Committee on STEM (2024) outlined the importance of STEM engagement and increased participation to address inequities. Improvements in accessing STEM knowledge in "communities historically underserved and underrepresented" (p. 17), along with broadening STEM approaches to include "invention understanding" (p. 16), were called out in the *Federal Strategic Plan* (Committee on STEM, 2024). IvE tenets embrace inclusivity for all youth by interweaving disciplines with pedagogy that promotes "learners' agency, leverages their cultural and linguistic assets, and centers their competence as sensemakers" (National Academies of Science, Engineering, and Medicine, 2025, p. 7).

The National Academies identified the following five pedagogical models for equitable STEM instruction (2025, p. 254):

- Funds of knowledge
- Culturally relevant pedagogy
- Culturally responsive pedagogy
- Culturally sustaining and culturally resurgent pedagogies
- Complex instruction

Current IvE research has added to the corpus of knowledge regarding inclusivity and pedagogical models for equity. D. Kim et al. (2019) reported case study results from a modified middle school science curriculum for English-language learners using invention curriculum and "home fun" activities, noting that the students made connections between their science learning and home cultures. Saenz and Skukauskaite (2022) qualitatively explored how high school-aged Latina students engaged in IvE in the innovation ecosystem utilizing their funds of knowledge. The researchers argued that this type of engagement with Latinas in inventing will contribute to solving complex problems that diverse communities face. Furthermore, they concluded that "[e]mbedding IvE in the school day would provide equitable opportunities for more, and more diverse, students to contribute to shaping the innovation processes and technological advancements in and for the rapidly changing U.S. and global societies" (Saenz & Skukauskaite, 2022, p. 311). D. W. Jackson et al. (2024) summarized from their phenomenological mixed-methods study that IvE promises equitable student engagement, especially related to the STEAM disciplines within middle school science classrooms and camps.

Other researchers addressed increasing the diversity of inventors to include more women, people of color, and individuals with lower incomes. Holly & Comedy (2022) called on the invention and innovation community to pay attention to factors that result in the lack of racial and ethnic diversity. Martin (2021) and Fechner et al. (2022) proposed policy recommendations to improve data collection and measurement that would promote equity in patenting. Maltese et al. (2024) shared results from a program where young women were introduced to using coding to design solutions to problems in the world around them. Focusing the program on problem solving, sharing stories of female inventors and innovators, and connecting to girls' cultural backgrounds all led to greater engagement than in similar programs without these elements. Burrage et al. (2022) researched pathways to invention by studying 2,000 collegiate inventors' applications to a prize program. They found that self-reported demographic data indicated striking differences in the pathways of the collegiate inventors and their inventions. This work identified potential areas for future research to examine ways universities support, develop, and contribute to underrepresented students' pathways to invention.

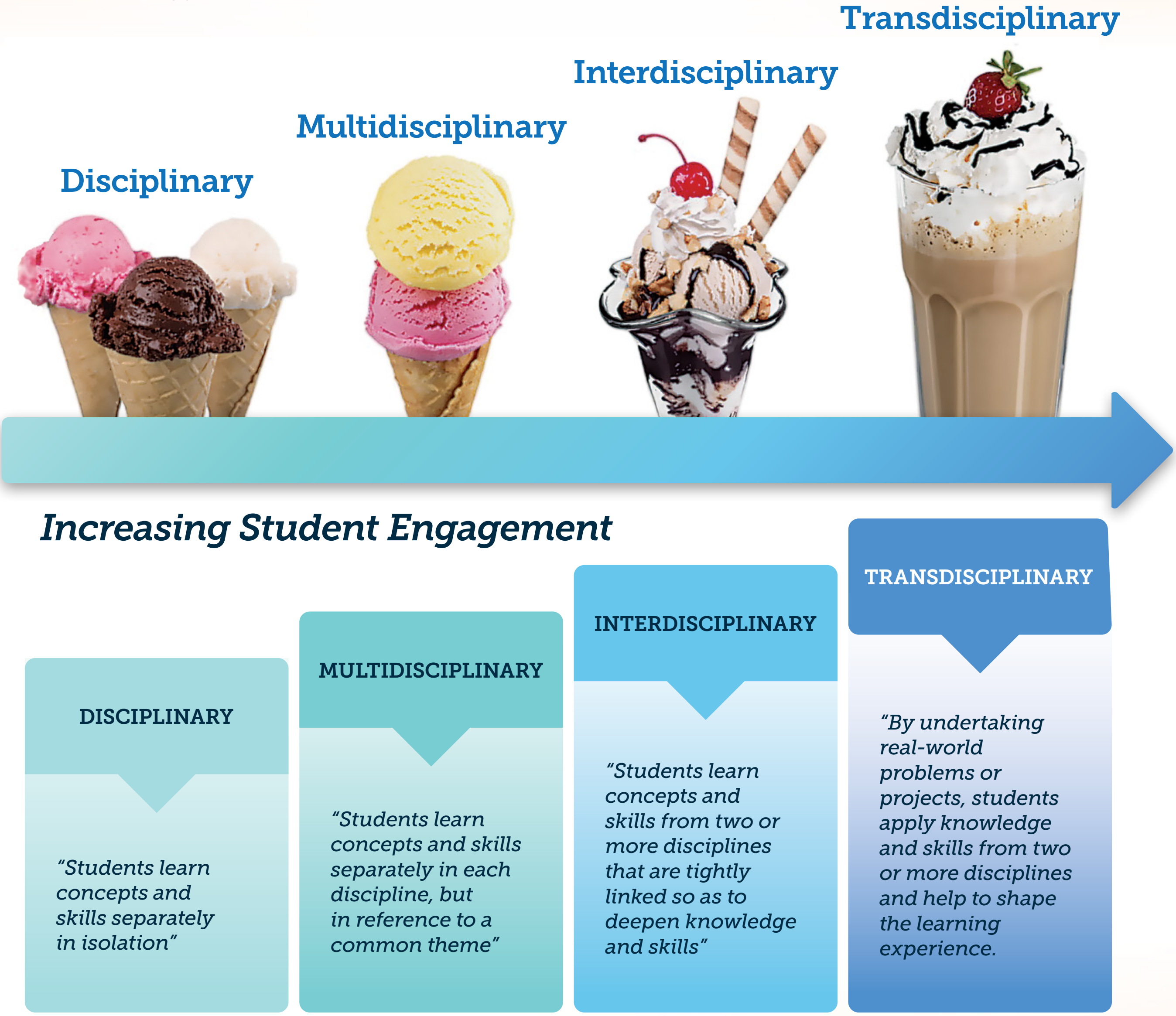
The education system in the United States, like most systems around the world, is rooted in the parsing of learning into disciplinary siloes (Budwig & Alexander, 2020; Committee for the Study of Invention, 2004; Herrenkohl & Polman, 2018; Sawyer, 2006). Although disciplines and disciplinary boundaries will not disappear in the near future, there is significant discussion and focus on various types of disciplinary boundary crossing for both individuals and teams of learners to engage in multi-, inter-, and trans-disciplinary work. Embracing this complex approach may benefit the field of IvE since "increasing boundary transgressions is associated with invention" (Committee for the Study of Invention, 2004, p. 12). Although the idea of multi-, inter-, and trans-disciplinary learning may be beneficial to the field, many educators do not engage in these practices because they lack comprehensive knowledge and expertise (Dalela & Ahmed, 2024; Kars-Unluoglu, 2016). This is a major reason teachers and educators often do not engage in inquiry-based learning and similar student-centered approaches (Fitzgerald et al., 2019; Strat et al., 2024) or maker education (Harlow et al., 2018). Thus, as invention education is promoted as involving transdisciplinary knowledge and skills, some educators may avoid it for the same reason that others seek to engage in it. A review of the transdisciplinary nature of invention education is warranted to clarify approaches.

2.2 Transdisciplinary Nature of Invention Education

The 2019 white paper described IvE as an emerging transdisciplinary field (Invention Education Research Group, 2019), and this continues to be not only a strength of IvE, but also essential to developing inventors and innovators (Chandra et al., 2021; Swayne et al., 2019). One challenge facing invention education is the misunderstanding of what it means to be transdisciplinary, especially compared to other varying levels of disciplinary integration. The Interagency Working Group on Convergence (2022) presented the distinction between multi-, inter-, and trans-disciplinary integration using the analogy of ice cream. As illustrated in Figure 2, ice cream is used to represent the four increasing levels of disciplinary integration in student engagement.

Figure 2

Distinctions Between Four Types of Disciplinary Integration, Demonstrated Using the Ice Cream Analogy



"Students learn concepts and skills separately in isolation"

"Students learn concepts and skills separately in each discipline, but in reference to a common theme"

"Students learn concepts and skills from two or more disciplines that are tightly linked so as to deepen knowledge and skills"

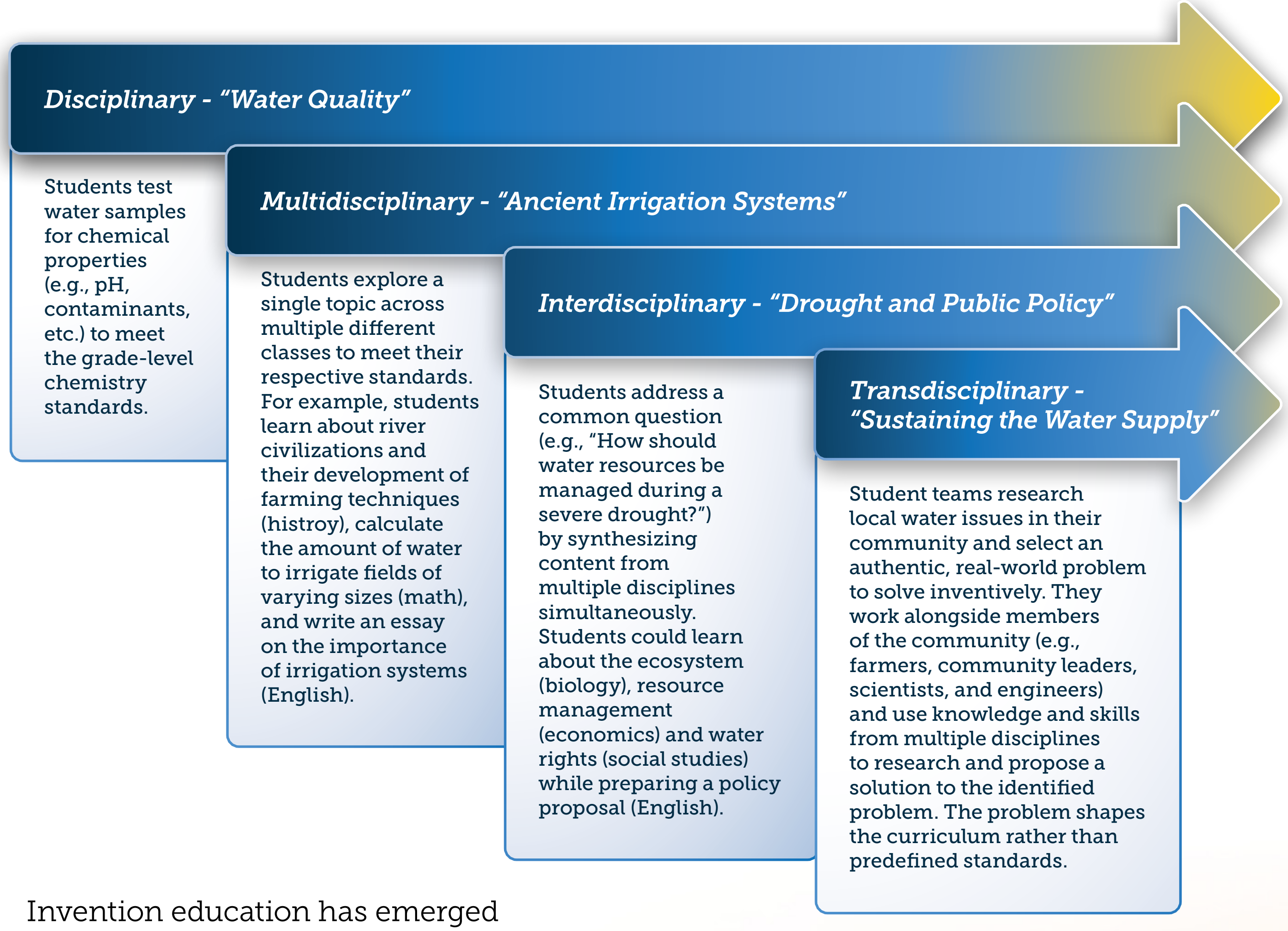
"By undertaking real-world problems or projects, students apply knowledge and skills from two or more disciplines and help to shape the learning experience.

Note. Image source: *Convergence Education: A Guide to Transdisciplinary Learning and Teaching*, by Interagency Working Group on Convergence, 2022, p. 19.

There are increasing levels of integration and boundary-crossing between disciplines, moving from an individual disciplinary approach to one that is transdisciplinary. The siloed structure of the current education system reflects the individual disciplinary approach, with students typically learning mathematics separately from English/language arts, which are taught separately from history. Recent initiatives in education have begun to utilize multidisciplinary integration where concepts and skills from several disciplines are drawn on to address a common theme; Figure 3 exemplifies students' disciplinary integration on water issues. A multidisciplinary approach has coincided with the increase in makerspaces and STEM labs in schools and communities. Interdisciplinary and transdisciplinary examples are fewer in number.

Figure 3

The Four Types of Disciplinary Integration in Students' Attention to Water Issues



Disciplinary - "Water Quality"

Students test water samples for chemical properties (e.g., pH, contaminants, etc.) to meet the grade-level chemistry standards.

Multidisciplinary - "Ancient Irrigation Systems"

Students explore a single topic across multiple different classes to meet their respective standards. For example, students learn about river civilizations and their development of farming techniques (histroy), calculate the amount of water to irrigate fields of varying sizes (math), and write an essay on the importance of irrigation systems (English).

Interdisciplinary - "Drought and Public Policy"

Students address a common question (e.g., "How should water resources be managed during a severe drought?") by synthesizing content from multiple disciplines simultaneously. Students could learn about the ecosystem (biology), resource management (economics) and water rights (social studies) while preparing a policy proposal (English).

Transdisciplinary - "Sustaining the Water Supply"

Student teams research local water issues in their community and select an authentic, real-world problem to solve inventively. They work alongside members of the community (e.g., farmers, community leaders, scientists, and engineers) and use knowledge and skills from multiple disciplines to research and propose a solution to the identified problem. The problem shapes the curriculum rather than predefined standards.

Invention education has emerged as a transdisciplinary field. Discrete STEM discipline boundaries are blurred beyond knowledge, skills, and concepts within IvE. Boundary crossing of discipline knowledge is combined with the application of skills and concepts to create new knowledge used to solve real-world problems that are societally impactful (Committee on the Study of Invention, 2004; Couch et al., 2024; Interagency Working Group on Convergence, 2022; Lawrence et al., 2022). However, there is a dearth of published research articles focused on transdisciplinary learning and IvE since the publication of the *Researching Invention Education* white paper (Invention Education Research Group, 2019). Integration with other disciplines tends to be restricted to the discipline approaches of STEM/STEAM, engineering/engineering design, and entrepreneurship, as presented in Table 1. Couch et al. (2024) utilized a case study methodology and explored the challenges of assessing the complex processes involved with transdisciplinary problem-based education offerings. The study emphasized that current assessment tools may be marginally modified, but a new, flexible assessment system is needed—one with multiple measures that account for individual and group achievements, as well as variations in learning contexts and IvE engagement time (Couch et al., 2024, p. 1). The reviewers posit that, without appropriate assessments and professional development for teachers, IvE adoption within the school day will be slow.

Transdisciplinary learning approaches have the potential to support all learners, including students in rural and Title I schools, as well as students underrepresented in STEM—yet there are integration challenges of transdisciplinary learning approaches, including invention education, for educational settings. The reviewers argue that there are four primary challenges that classroom teachers face:

- The first challenge relates to the context of education. As previously mentioned, the American education system continues to be structured into disciplinary siloes (Budwig & Alexander, 2020; Committee for the Study of Invention, 2004; Herrenkohl & Polman, 2018; Sawyer, 2006). Siloed disciplines, whether at the K–12 or university setting, are incompatible with the transdisciplinary nature of IvE, which seeks to blur the boundaries between disciplines (Dalela & Ahmed, 2024).
- The second challenge pertains to learners. Despite being the primary beneficiaries of the transdisciplinary nature of IvE, learners themselves pose a challenge to invention education, as students within a course are naturally at different developmental levels.
- The third challenge is that the blending of multiple disciplines required by transdisciplinary approaches like IvE is difficult for teachers, who often lack the pedagogical and discipline-specific content knowledge of multiple disciplines (Sawyer, 2019; Sawyer, 2022). Additionally, teachers face challenges in identifying opportunities, making connections, and forming partnerships within the broader ecosystem because transdisciplinary approaches include entire ecosystems of stakeholders. Even when the teachers form partnerships, schools must then find ways to fit these interactions within the existing structure and context of the established school day and rules; creating new structures may be necessary to include outside interactions within the school.
- The fourth challenge relates to the assessment of students' learning when the disciplines' boundaries are blurred. Most current assessment tools focus on the measurement of a single subject or discipline at a time; IvE would require identifying or creating new assessment tools or modifying existing ones.

Still, the potential (and promising) outcomes for transdisciplinary, project-based/problem-based invention education may be sufficient to encourage teachers and schools to invest in addressing these challenges.

2.3 Opportunities Moving Forward

While the reviewers found evidence that invention education often draws on STEM/maker disciplines and utilizes problem/project/process-based and design thinking pedagogies, future work can explore how to integrate IvE more broadly into the arts and humanities, as well as to better understand when, where, in what ways, and for what purposes they are integrated. More work is needed to better understand how to integrate IvE using a transdisciplinary approach to solve authentic real-world problems that benefit society.

Exploring how other fields have advanced on the continuum of engagement toward the transdisciplinary approach may inform the IvE community. For example, ongoing education research within the field of the Learning Sciences (LS) has progressed during the past six years in tandem with proclamations of the importance of invention and the advancement of IvE practices. LS has been defined as "a field that studies how people learn and how to support learning" (Hoadley, 2018, p. 11). The field seeks to bridge the gap between traditional education research and psychological research. Current research in LS has been productive. For example, R. Keith Sawyer, Morgan Distinguished Professor of Educational Innovations at the University of North Carolina at Chapel Hill's School of Education, edited the Cambridge Handbook of the Learning Sciences (3rd Ed.) in 2022. In addition to editing handbooks on LS, Sawyer has written extensively on educational structures and pedagogies that are complementary to IvE (Sawyer, 2006a, 2006b; Sawyer, 2007; Sawyer, 2019; Sawyer, 2025). LS may offer IvE a theoretical and methodological backbone, while IvE may offer LS practical real-world applications of authentic, transdisciplinary approaches to education. Also, LS constructs — e.g., productive disciplinary engagement, epistemic agency, and design-based implementation research — may be leveraged to advance the field of IvE.

Future research should focus on the assessment of transdisciplinary invention education. Learning outcomes that occur across multiple phases of the invention process — and within different disciplines — cannot be assessed using traditional assessment tools. Rather, there is a need for new assessment tools and systems that are able to capture multiple aspects of the invention process. The blended discipline and pedagogy approaches with new assessment tools will require pre-service and in-service professional development for teachers. Sawyer (2022) shared that his ideal teacher of the future is no longer focused on instruction. Rather, the teacher of the future is focused on how the learners collaboratively learn and create knowledge with the teachers' facilitation, as noted in the adopted working definition of IvE in the 2019 white paper.

> ***"[The] ideal teacher of the future is no longer focused on instruction; rather, the teacher of the future is focused on how the learners collaboratively learn and create knowledge with the teachers' facilitation."***
>
> **(Sawyer, 2022)**

3. Research on Invention Pathways

3.1 Studying Invention Education Over Time

The 2019 white paper *Researching Invention Education* called for longitudinal research to "track the learning, progress, and pathways of young people involved in IvE programs in order to assess the impacts of exposure to IvE across time and events" and to identify "pathways, supports, constraints, and ways of helping young inventors overcome obstacles" (Invention Education Research Group, 2019, p. 65). Longitudinal work has yet to be completed, most likely due to several factors, including a lack of sustained funding to complete such work, the logistical challenges of tracking individuals over time, and the epistemological challenges associated with attributing outcomes to specific factors. However, despite the lack of longitudinal studies, two important developments are noteworthy.

First, the IvE infrastructure has strengthened in recent years to include competition and incubator programs such as Invention Convention, Science Coach, the Institute for Competition Sciences, and Project Invent, as well as large-scale curriculum and camp provision by organizations such as Camp Invention and The Henry Ford (Burrage et al., 2022; Garrecht et al., 2023; Kalainoff et al., 2025). These organizations have established relationships with school districts and individual participants, and possess data-gathering tools that may support tracking over time. The field of invention education is therefore well positioned to contribute to longitudinal research and comprehensive retroactive studies to investigate the effects of participation on: students' STEM pathway persistence; short- and long-term career-related activities; evidence of inventiveness; educators' needs and priorities; and other significant programmatic outcomes. Collaborations between practitioners and researchers may yield insights into the factors that specifically support or deter students' and educators' persistence on an invention and entrepreneurship pathway (Garrecht et al., 2023).

The second development supporting a broad view of IvE is the publication of research by Rowe et al. (2024) and D. W. Jackson et al. (2024) describing a promising model for systemic K–12 invention education that could conceivably support cross-sectional or longitudinal research. Rowe et al. gave an overview of the iINVENT initiative in rural Oregon, which provided opportunities for students to engage in in-school and out-of-school time programming tailored for elementary, middle, and high school audiences. At the elementary level, iINVENT in the classroom delivers six lessons focusing on an invention project. At the middle school level, students participate in a five-day iINVENT Mobile Summer Camp, which fosters the development of inventive skills through solving a problem for the community. At the high school level, learners focus on inventing to solve a community problem through the three-week hybrid iINVENT Youth as Inventors program that involves college student mentors joining the high school teachers to deliver the program. Rowe and colleagues surveyed and interviewed the leaders of each program and found common themes that characterized the programs, regardless of grade level. These included: framing a well-defined problem; engaging students in discovering everyday problems; emphasizing the invention process over the creation of a specific product; learning to give and receive feedback on the invention process; and using curriculum materials that allow the students to see other young people involved in the invention process. In addition, the program's leaders valued the collaborations between K–12 and higher education.

D. W. Jackson et al. (2024) described six iterations of invention education curriculum and programming designed for use in middle school classrooms and in camp settings. The work, which was implemented in the northeastern region of the United States, involved collaborations among Lemelson-MIT, Boston College, and a public school district. Surveys and observations of participants revealed strong perceptions of cognitive and affective engagement. In-school invention education was associated with feelings of joy that were not experienced in other areas of the curriculum, such as science.

Out-of-school invention education was associated with opportunities to strengthen and deepen existing interests and hobby-related knowledge, such as making furniture. However, the researchers encountered evidence of little development of students' beliefs in their ability to be inventive in other domains, suggesting that without explicit attention to the value and relevance of invention-related skills to other contexts, students may glean an unnecessarily restrictive perception of themselves as inventors.

3.2 Invention Education Pathways through Competitions, Fairs, and Prize Programs

The Invention Education Research Group (2019) recognized the need to more fully understand the role of competitions, fairs, and prize programs in supporting young inventors' development along the pathway. Competitions, fairs, and prize programs continue to be evident in the lives of K-14 students. STEM and IvE research studies situate these activities in out-of-school time as well as school-related, extracurricular, and informal/nonformal experiences (Bahar & Adiguzel, 2016; Garrecht et al., 2023; Moore et al., 2019; Tang et al., 2024). The inconsistent identification of the time and space usage for these activities confounds the research. "In-school" is also referred to as "formal" and "traditional" within literature; "out-of-school" is referred to as "extracurricular," "informal," "non-traditional," and "free choice." Another confounding aspect of this inquiry is the dearth of research specifically on invention competitions, discussed later in this section. Therefore, current research pertinent to this section primarily focused on STEM competitions, fairs, and prize programs with the implicit understanding that inventing is transdisciplinary and weaves STEM fields together.

Fairs and competitions have long been part of the STEM fabric in the United States, with researchers studying the impact on students' college and career STEM paths and the overall impact on diverse learners (Bahar & Adiguzel, 2016; Kalainoff et al., 2025; Koomen et al., 2021; Miller et al., 2018; Zhou & Shirazi, 2025). Two influential federal reports — *Federal Strategic Plan for Advancing STEM Education and Cultivating STEM Talent* (Committee on STEM, 2024) and *Convergence Education: A Guide to Transdisciplinary STEM Learning and Teaching* (Interagency Working Group on Convergence, 2022) — mention competitions within the context of engaging K-12 learners with real-world problems, yet without referencing supporting research. Fairs, a type of competition, have been in existence for nearly 100 years, with some evolving into highly regarded international competitions, such as Regeneron Science Talent Search and the International Science and Engineering Fair (Science Fair, 2025). A STEM competition widely recognized in the United States, *FIRST*® Robotics, was founded in 1989, is in its

35th year (FIRST Robotics Competition, 2025). Additionally, STEM activities involving competitions have offered graduate students opportunities for research, leading to terminal degrees with dissertations focused on student impacts—especially among diverse populations (Meyer, 2023; Ulloa-Higuera, 2019; Wood, 2020).

Miller et al. (2018) utilized data from the 2013 Outreach Programs and Science Career Intentions survey (N=15,847) in a correlation study with funding from the National Science Foundation. The respondents to the survey were freshman students in 2-year and 4-year U.S. colleges during their first semester English class. The researchers sought to determine whether participating in STEM competitions increased the likelihood of STEM career interest and if the field of competition (robotics, engineering, science fair, IT) influenced the field of STEM career interest. Additionally, the researchers wanted to understand the relationship between the number of competitions and the probability of interest in a STEM career. The authors summarized that "competitions are an effective way to foster career interest in specific STEM careers" (p. 95), based on the following research findings:

- Students participating in STEM competitions in high school are more likely to be interested in a STEM career than those who do not compete, even when controlling for prior STEM interest.
- Competition participation and STEM career interest is domain specific (e.g., student participation in computing competitions or science fairs was not a significant predictor of interest in engineering careers).
- Participating in more than one competition influences the interest in a STEM career threefold.

> ***"Participating in more than one competition influences the interest in a STEM career threefold."***
>
> **(Miller et al., 2018)**

These research findings are meaningful to invention education competitions, given the overall importance of STEM competitions to career interests, the domain specificity, and the impact of participating in more than one competition.

The Institute of Competition Sciences (ICS) promotes online identification of STEM competitions. Founded in 2012, ICS is an international collaborative community for challenge-based learning for students in kindergarten through higher education. The founder and CEO, Joshua Neubert, was inspired by his experience with "incentivized innovation and challenge-based learning" (Institute of Competition Sciences, 2025, para. 5). ICS identifies six types of educational competitions:

- Exams
- Tournaments
- Fairs
- Performances
- Presentations
- Submissions

ICS maintains a database of 575 competitions and offers teachers, parents, and students a searchable selection of competitions by age (grade spans), type, category, and keyword (J. Neubert, personal communication, October 3, 2025). Table 2 indicates the number of STEM competitions ICS lists in its database when searched within grade spans with STEM being one of 55 selectable drop-down categories of competitions. A separate search was conducted within grade spans using the keyword "invent" since ICS does not include "invention" as a category. Only a fraction of the competitions within the database has the base word "invent" in the competition title or description. This scarcity of "invent" terms may affect career interests, given the Miller et al. (2018) second and third findings that a relationship exists between competition participation and STEM career interest being *domain specific*, and the threefold increase in this interest when participating in more than one competition where invention is explicit.

Table 2

Number of STEM and "invent" Competitions in the ICS Database

Age	All types of Competitions	Category STEM (% of all within age)	Keyword "invent" (% of all within age)
Elementary	111	57 (51%)	3 (3%)
Middle School	203	118 (58%)	4 (2%)
High School	354	178 (50%)	5 (1%)
Undergraduate	161	74 (46%)	3 (2%)
Graduate	93	37 (40%)	1 (1%)

3.3 Research on Invention Education Pathways

A group of eight program administrators — subject matter experts in IvE — collaborated in September 2024 with "mini-grant" funding from The Lemelson Foundation to compile a list of programs with competitions known to have an "invent" component. The group identified 44 programs. Interestingly, only half of the programs with an "invent" component are in the ICS database. Most notably missing from the ICS database is the largest competition with an "invent" component — Invention Convention — in which 184,000 students participate, starting at the local level (Invention Convention Worldwide, 2025). The Lemelson Foundation is one of five major partners that sponsors Invention Convention.

It is difficult to ascertain how many students participate in competitions that have an inventive component. Seeking to quantify the number of students who compete, Scholar ChatGPT was prompted: "How many competitions in the US are there that include inventing solutions to real-world problems?" ChatGPT-generated text indicated that there are 8-10 large scale U.S. competitions including Invention Convention, *FIRST*® LEGO® League, *FIRST*® Tech Challenge, *FIRST*® Robotics, Destination Imagination®, eCYBERMISSION, Exploravision, Future Problem Solving Program (U.S. division), the Conrad Challenge, and regional state inventors programs (OpenAI, 2025a). A follow-up prompt of "How many K-12 youth annually participate in these competitions?" provided additional Scholar ChatGPT-generated text estimating that "there may be as many as 350,000-400,000 K-12 direct students [participating] in invention and innovation competitions. This equates to less than 1% of the K-12 student population of around 50,000,000" (OpenAI, 2025b). While these are inexact numbers, they indicate a great potential for the growth of U.S. student involvement in IvE through competitions.

Recent IvE research referencing competitions includes one program, Science Coach®, with a competitive underpinning. Additionally, current research includes two competitions: 1) the K-12 InVenture Prize, affiliated with the Georgia Institute of Technology, and 2) InvenTeams, a competitive grant for high school students, affiliated with the Lemelson-MIT Program administered by the Massachusetts Institute of Technology School of Engineering.

Kalainoff and colleagues (2025) researched the Science Coach® program, which has an underpinning of science and invention competitions. Science Coach® has built a local ecosystem in a Midwestern city with partnerships, mentors, and community leaders to support students with real-world research and invention. The research on Science Coach® utilized theories and methodologies from interactional ethnography to make visible the types of support grades 6-8 science teachers used to coach students' research that culminated in competitions. The program's outcome data included the number of students participating in competitions and science fairs. Data showed that 93% of students in 2024 competed in more than one competition, and 22% of students participated in a fair and advanced to the next level (Kalainoff et al., 2025, p.17). Findings indicated that student persistence in the program is high, especially for underrepresented students in STEM. These Science Coach® findings may bode well for IvE effectiveness in light of the Miller et al. (2018) finding that STEM career interest from competitions is domain specific and participating in more than one competition influences the interest in a STEM career threefold.

Moore and colleagues (2019) examined program data for the K-12 InVenture Prize, a university-based outreach and prize program described as invention experiences that include multiple grade levels, levels of student course-taking (e.g., regular, gifted, and advanced placement), and settings (e.g., in school and after school). The invention experiences culminate in local competitions of the students' inventions. Local winners then participate in a statewide competition at Georgia Tech. State-level winners can then participate in the National Invention Convention held each June at The Henry Ford in Michigan. The impact on the teachers' motivation and self-efficacy for teaching engineering and entrepreneurship, based on online survey data (N=157), was discussed in this NSF-supported research (Moore et al., 2019). Teachers were found to have a high level of self-efficacy in teaching engineering and entrepreneurship. They were motivated to be involved with the InVenture Prize because they enjoyed it and the program corresponded to their own goals. The survey also queried teachers about their perception of the program's influence on students. Teachers indicated a high level of agreement that the program had a positive effect on students' communication, teamwork skills, enthusiasm for engineering, and knowledge about the engineering design process.

The InvenTeams® grants initiative, a competitive grant for high school students that is now in its 22nd year, was first mentioned in the Committee for the Study of Invention (2004) report, along with *FIRST*® robotics, as opportunities to extend design and invention into schools (p. 61). InvenTeams' competitive grant amounts varied from $7,500–$10,000 to build technological inventions for real-world problems over one school year; these grants were awarded based on judged submissions. The InvenTeams initiative was the site of study for 10 IvE research studies conducted and published between 2018 and 2024. Two of these studies were published in 2024 (Couch et al., 2024; Skukauskaite & Couch, 2024). A third publication by Couch & Kalainoff in 2024 examined the transformation of a national invention education program using a systems-level ethnographic study approach to explore the shift in program offerings; InvenTeams was one of these program offerings. Couch & Kalainoff (2024) included a comprehensive list of all publications that identify InvenTeams as a site of study; this one competition provided IvE research opportunities for many years. Other competitions may also provide opportunities for research, such as the longitudinal research discussed later in Section 4.1.

The current white paper focuses heavily on contexts and pedagogies of IvE in K-12. However, the reviewers acknowledge that there has been a substantial convergence between K-12 and higher education, affecting the boundaries between the two (K. J. Dougherty & Henig, 2016, p. 39). The InVenture Prize, sponsored as K-12 outreach by Georgia Tech, also has a higher education component. The InvenTeams grants initiative is K-12 outreach through the Lemelson-MIT Program. Take AIM (Analytics, Innovation, and Mathematics) is a new entry into the K-12 outreach space from higher education with a competition. The competition was announced in 2025 by INFORMS, an international network with 12,000 members across multiple sectors, including academia. It offers a good example of the convergence that may inform the high school-to-college transition and/or impact college preparedness. Take AIM is national, team-based, online, instructs through a game, and offers cash awards and certificates. The competition seeks to connect high school students with higher education while introducing STEM career pathways (INFORMS K-12, para. 2, accessed Oct. 4, 2025).

The last decade has seen changes in the collegiate competition and prize landscape that include convergence, discipline expansions beyond engineering in collegiate competitions, a prize landscape that includes more financial awards with entrepreneurial new venture start-up components, and an end to one multi-decade prize program. A notable new national prize program introduced in 2023 that spans K-20 is the Genspiration Prize, which awards cash prizes to “student invention teams and individuals whose innovations have impressive potential in creating positive societal impact” (NAI, para. 1, accessed Oct. 6, 2025). This prize program is sponsored by the National Academy of Inventors and the Genspiration Foundation. SolveCC, an initiative of Enovant Foundation, was introduced in 2022 to engage community college students to tackle and solve critical community-based challenges (SolveCC, accessed 10/6/2025). Older, more established prize competitions, like the 35-year-old Collegiate Inventors Competition sponsored by the National Inventors Hall of Fame/United States Patent & Trademark Office (USPTO), remains intact, though the USPTO Education department has been eliminated, which may impact this prize in the future. Other major competitions that continued through the COVID-19 pandemic include: VentureWell E-teams, Hult Prize, Microsoft’s Imagine Cup, Shell Ideas 360, MIT Solve

Global Challenges, XPRIZE, and the BASF Innovation Challenge. The Lemelson-MIT Collegiate Prize was discontinued in 2021.

In summary, it is difficult to quantify the number of students participating in K-12 inventive-activity competitions, and to discuss the impact of these competitions beyond discrete, programmatic outcomes. There is a dearth of research and an incomplete database of competitions. Competitions within IvE therefore remain fertile ground for rigorous research to quantify actual numbers of youth participants in competitions with inventiveness and invention components, and to explore how participation supports young inventors' development. Future research may attempt to identify in-school, out-of-school, and shared participation to more fully understand the impact on inventors' development and future career interests. Additionally, there is a communications opportunity to make explicit how IvE weaves together many disciplines, and to address the lack of direct identification of the base word "invent" within competitions, fairs, and prize programs.

4. Developing Inventiveness

4.1 Tracing Inventiveness

As noted by the Committee for the Study of Invention (2004), while many accounts of inventors and inventive thinking place in the foreground knowledge and abilities of various sorts that swing into operation as a problem is solved, it is especially notable that inventiveness is not just a matter of knowledge and ability. The dispositional side of invention is crucial (p. 18).

Although the 2004 report is often cited as a key moment in identifying the importance of inventiveness, it did not go so far as to define inventiveness and its attributes. Recently, researchers have begun to examine how participation in IvE programs and experiences can support the development of invention-oriented *traits, dispositions, and habitual ways of approaching the world*. This shift toward

> ***"…in addition to deep technical knowledge, inventors display tendencies such as resourcefulness, an inclination toward action, and a willingness to cross existing disciplinary and practical boundaries."***
>
> **(Committee for the Study of Invention, 2004; InventEd, 2020; Rowe et al., n.d.)**

the study of inventiveness is grounded in literature describing the importance of broad-scale participation in the innovation economy to maintain national progress and global competitiveness (Day One Project, 2021). It is also connected to research that has documented the proclivities of influential inventors, finding that in addition to deep technical knowledge, inventors display tendencies such as resourcefulness, an inclination toward action, and a willingness to cross existing disciplinary and practical boundaries (Committee for the Study of Invention, 2004; InventEd, 2020; Rowe et al., n.d.). This critical development for the field, teasing apart constructs that support process and output, was given simple nomenclature in the recent Lemelson Foundation white paper, *Beyond Big Inventions: Cultivating Everyday Inventiveness in K-12 Education*, where its authors (Rowe et al., n.d.) declare the value of both "Big I," or *being an Inventor*, and "Little i," or *being inventive*. Research on the dispositional and non-cognitive components of inventiveness may improve the understanding of the strengths individuals bring to IvE contexts (Couch & Kalainoff, 2024) and may reveal ways to promote persistence in invention-related pathways (Moore et al., 2022; Saenz, Skukauskaite, & Sullivan, 2024; Subramani et al., 2021).

> ***"Research on the dispositional and non-cognitive components of inventiveness may improve the understanding of the strengths individuals bring to IvE contexts."***
>
> **(Couch & Kalainoff, 2024)**

4.2 Dispositional Approaches to Inventiveness

Increased attention to the challenge of developing *inventive dispositions* in individuals with diverse backgrounds and experiences yielded a number of conceptualizations that share a common goal: describing a worldview that may support persistence in invention- and innovation-related career pathways. InventEd (2020) outlined the following eight trait-like characteristics of inventive thinking in their report, *A Framework for Invention Education*:

- empathy
- creativity
- curiosity
- resilience
- calculated risk-taking

- passion
- resourcefulness
- tolerance for ambiguity and complexity

Trait-like framing of inventive characteristics is also present in mindset literature, which seeks to support and evaluate the emergence of trait-like constructs that are adaptive for a particular context or domain. One example is the inventive "maker mindset" described by Scharon et al. (2024), which highlights habitual imagination, exploration, reflection, initiative, perseverance, teamwork, skill building, and perspective taking.

Other researchers have used the term "identity" to capture the phenomenon of using such skills, but with added emphasis on the individual's self-attribution or identification with the domain of invention and the role of an inventor. For example, Rowe et al. (2024) highlight inventive actions as critical inputs for the development of students' emerging "Inventor Identity." These included embracing iteration, using critical thinking routines, being persistent, problem solving, and showing empathy. Meanwhile, researchers and invention educators at the Lemelson Center for the Study of Invention and Innovation recently coined the term "inventive identity," defining it as "a person's network of inventive-related beliefs, goals, self-perceptions, emotions, and possible actions oriented toward creative solutions for complex problems" (Buning et al., 2025, p. 4; Kaplan et al., 2023). This definition is situated within a theoretical framework proposing that, with support, individuals can develop an understanding of how their inventive capacities can span different types of problems and varying domains of life.

4.3 Inventive Mindsets

There are challenges and opportunities for researchers who investigate inventiveness. The challenge is that when there are different disciplines conducting related work, they often use different terminology, theoretical grounding, methods, etc., and rarely do they seek congruence. All of this makes it more challenging to find and utilize the contributions of related work across disciplines. The opportunity exists for those willing to work through that translation challenge, as this allows researchers to build on a larger body of previous research, which is likely more diverse than that from a single discipline. In this section, the reviewers attempt to briefly discuss some of the bodies of literature that can contribute to developing a wider understanding of inventive mindsets and inventiveness.

In the 2019 white paper, the concept of developing an inventive mindset was prominently mentioned throughout. However, no specific definition or explanation was given for what characteristics make up an inventive mindset. Differing from Dweck's (2006) original characterization of fixed and growth mindsets, recent uses of the concept often are used to explicate the enduring beliefs, habits of mind, and attributes that characterize an exemplar within that field or pursuit, some of which are relevant to invention and inventiveness. These include maker mindset (D. Dougherty, 2013), innovation mindset (Kuczmarski, 1996), engineering mindset (Lottero-Perdue & Lachapelle, 2020), entrepreneurial mindset (McGrath & MacMillan, 2000), STEM mindset (Murphy, 2019), and various permutations of these categories. Mindset components often include trait-like constructs such as curiosity, persistence, tolerance for ambiguity, and empathy. Therefore, despite these mindsets not having consensus or well-defined characteristics, there is likely substantial overlap between them and what is needed to invent or to be inventive. In a similar framing, Scharon and colleagues (2024) from KID Museum shared their *Mind of a Maker*, which presents the framework they utilize in many of their programs and evaluations. The authors compare their framework with other maker-related frameworks and discuss how the *Mind of a Maker* framework has been used to develop and evaluate the set of invention-focused programs that KID Museum developed over the last decade, with results showing positive outcomes for learners based on program evaluation data.

Others have also focused on identifying the capacities, ways of thinking, and skills needed to be inventive. One purpose for making the distinction between invention and inventiveness is to center on ways to increase the size of the community and to support a broader range of individuals to develop the habits of mind and skills associated with invention, without focusing specifically on invention as the main product or outcome. A large team of IvE researchers participated in extensive discussions about the attributes that would support individuals to develop inventiveness. The results of this work were shared by Moore et al. (2022) and described inventiveness as the combination of novelty, unpredictability, creativity, and uniqueness, and argued that this can be used to evaluate both students and their work. They used this framing to evaluate 23 common curricular activities and compared how likely each activity was to elicit attributes of inventiveness and analytical skills to demonstrate this. The authors argued that purposefully designing activities that occur at the nexus of engineering and entrepreneurship, which offers more opportunities for students to display inventiveness, will likely improve the chances of engaging individuals from populations that are traditionally underrepresented in IvE. An additional contribution of this paper was the approach of using a documented framework to evaluate educational resources and curricula to identify where opportunities for engaging in inventiveness exist or can be incorporated.

Along with identifying where the components of "inventiveness" may be developed in formal and informal settings, it is critical to be able to evaluate whether individuals possess or are developing these attributes. Assessment and evaluation of how learners are influenced by engaging in IvE is critical to understand impact, build theory, and inform related policymaking. Previously discussed research contributions may be used to assess impact on learners. Maltese and collaborators have taken a different path to address the shortage of research-based tools in this problem space: their work focused largely on developing assessment tools to evaluate the impact of STEM and maker experiences on learners before the pandemic. This included examining outcomes such as STEM identity, creativity, agency, and responses to failure (Maltese et al., 2019). The research team increased its focus on inventiveness and how to best prepare young people for solving future problems. Maltese and colleagues initiated a Delphi study in 2023 with more than 80 experts from across the United States. The experts were asked to name and describe the key capacities required for an individual to engage in inventive problem solving. After three rounds of iterations, the work culminated in a set of capacities and skills that the experts deemed essential for creative and adaptive problem-solving across contexts (Maltese, Paul, et al., 2025; Maltese, Penney, et al., 2025). The capacities and skills identified in the Delphi study are listed in Table 3, Column 4 and are compared to three earlier sources that also identified capabilities and skills of inventiveness.

Table 3

Similarities and Differences in Capacities and Skills from Four Sources

Invention: Enhancing Inventiveness for Quality of Life, Competitiveness and Sustainability (Committee for the Study of Invention, 2004)	A Framework for Invention Education (InventEd, 2020)	Mind of a Maker (Scharon et al., 2024)	Capacities Needed to be a Problem Solver (Maltese, Paul, et al., 2025; Maltese, Penney et al., 2025)
	Calculated risk-taking	Exploration	Boldness
	Creativity	Imagination	Creativity
Curiosity	Curiosity		Curiosity
	Empathy	Perspective taking	Empathy
Passion	Passion		Passion
Resilience	Resilience		Resilience
Resourcefulness	Resourcefulness		Resourcefulness
Tolerance for complexity and ambiguity	Tolerance for ambiguity and complexity		Navigating ambiguity
Learn from failure			Adaptability
			Autonomy
			Confidence
			Ethics
			Focus
Critical stance toward own work			Humility
		Initiative	Initiative
			Intentionality
Conceptualize and break down problems			Motivation for problem solving
			Open-mindedness
		Perseverance	Perseverance
			Playfulness
		Reflection	
		Skill building	
		Teamwork	Teamwork
Practical action			
Nonconformity			
Optimism			
Persistence			
Delay of gratification			

The next steps for Maltese and colleagues' research will involve working with educators to create assessments for the capacities and implement strategies for learners' development of the "inventiveness" capacities in formal and informal learning environments.

4.4 Inventive Identities

In contrast to the large corpus of research on STEM identity development (Carlone & Johnson, 2007; A. Y. Kim & Sinatra, 2018; Lockhart et al., 2022), research on "inventive identity" is a relatively recent topic in IvE research. A small number of recent studies have examined the psychological outcomes of participating in invention competitions with a view to capturing the development of "Big I" identification as an inventor, and results have been mixed. For example, in one study of a yearlong invention competition program, Couch, Skukauskaite, and Estabrooks (2019) found that at the end, only one-third of the nearly 200 high school-aged participants self-identified as "an inventor." However, interviews with a smaller sub-sample of participants revealed that identity shifts were underway. More recently, in a retrospective single case study by Saenz, Skukauskaite, and Sullivan (2024), the participant attributed the development of their identity as an inventor to having taken part in multiple invention competition experiences, as well as to the emerging recognition from others. These studies highlight that serial participation in invention competitions and related contexts may be needed to foster self-identification as an inventor among young people, through both the continued practice and refinement of invention-related skills and strategies and "Big I" *Inventor* endorsements from others.

It is likely, however, that the broadest-reaching and most common exposure to IvE will occur in settings that entail less intensive programming than a yearlong invention competition, such as in STEM or engineering classrooms, or out-of-school time settings such as camps and museums. In these contexts, the question shifts from whether students self-define using the moniker of "Inventor" to whether students perceive that they possess an inventor's perspective on the world. Specifically, IvE researchers may ask: *How can invention education experiences promote students' ability to define themselves as possessing the dispositions, worldviews, and strategies of inventors*? Such a question encourages researchers to acknowledge a more nuanced approach to the construct of inventive identity, and encourages practitioners to consider how the learning environments they create can offer students the opportunity to develop knowledge, technical skills, and new ways of thinking about themselves. Several studies by Garner and colleagues demonstrate that even brief exposure to IvE can promote students' exploration of their inventive identity.

Garner and colleagues use the Dynamic Systems Model of Role Identity (Kaplan & Garner, 2017) to conceptualize inventive identity. They define it as a person's network of inventive-related beliefs, goals, self-perceptions, emotions, and possible actions oriented toward creative solutions for complex problems (Buning et al., 2025). According to this definition, a person's inventive identity develops over time, is of their own construction, and can manifest variably as the person enacts different social-cultural roles in various contexts that may or may not present opportunities to behave inventively. Over time, an individual may develop an inventive disposition or mindset, and this can support the expression of an inventive identity in multiple roles and contexts.

The individual's inventive identity in a given role (e.g., invention competition participant) involves one or more of the following psychological elements acting interdependently, in support of and in response to action, in a particular social-cultural context:

- self-perceptions, such as describing oneself as being a curious person who likes to find and solve problems
- ontological and epistemological beliefs, such as holding an assumption that there are problems in the world that can be solved through the invention of new tools or products
- purposes and goals, such as adopting the goal of creating a product that can solve an identified problem
- perceived action possibilities, such as using knowledge of additive manufacturing to develop a prototype or tweaking a design that has failed during initial testing

Each of these elements is imbued with emotions such as pride, disappointment, or self-efficacy. All elements of the role identity system, including action, are subject to the influences of four interdependent control parameters: dispositions, such as need for achievement, extraversion, or an inventive mindset; the domain, such as agriculture or medicine; the social context, such as an IvE lesson in a classroom involving a teacher and peers; and culture, such as a normative value of collaboration or an absence of representation in the patent-holding community.

Inventive identity development can occur in short- and long-term timeframes through a process of identity exploration, deliberately processing information in relation to the self in ways that engender change in the content and structure of the identity system (Kaplan et al., 2014). Learning environments can support or impede identity exploration through the presence or absence of several features of the context, including materials and prompts that increase perceived relevance to the self and one's life, and scaffolds that support efficacious and emotionally safe exploration of new perspectives and possibilities. On a practical level, such features might include the presence of novel and interesting activities that align with students' goals and perceived interests, such as designing something new, inventing something, and finding out something they do not already know. In one recent empirical study of Camp Invention, Garner et al. (2021) examined students' ratings of their most- and least-liked activities. The most-liked activities involved making, creating, and building, with respondents agreeing that these activities involved designing something new and finding out something that was previously unknown. The least-liked activities involved being coached and sharing their ideas in a group setting, where students rated themselves as feeling significantly less confident and more unsure. Together, the findings support the notion that IvE can support students' inventive identity exploration and that the activities rated as the most enjoyable and valuable also supported feelings of confidence and safety.

In another study, Kaplan et al. (2023) explored the scaffolds that might support inventive identity exploration among individuals who have traditionally been underrepresented in the innovation ecosystem: teens with minority backgrounds, females, and individuals with disabilities. Using a focus group protocol, the researchers solicited participants' perspectives on invention in the context of sports and technology, within the simulated social context of a museum exhibition. The researchers found that even though the topic of the museum exhibition included invention, participants needed prompts to recognize and interpret their own behaviors and past experiences as involving inventiveness. Participants instead tended to consider invention as something that was done by others rather than by them, and benefited from explicit language that named and described strategies that could be used during the invention process. This information was used to refine the museum exhibition's signage and interactives. Post-exhibition opening interviews with additional participants revealed that the exhibition promoted personal relevance in relation to the topics of invention and sport, and made effective use of interactive stations to support visitors' exploration of inventive beliefs, goals, and action possibilities in non-museum-visitor roles, including parent, professional, and student (Garner & Kaplan, 2024).

This research highlights that inventive identity development involves internal, psychological processes, but also psychosocial and sociocultural processes of learning by considering one's own and others' experiences, and by participating in contexts in which the individual is recognized as inventive and supported to demonstrate inventiveness. The social identity characteristics of the participants in the above studies are aligned with traditionally underrepresented groups in the invention sectors of the economy, including females, individuals of color, and individuals with disabilities. Through situated reflection and action in multiple contexts, these individuals demonstrated both existing knowledge of their own inventiveness and exploration of whether inventiveness might be a cross-cutting component of their identity. Further research is needed to understand if, when such a component is reliably deployed in multiple contexts, it becomes a disposition or, as described previously, an inventive mindset.

4.5 Affective Aspects of Inventiveness

Research in STEM education has revealed that ongoing, supported experiences are needed to develop both a sense of belonging in STEM and self-efficacy for tackling STEM and engineering-related tasks (Penuel et al., 2023). Notably, affective or non-cognitive constructs such as interest, anxiety, and self-efficacy have been shown to influence students' intentions to persist in STEM career pathways (Xu & Lastrapes, 2022) and may also be differentially impactful to the retention of individuals from historically underrepresented groups, including females and individuals of color (Hughes et al., 2015; Penuel et al., 2023). The reviewers suspect that this is also true for IvE. Students may need substantial and long-term support to develop positive attitudes and self-perceptions toward invention-related activities to identify as an inventive person or as an inventor, and to remain in educational or career pathways that offer invention and innovation opportunities (Couch, Skukauskaite, & Estabrooks, 2019; Saenz, Skukauskaite, & Sullivan, 2024). Next, several studies are summarized that document the affective correlates of inventiveness and point to their importance in the design and evaluation of IvE programming. It is important to note that participants in these studies had, for the most part, self-selected into an IvE camp or competition context. The reviewers assume a predisposition of positive affect for these settings and acknowledge that this may limit the generalizability of the findings to other student and teacher populations.

A mixed-methods study by Patel and colleagues (Patel et al., 2024, 2025) investigated changes in students' beliefs and emotions pertaining to inventing, being inventive, and using science and math to solve real-world problems. The researchers surveyed more than 800 elementary and middle school students from rural and suburban areas who were participating in a Camp Invention summer program. Students completed pre- and post-camp surveys, and a smaller sub-sample of students participated in focus groups to provide more in-depth information about their experiences. The survey portion of the research (Patel et al., 2024) examined pre- to post-camp changes in STEM confidence, interest, and anxiety associated with math and science, and also examined students' perceptions of their problem-solving and invention activities. Students with low levels of interest or high levels of anxiety at the initial timepoint showed increased interest and lower anxiety at its conclusion. Affect toward math and science also tended to improve, while perceptions of worry about math and confusion about science reduced for those who initially scored in the high range. Students with lower initial perceptions of their problem-solving and inventing skills showed improvement at the post-camp timepoint. These findings were not systematically associated with differences in gender or geographic location, suggesting that the pedagogy was effective for students with different demographic characteristics.

> ***"Students with low levels of interest or high levels of anxiety at the initial timepoint showed increased interest and lower anxiety at its conclusion. Affect toward math and science also tended to improve, while perceptions of worry about math and confusion about science reduced."***
>
> (Patel et al., 2024)

In the second part of the study (Patel et al., 2025), researchers conducted a thematic analysis of the focus group responses. Students revealed developing awareness of the relations between inventing and professional social skills, such as collaboration, teamwork, and empathy. They were able to identify specific STEM concepts and were able to articulate their own definitions of what it meant to be inventive. The students described enjoying the problem solving, iterative learning, and hands-on style of the camp activities, and incorporated this excitement into expressions of future goals to continue to develop these real-world applications of STEM.

Other scholars have also used qualitative methods to document associations between positive emotions and students' motivation to learn in the context of IvE. For example, in a small-scale study, Kim and colleagues (D. Kim et al., 2019) implemented invention problem-based learning activities with middle school students, many of whom were English language learners. The four focal students in the study talked and wrote about their experiences. Notably, activities were described in ways that co-located positive emotional and motivational terms, such as "interesting," with descriptions of the activities, such as "I got to learn something that I did not know."

Finally, teachers have also reported positive perceptions of student engagement and affect toward invention and inventive problem solving after exposure to IvE in formal and out-of-school time contexts. Garner and Kuhn (2022) surveyed more than 200 teachers who had participated as Camp Invention facilitators and found that one of the most meaningful experiences for the teachers was witnessing "student growth" in the affective domain, which they described as increased confidence and ability to manage emotions in the face of failure. In a technical report summarizing a national, cohort-based professional development program for K-12 teachers, Pasquantonio and Gerwe (2024) noted statistically significant increases in teachers' ratings of their students' interest in the topic of invention from the beginning to the end of the invention-oriented lesson. In addition, teachers perceived that students saw themselves as being more inventive after completing the IvE lessons, which emphasized connections between invention and current events.

> ***"One of the most meaningful experiences for the teachers was witnessing 'student growth' in the affective domain, which they described as increased confidence and ability to manage emotions in the face of failure."***
>
> **(Garner and Kuhn, 2022)**

4.6 Developmental and Cultural Considerations for Inventiveness

> ***"During imaginative and free play, young children spontaneously display inventive behaviors such as combining objects in novel ways and transforming objects to solve problems."***

To date, invention education research has largely progressed without developmental and sociological perspectives. These approaches could offer insights into how inventiveness develops throughout life and manifests across cultures, which could be fruitful for IvE practitioners seeking to broaden the public's grasp of inventiveness while strengthening their own understanding of cultural variations in inventiveness. For example, although little is known about the developmental origins of inventiveness, early childhood research has documented how, during imaginative and free play, young children spontaneously display inventive behaviors such as combining objects in novel ways and transforming objects to solve problems. In a recent systematic review of 25 studies, Cankaya et al. (2025) concluded that young children's engagement in "loose parts" exploratory play, which has similarities to making, can benefit creativity as well as convergent and divergent thinking—cognitive domains associated with dispositional inventiveness (Committee for the Study of Invention, 2004). Other research has even noted that adopting a specific role — such as often happens in imaginative play — can improve children's task perseverance (White et al., 2017). These findings posited interesting questions about the use of play and the adoption of roles to support persistence during routine or frustrating aspects of IvE.

> ***"Young children's engagement in 'loose parts' exploratory play... can benefit creativity as well as convergent and divergent thinking—cognitive domains associated with dispositional inventivenes."***
>
> **(Cankaya et al., 2025)**

Research by Colangelo and colleagues (Colangelo et al., 1992) found similarities between youth invention competition participants and adult inventors. Compared to noninventors, inventors demonstrated high levels of intrinsic motivation, a desire to improve, and high satisfaction with invention-related activities. In research by Tang (2011) on Chinese youth invention competition participants, differences in dispositional openness and intrinsic motivation emerged among those with and without patents. Tang's study is notable as it also found minimal evidence of gender differences in inventiveness, with evidence favoring girls in some aspects of experts' judgments of submitted inventions. However, this research also revealed the important role of culturally-endorsed support in young inventors' persistence to acquire patents, suggesting that inventiveness may originate in individual differences such as openness to experience and divergent thinking, *and* it may also require the provision of sustained social support and material resources, which can vary across cultures.

Children grow up in particular cultural settings, and the types of exploratory, imaginative, and object-oriented play that may support successful participation in IvE reflect culturally endorsed activities and associated behavioral norms (Doebel & Lillard, 2023). As children develop, their participation in free-choice activities, such as play and extracurricular activities including sports, and their motivation for particular types of tasks including project-based learning, increasingly reflects cultural norms and practices (Iyengar & Lepper, 1999; D. Kim et al., 2019; Pervun et al., 2022). This can lead to manifestations of inventiveness that reflect variations in cultural interests, culturally relevant problems, and even in invention criteria, such as what constitutes novelty and usefulness (Elliot & Nakata, 2013; Nwoke, 2018). However, it can also lead to the development of stereotypical beliefs about what is and is not considered to be inventive, and perpetuate gender and socioeconomic disparities in STEM and invention-related career pathways (Master & Meltzoff, 2020). These findings support the need for practices in STEM and IvE contexts that mitigate disparities in resource access and that target exclusionary cultural beliefs. Regarding the latter, evidence-based practices include exposing students to counter-stereotypical interactions and role models (Lewis et al., 2019), creating mentoring opportunities for students from historically marginalized groups (Alqudah et al., 2020), and fostering supportive interpersonal relationships (Yu et al., 2023).

5. Community Engagement and Ecosystem Development

5.1 National Importance of Communities and Ecosystems

Community engagement and ecosystem development have been important for national STEM education, and IvE specifically. The Committee on STEM (2024) highlighted the need to develop partnerships and an ecosystem — one of three underpinning, cross-cutting principles crucial for nationally nurturing STEM abilities for everyone. The committee reported that the federal government cannot produce the needed STEM talent and called on multi-sector and multi-agency partnerships to help develop the needed talent. This principle helps connect these five pillars in the federal plan:

- Pillar 1: STEM Engagement
- Pillar 2: STEM Teaching and Learning
- Pillar 3: STEM Workforce
- Pillar 4: STEM Research and Innovation Capacity
- Pillar 5: STEM Environments

The plan recognized that "strategic, mutually beneficial partnerships with local organizations ... enhance the long-term viability of STEM ecosystems" (Committee on STEM, 2024, p. 13). Local partnerships are imperative to bring diverse voices and lived experiences into the STEM ecosystem, thus strengthening the ecosystem itself. The STEM ecosystem was defined as a local, regional, or statewide network, consortium, or multi-sector partnership which may be led or co-led by a nonprofit organizational entity that is operating with the goal of supporting participation in STEM study, activities, and career pathways ... A STEM education ecosystem continuously evaluates its activities and adapts as needed, plans for the long-term, and communicates its work to build broad support and advance best practices (Committee on STEM, 2024, p. 3).

5.2 Research on Communities and Ecosystems in Invention Education

Buning et al. (2024) produced an unpublished report for The Lemelson Foundation, *InventEd Ecosystem Mapping and Development*, which was made available by the InventEd organization to inform this review of IvE since 2019. The report summarized that IvE has growth potential, finding that "collaboration among stakeholders is critical to scale IvE effectively" (p. 3). The IvE ecosystem was described as a diverse and collaborative network in the K-16 space, encompassing organizations beyond education — nonprofit organizations, businesses, community groups, and government entities. The authors identified complementary large networks supporting invention, innovation, and STEM. The InventEd network was referred to as a convener and nurturer of the network's stakeholders. Ongoing mapping of the ecosystem was determined to be essential to build a larger, more inclusive, and effective network. Guiding principles were articulated for this building out of the IvE network. The conclusions and next steps in the document clearly outlined a call to action for members to stay connected to their schools and communities while forging connections with businesses and community groups.

Kalainoff and colleagues' research (2025) on one site of study, Science Coach®, specifically addressed the development of a community-based research and invention ecosystem. The research used theories and methodologies from interactional ethnography and explored the social dynamics among actors that evolved over time into a well-developed, albeit complex, research and invention ecosystem. This research and invention ecosystem was significant to the program but difficult to explain, which led Kalainoff and colleagues to examine the ecosystem in detail. Their findings brought to light the actors and their relationships, with their ecosystem consisting of four interacting hubs: researcher/inventor students, STEM teachers, community partners, and the organization. This research is informative to IvE as other program and organization leaders establish ecosystems that support and sustain their work in communities.

5.3 Programmatic Evidence of Community Partnerships and Ecosystems in Invention Education

The 2019 white paper noted benefits of community partnerships in facilitating students' work and development as inventors, and the Invention Education Research Group (2019, p. 65) suggested the following four areas for future studies to address community-related gaps in IvE knowledge:

- Community Gap 1: the ways teachers and students find and utilize resources in local communities
- Community Gap 2: how the communities interact with students and educators
- Community Gap 3: the impacts that school-community connections have on the community (i.e., formation and development of the IvE ecosystem), including perspectives from community members who actively engage with students
- Community Gap 4: the experience of and impacts on the beneficiaries of students' inventions

A review of current programmatic publications, American Society of Engineering Education (ASEE)-reviewed publications, and published research in scholarly journals illustrates the various aspects of "community" that were prevalent in IvE, though not directly researched. "Communities," however, are referred to as various types of organized activities with different actors, goals, and sizes, making direct comparison difficult. Some communities are geographically bound, while others are affinity bound. Organizations and programs refer to their "wider community" that supports their endeavors, while some larger and more complex communities are referred to as ecosystems. Within the pedagogy of IvE, student and teacher engagement with community members to find problems and solve them are common activities.

Two programs, for illustrative purposes, highlighted community engagement in their IvE work. The Lemelson Center for the Study of Invention and Innovation at the Smithsonian Spark!Lab (n.d.) case study addressed the geographic aspect of a community. It described how the Spark!Lab networks of science centers and children's museums in local communities extend their impact. The local networks connect to their communities and serve as bridges to the invention and innovation that takes place geographically near the centers and museums, making relevant Spark!Lab's work with young people and their educators. Project Invent, a middle and high school program, referred to communities in a recent annual report (Project Invent, n.d.) as a component in teaching IvE, from the standpoint of the organization. The organization considered their community to include donors, corporate and foundation partners, volunteers, school leaders, and passionate advocates. Partners and volunteers were important to teaching and learning with Project Invent; the organization connects teachers and learners to community partners who share knowledge and experiences, helping students identify, understand, and tackle real-world challenges to solve.

Four ASEE-published papers included "community" from different perspectives. Two papers (Newton et al., 2020; Talamantes et al., 2022) noted how communities interact with students and teachers — Community Gap 2, as identified in the 2019 white paper. Newton and colleagues studied and reported on the K-12 InVenture Prize in rural counties of Georgia that utilized a regionally-centered hub. The prize program's expansion included creating an ecosystem with local business professionals who interacted with the students during judging. Regional partners included community-based organizations such as the Rotary Clubs and college alumni associations. Talamantes and colleagues presented a paper positioning IvE as a way to make students agents of change within their community through integration into spaces like community centers, libraries, maker spaces, and professional/industry settings. Community partners helped facilitate the invention process, and young people involved in the program—an unnamed site of study—noted that mentors, inventor users, and community members provided feedback to the youth during the design processes. Making connections with community hosts, partners, and industries aided in the authentic invention process using young people's community wealth perspective. The authors stated that IvE built young people's agency in their communities.

Two other ASEE-published papers (Moore et al., 2022; Recktenwald, 2022) included aspects of "community." Moore and colleagues examined the intersection of engineering design and entrepreneurship and posited that the intersection of these two disciplines promoted community-centered student habits and outcomes that leveraged the cultural wealth within communities. Recktenwald shared the improvements over time to a four-week summer camp for high school students underserved in STEM, sponsored by an institute of higher learning on their campus. The camp included IvE pedagogy with a goal to increase interest in STEM courses, college degrees, and career choices. Rectenwald referred to building a community rather than how a local community interacts with students.

As with the ASEE-published papers, researchers addressed the four Community Gaps, as shown on Table 4:

- Community Gap 1: The ways teachers and students find and utilize resources in local communities
    - Was minimally researched

- Community Gap 2: How the communities interact with the students and educators
    - Researched more than the other three community gaps in describing actions within their sites of study.
    - Evidence of these community interactions in reviewed journal articles included meetings/events/showcases (8 examples); talking to people/feedback (7); mentors/SMEs/collaborators (6); community need/ideas from colleagues (3); resources (3); ecosystem (2); and partnerships (1).
- Community Gap 3: The impacts that school-community connections have on the community (i.e., formation and development of the IvE ecosystem), including perspectives from community members who actively engage with students.
    - Not as well researched as the other three Community Gaps. However, the few extant research studies included rich details regarding types of community impacts and offered insights into the data collected, as well as recommended future studies that may address this gap in greater detail.
- Community Gap 4: The experience and impacts on beneficiaries of students' inventions
    - No research.
    - Results were not evident.

Table 4 identifies how these community gaps were mentioned or addressed.

Table 4

Community Gaps Addressed in Current Scholarly Research

Gap 1: The ways teachers and students find and utilize resources in local communities			
Author(s)		**Study methodology**	**Evidence addressing gap**
Maaia, L. C.		Interactional ethnography	Maker-community resources
Gale, J.		Case study with cultural historical activity theory as the primary theoretical and analytical framework	Identified how one student used contacts and knowledge within the school community to progress work on the team-based invention
Kalainoff, M., et al.		Interactional ethnography	One program, external to formal school environments, developed a local use-inspired research and invention ecosystem to provide students and teachers with community-based resources and a network of support

Gap 2: How the communities interact with the students and educators

Author(s)		Study methodology	Evidence addressing gap
Gale, J.		Case study with cultural historical activity theory as the primary theoretical and analytical framework	Teacher held community meeting
Jackson, D. W.		Mixed-methods case study	Community showcase of students' work; visits from community members
Ewell, E., et al.		Case study	Talked to friends, police officers, and firefighters; community engagement meeting with NJ DEP; competitions; connected to subject matter experts
Skukauskaite, S., S., , et al.		Interactional ethnography	Engaged community in feedback; presented design locally and in a final public celebration
Skukauskaite, A., Saenz, C., et al.		Interactional ethnography	Working with mentors; problem was student identified in their community
Couch, S., et al.		Guided by constructivist and sociocultural theories	Mentors and others from the larger community beyond the school or classroom; technical solutions reflect needs of the community; multiple actors who engage share expertise and guide student work; community provides feedback
Couch, S. & Kalainoff, M.		System-level ethnographic study	Offer cultural community wealth; community collaborators invent with students; provide feedback; common approach 20 discusses building an invention ecosystem as a critical support component for IvE and as a resource for community information
Jackson, C. R., et al.		Program evaluation study	Students communicate technical findings to community members
Jackson, D. W., et al.		Cultural psychology approach to design-based research	Students talk to community members; community showcase at the end of the camps; strong connections amongst community members
Rowe, S. R. M., et al.		Program evaluation study	Beneficial partnerships; leverage community-based problems; near-peer mentoring; interview users; pitch to community; and community experts
Scharon, C. J., et al.		Framework comparison	Large-scale community event; community members present design challenges
Kalainoff, M., et al.		Interactional ethnography	Community partners as a part of a larger ecosystem; community partners as primary actors and equally as important as teachers; Fig. 1 identifies community partners as access to community research labs, subject matter experts, community college dual enrollment research course, research ideas from community colleagues, individuals and businesses funding programs/supplies (p. 07)

Gap 3: The impacts that school-community connections have on the community (i.e., formation and development of the IvE ecosystem), including perspectives from community members who actively engage with students

Author(s)		Study methodology	Evidence addressing gap
Gale, J.		Case Study with cultural historical activity theory as the primary theoretical and analytical framework	Community is defined as other people or groups who share the same general object, although they may belong to the activity system at varying levels of Influence; Tension (b): Community expectations versus student goals extensively discussed (pp. 14–15)
Skukauskaite, A., Saenz, C., et al.		Interactional ethnography	Section on Fostering Human Connections Beyond the School as a Support with one telling case of one community member's participation at an event was impactful and that students "held onto" his belief in their work
Couch, S., & Kalainoff, M.		Systems-level ethnographic study	Table 6 Enhancing Strength-based Practices in the LMIT Program illustrates existing practices and how practices may be enhanced; two of the seven practices focus on community—invent with people in local communities and recognize cultural assets and community wealth diverse students bring to their work within teams
Rowe, S. R. M., et al.		Program evaluation study	The abstract mentioned that program data from 2019–2023 was collected via learner, educator, community partner, and parent surveys. However, the data from the community partner survey was not discussed
Scharon, C. J., et al.		Framework comparison	KID Museum's future evaluation could benefit this gap; the organizations envisions survey, interview, focus group, and observation instruments that consistently measure core Mind of a Maker outcomes for students of different ages; alumni offer an opportunity to conduct longitudinal research; data collection constraints are mentioned with regards to community participants

Gap 4: The experience and impacts on beneficiaries of students' inventions

Author(s)		Study methodology	Evidence addressing gap
none		none	none

Opportunities exist for research and evaluation of community engagement and ecosystem development. Buning and colleagues' *InventEd Ecosystem Mapping and Development* (2024), Kalainoff and colleagues' *ecosystem research* (2025), and Scharon and colleagues' *envisioned future evaluation* (2024) all offer insights to more fully understand "community" impact and importance to IvE.

6. Research and Evaluation Methodologies

The 2019 white paper, *Researching Invention Education*, proposed that

> *[a]n 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* (Invention Education Research Group, 2019, p. 66).

Since 2019, there have been varied methodological and epistemological approaches to studying IvE. Recent efforts have included “research,” defined as systematic investigations to develop new knowledge and generate generalizable insights, and “program evaluation,” defined as systematic efforts designed to examine the effectiveness, processes, and outcomes of specific programs or projects. Next, the reviewers describe the most common methodological designs and data-gathering techniques in IvE research and program evaluation studies from 2019 to 2025.

6.1 Invention Education Research and Program Evaluation Designs

The majority of IvE research and program evaluation studies have been exploratory or descriptive rather than experimental in nature. This means that in most cases, data have been gathered in contexts where IvE is not framed as an intervention to be evaluated against a comparison, control, or business-as-usual condition. In addition, IvE research is typically field- rather than laboratory-based, and involves the collection of data either once or over a relatively small number of time periods, such as in a pre- and post-test design or periodically over a yearlong project in the context of an ethnographic case study. A small number of studies have used a correlational design to examine relationships among constructs and behaviors, or investigate potential differences in the direction and magnitude of relationships among constructs for particular subgroups.

6.1.1 Descriptive Designs

Ethnography. In one ethnographic study, Couch & Kalainoff (2024) examined the extent to which the Lemelson-MIT IvE initiatives corresponded with a strengths-based approach, which embodies values such as recognizing the assets of the participants’ prior lived and cultural experiences, encouraging connections with participants’ social networks and communities, and managing the development of positive and resilience-oriented approaches to challenges (Hammond, 2010). The researchers created and analyzed a research archive containing a number of data sources including annual reports, interview transcripts, published research papers, and participant testimonials. They examined the corpus of data according to various features of each program, including audience type (e.g., high school, undergraduate students), years in operation, and resources. After using this approach to describe the initiatives in relation to seven existing strengths-based practices, the researchers laid out several additional phases of programmatic development that would further enhance this core value.

Kalainoff et al. (2025) used interactional ethnography (Skukauskaite & Green, 2023) to evaluate the evolution of Science Coach®, an educational STEM and invention nonprofit organization. Two theoretical frameworks were also woven into the design, with one proposing that students' interest precedes the development of technical proficiency, and the other proposing that self-efficacy derived from prior successful action as well as environmental support provides the foundation for students' subsequent career choices (Lent et al., 1994). Data sources included interviews with key informants, archival participant survey and competition outcome data, and reports and other documents produced by the organization over a period of 17 years. The researchers created a timeline of the development of the organization and created an "actors and relationships" diagram depicting key resources, activities, partnerships, processes, and products. Through this process, the researchers were able to map the ecosystem of components associated with the growth of the program and its impact on students. They organized their evidence according to design principles, which can be summarized as follows: connecting phases of the program to a theory of change; supporting students' agency for problem selection followed by connection to a coach or mentor; building an ecosystem of mentors with diverse areas of expertise; honoring the professionalism of participating teachers; supporting the development of students' STEM identity and sense of belonging; and building a community of belonging for students and teachers.

Case Studies. Invention Education research frequently uses case study designs, where a "case" can include one or more individuals within a program, or can refer to strategies for describing an entire program (Yin, 2014). In a qualitative single embedded case study of a Lemelson-MIT InvenTeam, Gale (2022) used Cultural Historical Activity Theory (Cole & Engestrom, 1993; Roth & Lee, 2007) to examine the ways in which 15 high school students developed and used tools, created group norms, and embodied new and changing roles to navigate the process of inventing a device that alerted the user to the presence of a child left unattended in a hot car. Data sources included brief repeated interviews, weekly observations, end-of-project surveys, design logs, and project group chat logs. Analysis involved iterative coding and comparisons among the data sources that yielded a CHAT diagram depicting the activity system, including its subjects (people), objects (the goal), outcome (the consequences of goal-directed action), tools used (e.g., curriculum, technology), the community, the rules (e.g., the norms of participation), and the division of labor among the individuals. This case study revealed that students worked toward the object (goal) of creating a working device. They used a combination of formally and informally gleaned STEM knowledge as a tool to solve the many problems that the team faced as they completed their invention journey. The division of labor emerged over time and represented a point of personal growth (and frustration) for the students. Such growth was captured through the outcome of using epistemic practices of engineering, including working well in teams, persisting in the face of failure, and identifying as an engineer. Tensions emerged in the activity system around technical challenges, in managing the community's expectations of the team's performance, and in negotiating invention activities in the context of a high school. The study revealed that the students cared deeply about the process, outcome, and consequences of their invention activities.

In an instrumental case study, Garner and Kaplan (2024) examined the ways in which individuals construct personal relevance and engage in inventive identity exploration while in the Lemelson Center's Spark!Lab, a facilitated museum space dedicated to IvE. They used a purposively diverse sampling strategy to observe and interview young male and female visitors of varied demographic backgrounds who visited Spark!Lab with family members. By conducting observations of the visitors' paths through the activities and by asking prompt questions at the beginning and end of the visit, the researchers gained insights into visitors' preferences and inventive behavior patterns. They found that visitors often chose to engage in activities that appeared to be familiar to them, and that matched their prior interests and skills. When faced with activity station materials, visitors' inventive activities often began with a period of materials exploration and problem definition, followed by a period of goal-directed action and iterative testing and tweaking. Over time, both the materials and the goal became refined until a satisfactory solution was produced and, in many cases, spontaneously shared with others. By observing the family members as well, the researchers gained information about the ways in which adults can both facilitate and impede young inventors' actions. The findings were articulated along with recommendations to support agentic inventive identity exploration by visitors in Spark!Lab.

6.2 Pre- and Post-test and Correlational Designs

A small number of studies have investigated changes over time in students' knowledge, self-perceptions, and attitudes that are associated with participation in IvE. In Patel et al.'s (2024) large-scale study of Camp Invention students, the researchers used previously validated measures (Bai et al., 2009; Glynn et al., 2009) to assess students' pre- and post-camp self-perceptions of science and mathematics interest, anxiety, problem-solving ability, and inventing. Their initial findings revealed stability and ceiling effects on some of the variables, speaking to the self-selected nature of summer camp participation. However, when the analytical sample was restricted to those students who did not score the maximum at the pre-camp timepoint, the researchers noted pre- to post-camp gains for science and math interest, perceptions of problem solving and inventing skills, and reductions in science and math anxiety. The data also showed that boys and girls benefited in similar ways from the camp; no gender differences in math and science interest and anxiety were noted.

In an earlier study of Camp Invention students, Garner et al. (2021) examined pre- and post-camp responses by a diverse sample of students on *Inventive Mindset* (divided into Ingenuity and Solution Seeking), and *identification with STEM subjects* (science, mathematics, and technology). The research revealed that Inventive Mindset scores were stable from pre-test to post-test, although — similarly to Patel et al. — fewer students responded to the post-test survey. Notably, gender differences were found in inventive mindset and identification with STEM: whereas boys' inventive mindset scores were positively correlated with being "a science person" and "a technology person," they were not correlated with being "a math person." This pattern was reversed for girls, whose inventive mindset scores were correlated with identification as "a math person" but not the other two subjects.

6.3 Design-Based Research

Design-based research (DBR) uses a collaborative, iterative approach in which researchers and practitioners co-design and test educational innovations in authentic settings, with aims of improving practice and generating theory (Reeves & McKenney, 2015). When applied to invention education, DBR allows collaborative teams to develop and refine learning environments that support students as inventors.

These environments may leverage design thinking, prototyping, and iteration. The research is designed to inform and examine iterations of the learning environment to determine its impact on participants (Design-Based Research Collective, 2003).

D. W. Jackson's (2022) sequential mixed-methods study involved DBR that aimed to explore a conceptual framework of student engagement and inventive self-efficacy development and to generate information that could be used to revise a five-day invention-themed camp for middle school students. The camp's activities included an adapted form of the Lemelson-MIT JV InvenTeams curriculum and allowed for the invention of one pre-determined and one free-choice device. The study's conceptual framework proposed reciprocal relations among student engagement and self-efficacy for invention, with both developing in the context of the "practices of inventing" (p. 377). Data sources included pre- and post-camp interviews, observations, audio and video recordings, and daily questionnaires. Two diverse teams were chosen for more in-depth study. Statistically significant gains were noted in students' self-efficacy for aspects of inventing that were highly specific to the camp (e.g., using electronics), and students also gained in the degree to which they felt engaged in the camp relative to their school contexts. These gains were similar for boys and girls. The qualitative data revealed high behavioral engagement and motivation to succeed in creating an invention, although the author noted that such engagement may have impeded social relations among the students. The students responded with positive emotions to the tasks' novelty and choice, and perceived distinction from tasks typically encountered in school. The findings also revealed dynamic, non-linear changes in engagement and self-efficacy that were closely tied to the nature of the activities as well as students' progress and challenges while they worked to create their inventions.

A brief or wise intervention is a targeted psychological strategy designed to produce lasting change in thoughts, emotions, or behaviors. Such interventions are often simple and concise, but can have enduring effects if they shift the ways in which individuals make sense of recurring experiences (Yeager & Walton, 2011). Using a DBR-informed approach, Garner et al. (2023) designed and tested a brief or wise intervention, the Innovators' Promise, and examined the impact on those students who had reported having seen it in their workbooks while at Camp Invention. The study involved administering the Inventive Mindset questionnaire (Garner et al., 2021) and a measure of identification with STEAM subjects to students before and after the week-long Camp. Students who reported having read the Innovators' Promise in their workbook rated themselves statistically significantly higher on the Solution Seeking subscale of the Inventive Mindset questionnaire than those who reported that they had not read it. This group of students also demonstrated statistically significant increases in their identification with science compared to those who did not report exposure. These patterns were similar for boys and girls. The researchers also asked students if the Innovators' Promise was helpful to them, and the responses were coded using the Dynamic Systems Model of Role Identity (Kaplan & Garner, 2017). Half of the students who provided a response to this prompt referenced self-perceptions associated with inventiveness, and approximately 40% referenced its motivational nature. The researchers concluded that there was some evidence for positive benefits for those students who were exposed to the brief intervention, even though it was only presented for five days.

6.4 Large-Scale IvE Program Evaluation Example

Large-scale, multi-phase evaluations of IvE programs and experiences are rare yet valuable. One such study was conducted between 2019 and 2024 by RK&A/Kera Collective, who gathered data to inform the design, implementation, and summative evaluation of *Change Your Game* | *Cambia tu juego*. An exhibition at the National Museum of American History (NMAH) in Washington, DC, *Change Your Game* | *Cambia tu juego* was created by the Lemelson Center for the Study of Invention and Innovation. In addition to presenting the history of sports and technology, the exhibition was designed to prompt diverse visitors to explore their inventive identity through the use of innovative interpretation strategies including question-oriented label text, interactives that supported practicing specific inventive strategies, and a reflection space where visitors could consider inventiveness in multiple life domains. The technical reports by RK&A/Kera Collective are notable, as they reveal how program evaluation can help IvE professionals identify key audiences for their work, develop strategies to promote interest and engagement among these audiences, and capture the impact of participation in a program or experience.

6.4.1 Front-End Evaluation

In 2019, ahead of exhibition development, R&KA/Kera Collective presented a front-end evaluation report (RK&A, 2019). This type of evaluation is typically conducted at the beginning of the exhibition design process in order to gather information about potential audiences' understandings and associations with exhibition concepts and themes, reactions to preliminary concepts and ideas, and responses to possible titles for an exhibition. In this case, the report presented the findings of 40 in-depth interviews with adult and youth visitors to the museum. Interviews solicited responses to the tentative title of the new exhibition, reactions to the topics of the "history of invention and technology related to sports" and the "role of invention in technology and sports," and perceptions of relevance and interest toward the exhibition's proposed topic and themes. The front-end evaluation provided input on visitors' preferences toward each aspect of the exhibition, and its findings were used to retain or remove topics and adjust the exhibition's focal themes.

6.4.2 Formative Evaluation

Two years later, after the content and design of the exhibition had reached the alpha and beta prototyping stage, RK&A conducted interviews and focus groups in which they presented images, graphics, and sample text to individuals who were representative of the target audiences (RK&A, 2021a, 2021b). Formative evaluation is typically conducted during a pilot or testing phase to provide feedback that can inform changes that better meet the needs of the participants. In this case, the reports described target audiences' reactions to particular materials and perceptions of their own inventive identity. The diverse audiences included nine adults, 12 females 10-17 years old, six males 13-14 years old, and nine individuals with disabilities. Early-stage findings included positive responses to the variety of people, artifacts, and sports that were proposed for inclusion, as well as an appreciation for the exhibition's cultural diversity and bilingualism. However, the findings also revealed that the initial materials selection and descriptive text did not resonate with target audiences' personal sense of inventive identity. Specifically, many felt that the term "Game Changers," which was the proposed title of the exhibition, applied to others and not to themselves. This information became critical for decision making around the interactives and the subsequent revision of the exhibition title from "Game Changers" to "Change Your Game."

6.4.3 Summative Evaluation

In 2024, RK&A/Kera Collective conducted a summative evaluation after the exhibition opened. Summative evaluations aim to provide information about the overall effectiveness of a program or project. They typically focus on questions about whether the desired outcomes have been achieved and how targeted populations of participants or stakeholders are impacted (Garner et al., 2025). The summative evaluation study synthesized 106 qualitative interviews "to collect firsthand experiences from walk-in visitors to NMAH as well as four priority audiences for the exhibition and/or the Smithsonian—females, ages 10-17, African American males, ages 10-17, persons with disabilities, and self-identifying Latinx visitors" (Kera Collective, 2024, p. 6). The interviews reflected 56 individuals who had visited the exhibition and 51 who visited the museum but not the exhibition. Additional data sources included: three sets of group interviews that were conducted with youths, ages 10-17 who had visited the exhibition; contextual inquiry sessions involving observations and interviews with nine exhibition visitors with disabilities; and six cued interviews with self-identifying Latinx visitors, who offered feedback on the exhibition's content and bilingual interpretation.

The evaluators found that both visitors and non-visitors to the exhibition were able to apply the concept of invention to multiple domains in their own lives. Approximately half of the exhibition's visitors found the stories relatable, with those who did not find it relatable commonly citing a lack of interest in sport. Many of the visitors revealed that the content of the exhibition impacted their previous understanding of the world, including the ubiquity of inventions that they see or use every day. Diverse youth visitors enjoyed artifacts and stories that related to their own personal experiences, but some were flummoxed by the presentation of some inventions as being innovative, simply because they had always been present in their own lifetime. The young people also unanimously agreed that the interactive in which they could leave a drawing and description of their own invention needed no improvement. Although the exhibition required interpretation for individuals with disabilities, these visitors self-identified as being highly inventive even ahead of visiting the exhibition, due to the need to adapt and respond to the environment to accommodate their needs. When asked to define the qualities of an inventor, the youth visitors responded with terms that echo the literature, including "creative," "determined," "intelligent," "courageous," "collaborative," "open-minded," and "empathetic." Approximately half of the youths indicated that they felt "somewhat more inventive" than before they entered the exhibition. The most positively received aspects of the exhibition were stories that related to visitors' personal experiences, the presence of provocative questions, and the slick design elements that conveyed the exhibition content in contemporary ways.

In sum, this large-scale evaluation revealed both the process and the impact of a museum exhibition that provided visitors with the dual opportunity to examine "Big I" *Inventor* in society as well as "Little i" *inventiveness* in themselves.

6.5 Research and Evaluation Tools

Since 2019, new survey tools have become available to the Invention Education research community. Some are intended for use with students (Garner et al., 2023; Scharon et al., 2024), while others aim to capture teachers' perceptions of their own inventiveness in their teacher role and in non-teacher roles (Garner & Kuhn, 2022) as well as teachers' attitudes toward invention pedagogy (Pasquantonio & Gerwe, 2024; Rowe et al., n.d.).[1]

6.5.1 Inventive Mindset Measure

Garner et al. (2023) created a 10-item Likert scale *Inventive Mindset* measure intended for use with upper elementary and middle school-aged students. The measure was validated with a national sample of 462 students (47% female, 66% White) attending Camp Invention. It was found to have adequate psychometric properties, including internal consistency reliability (ω = .78) and construct validity (NFI .90; CFI .93; RMSEA .07). In its final form, the measure included two correlated subscales labeled "ingenuity" (e.g., I have lots of good ideas; I like to design things) and "solution seeking" (e.g., I am a problem solver; I like to make things better).

6.5.2 Inventive Mindset Measure for Teachers

In a technical report for Camp Invention, Garner & Kuhn (2022) adapted the Inventive Mindset Measure using a preamble in which facilitators completed the measure twice: once with the context of "everyday life" and again in their role "as a teacher." This research showed that the measure functioned adequately in a sample of adult respondents. The researchers also found that, although facilitating Camp Invention did not impact their self-perceptions of inventiveness, the facilitators rated themselves significantly higher on inventiveness in their role as a teacher than in everyday life.

6.5.3 Mind of a Maker Survey

To capture the perceptions of students who participated in invention-focused programming by KID Museum in Bethesda, MD, Scharon et al. (2024) present survey data from middle and high school students who participated in programs including *Teen Innovators* and *Invent the Future*. The three-point Likert scale items assess students' self-perceptions of the eight dimensions within KID Museum's Mind of a Maker Framework, which are: *Perseverance, Imagination, Initiative, Perspective Taking, Teamwork, Reflection,* and *Skill Building* in Mathematics, Science, and Engineering. In their sample of 1,046 participants, between 70% and 92% reported experiencing "a little" or "a lot" of these dimensions during the program. Reliability and validity statistics for the items were not reported in the paper.

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[1] Recent research and program evaluation efforts have also used interview protocols and open-ended survey prompts to gather qualitative data that can then be coded to provide insight into patterns of experiences across individuals and over time. The interested reader may be able to obtain a protocol by contacting a corresponding author.

6.5.4 Teachers' Inventive Practices

Recently, Rowe et al. (n.d.) developed an *Inventiveness Survey* designed to measure teachers' perceptions of practices or teacher behaviors that foster student creativity, such as brainstorming and iterating, and perceptions or teachers' beliefs about what "invention" entails. The survey was administered to 94 educators and was found to have adequate psychometric properties, including internal consistency reliability and construct validity. The final 22-item measure included two subscales labeled "aspirational practices" (e.g., I cultivate curiosity and wonder in my learners; In my learning environment, we use materials in novel ways to solve problems) and "foundational practices" (In our learning environment, every idea holds value, irrespective of its perceived merit; I create opportunities for my learners to try and fail and try again). One notable contribution is that these practices were classified by expert informants as falling into either foundational pedagogical strategies or aspirational, more challenging pedagogical strategies for teachers striving to implement STEM and STEAM in their classrooms. The survey tool also included seven items through which respondents indicated the extent to which they felt that they are inventive, who qualifies as an inventor, and the extent to which all individuals can be inventive.

6.5.5 "Inventive Me" Single-Item Assessment

Using a different approach, Garner & Kaplan (2024) developed a single-item assessment tool to measure an individual's perceived overlap between themselves and "an inventive person." Drawing on other single-item assessment techniques (Allen, Iliescu, & Greiff, 2022), the researchers developed the measure to be used in a pre-test/post-test fashion with participants in Spark!Lab, a hands-on invention education space, and *Change Your Game | Cambia tu juego*, an exhibition at the National Museum of American History designed to promote visitors' inventive identity exploration. The measure involves two identically sized paper circles that are labeled with "an inventive person" and "me." The individual is asked to place the circles in relation to one another to represent the degree to which they feel there is overlap. The paper is lined, allowing measurement of overlap in intervals of 0, 25, 50, 75, or 100%. The measure has been successfully used with upper-elementary aged students, teens, adults, and individuals with disabilities.

6.6 Future Directions in IvE Design and Measurement

Despite the recent increase in available tools for measuring perceptions of inventiveness and key components of invention education-related programs, researchers and evaluators still face informational challenges when selecting a measure to use in an IvE context. It would be helpful for IvE researchers, evaluators, and practitioners to have access to a repository that includes information about various measures, including directions for use, descriptions of the population(s) for whose use each measure is intended, and whether a validation study has been conducted. Such a repository could include useful contextual information about the measure by including papers and technical reports describing its use. Gathering these measures would also enable researchers to conduct comparison studies to better understand the psychological constructs that each measure purports to assess, and how the constructs manifest in various IvE contexts for diverse participants. Such work would benefit the IvE community by elevating the trustworthiness, reliability, and validity of its most commonly used measures, and by promoting conceptual clarity when IvE is integrated with one or more of the disciplinary and pedagogical approaches described in Figure 1.

7. Concluding Remarks

Researching Invention Education: 2019-2025 deepens the understanding of the field of IvE research. Through an in-depth review of contemporary literature, it reveals how the contours of the research landscape have changed to include renewed interest in lifting the voices of those participating in invention pathways, and in conceptualizing and cultivating inventiveness as an everyday habit of mind. By comparing these new discoveries to the findings of its 2019 predecessor, this white paper highlights the IvE processes and outcomes that have—and have not yet—been investigated. The following conclusions reflect critical ideas and recommendations arising from the review.

7.1 Conclusions

7.1.1 Transdisciplinary Learning and Pedagogical Approaches are Complex, Making Research Complex

As noted in this white paper in Section 1 (Background on *Researching Invention Education: 2019-2025)* as well as Section 2 (IvE: Related Disciplines and Pedagogies), IvE has been defined as the identification and selection of meaningful real-world problems, and the design and development of novel solutions. Often, this requires participants to engage in facilitated transdisciplinary learning, where knowledge from two or more disciplines is utilized to solve problems that manifest outside of the boundaries of either individual discipline. It also calls for the dynamic integration of domain knowledge with higher-order thinking skills and affective propensities, which are challenging for teachers to support and evaluate and difficult for researchers to measure authentically. Contemporary research reveals the complex, dynamic nature of IvE. Its methods reflect that IvE contexts are not easily described or manipulated using traditional large-scale, linear research methods and experimental designs. As such, the frequency of qualitative and design-based research approaches described in Section 6 (Research and Evaluation Methodologies), reflects IvE researchers' attempts to accommodate this complexity.

Increasingly, however, transdisciplinary technical contexts like those included in IvE are being recognized for their potential to develop critical and transformative skills and competencies in young people (Committee for the Study of Invention, 2004). The nature of IvE, with its committed community of IvE researchers, therefore has the opportunity to lead the field of educational research *as a whole*, as it grapples with the issue of conceptualizing and evaluating the impacts of complex, transdisciplinary learning environments (The Spencer Foundation Task Force on Preparation for Transformative Research [The Spencer Foundation], 2025).

7.1.2 The Literature Reflects Genuine Partnerships Between Researchers and Practitioners Providing Answers to Challenging Questions

Genuine partners, albeit in a small number of published research papers, focused specifically on IvE and were identified in this review. Mutually beneficial, organic partnerships require time and funding to design, develop, implement, and then study. This review revealed ways in which higher education researchers work alongside IvE practitioners and program designers. Sustained researcher-practitioner partnerships emerged as a source of new knowledge for meaningful and practice-oriented questions about how IvE works in different settings and for whom. Notably, the multidisciplinary InventEd "hub" community organization has produced many of these partnerships. Examples of partnerships included:

- D. W. Jackson and colleagues published on the work of researchers from Boston College and MIT who partnered with middle school science teachers in Waltham Public Schools (Mass.) in an iterative educational design of IvE curriculum within the school day and in camps. IvE was found to be flexible, versatile, and synergistic for both in-school and out-of-school learning, with strong partners supporting learning, evaluation, and research.
- Garner and colleagues, with partners from Old Dominion University and the

National Inventors Hall of Fame, examined a STEM-based IvE program to better understand the development of inventive mindsets and the effects of a brief intervention designed to promote children's inventive self-perceptions.

- Skukauskaite's team included researchers from the University of Central Florida and MIT, plus a high school teacher and a high school student from Oregon. The teacher and student had been involved in a yearlong invention project that was both in-school and out-of-school. This ethnographic study uncovered support networks utilized for an IvE program; some of these supports were made visible by having a teacher and student as researchers.

7.1.3 IvE Research is Making the Case that Invention Education is for All

As stated in Section 1 (Background on Researching Invention Education:2019–2025), the IvE community has embraced the tenet that every learner should have equitable access to invention education, and that historical, systemic disparities should be addressed through intentional investments in underrepresented youths. Research studies have shown that IvE is inclusive and benefits those who are underrepresented in STEM. This may be due, in part, to the flexibility and versatility of IvE allowing for curriculum to be tailored to community needs. Cultural relevance and funds of knowledge can be introduced, thus strengthening the IvE process. Multiple studies addressed equity for all students by including IvE within the school day (Saenz & Skukauskaite, 2022; Saenz et al., 2024; Zhang et al., 2019) and offering inclusive programs and spaces (Kalainoff et al., 2025; Moore et al., 2019; Rowe et al., 2024; Saenz & Skukauskaite, 2022).

Invention education program evaluation studies have shown positive outcomes for students underrepresented in the STEM and innovation economic sectors. Specifically, Kalainoff et al. (2025) reported no difference in college trajectories among participants in a program focused on research and invention; over 90% of all surveyed respondents — and the subset of respondents identifying as underrepresented minority (URM) — were pursuing a STEM degree or career. Also, URM participation rates were higher than non-URM at the high school level.

Studies by Kera Collective (2024) and Kaplan et al. (2023) also demonstrated that individuals from diverse backgrounds, URM groups, and (dis)ability statuses were able to use material in IvE educational contexts to create self- and community relevance, and to consider how they are inventive in their own lives. This work demonstrated cross-cultural similarities in both the barriers to considering oneself as being inventive and the prompts that can promote considering oneself as being inventive. Notably, research also revealed the near-universal benefit of implementing educational design principles in IvE contexts such that *all* learners are supported to create self-relevance, to re-position the self in relation to invention, and to use scaffolds to explore new inventive actions and ideas within a psychologically and emotionally safe environment (Garner & Kaplan, 2024). Together, these findings suggest that under the right conditions, IvE can be successfully implemented in diverse contexts.

7.1.4 As a Growing Field, IvE Research Benefits From and is Challenged by the Use of Multiple Theoretical and Conceptual Frameworks and Methodological Approaches

The research studies included in this white paper reflect the application of a variety of theories. Examples include constructivism (Maaia, 2019), identity theories (Kaplan et al., 2023 and Saenz, Skukauskaite, & Sullivan, 2024), motivation theories (Scharon et al., 2024 and Patel et al., 2025), Social Cognitive Career Theory (Xu & Lastrapes, 2022), and Cultural Historical Activity Theory (Gale, 2022). Similarly, the studies reveal the varying methodological approaches to investigating IvE experiences and program structures, including retrospective case studies (Saenz, Skukauskaite, & Sullivan, 2024), purposively sampled focus groups with simulated learning environments (Kaplan et al., 2023), interactional ethnography (Kalainoff et al., 2025), pre- and post-test designs (Garner et al., 2021 and Patel et al., 2025), and design-based research (D. W. Jackson, 2022).

The creation of a body of literature that reflects multiple theoretical and methodological approaches poses both opportunities and challenges for the field of IvE research. On the one hand, there are advantages to theoretical pluralism, defined as strategic engagement with "a range of theoretical perspectives" to inform the understanding of a problem space and its larger context (The Spencer Foundation, 2025, p. 6). Theoretical pluralism may result in new or refined theories about the nature of IvE phenomena, and new theories of action that hypothesize how IvE programs can create lasting impacts. Such knowledge can be used in design and evaluation work. Similarly, methodological pluralism — involving the use of multiple approaches to the design and execution of research — allows for a variety of ways of knowing that can inform theory and practice (The Spencer Foundation, 2025). The flexible alignment of theory with research questions and methods can allow multiple forms of evidence to emerge.

On the other hand, theoretical pluralism can cause confusion through the jingle-jangle fallacy (Marsh et al., 2019). This occurs when a phenomenon is characterized using different constructs and terminology, or when the same construct or term is used to refer to different phenomena. Although scholars attend to such definitions carefully, they often work in academic siloes that make it difficult to resolve questions about the degree to which theories are aligned. An analogous challenge arises when methodological pluralism is abundant. As revealed in this white paper in Section 4 (Developing Inventiveness) and in Section 6 (Research and Evaluation Methodologies), when studies draw conclusions using very different methods, it is challenging to generate a definitive, consensus perspective.

7.1.5 Questions About the Impact of Serial and Prolonged Participation in Invention Education Ecosystems Remain Difficult to Answer

The 2019 *Researching Invention Education* white paper called for longitudinal research to "track the learning, progress, and pathways of youth" (p. 65). As noted in Section 3 of this paper (Research on Invention Pathways), such longitudinal and outcome-oriented work (e.g., impact on beneficiaries, invention artifacts, and intellectual property) remains to be completed, but advances in the capacity of IvE program providers to support such work have increased. Recent increases in attention to the questions of how to build and sustain IvE Ecosystems (Buning et al., 2024; Kalainoff et al., 2025) and how to support educational researchers to conduct transformative research in the context of such systems (The Spencer Foundation, 2025) present opportunities for initiatives that investigate individual and system-level impacts of IvE programs. However, as discussed in Section 2 of this paper (IvE: Related Disciplines and Pedagogies), invention education has not yet found an epistemic home, meaning that it has not become aligned with a particular educational research paradigm that offers a shared consensus about how to engage in knowledge building. At present, this means it would be challenging to reconcile longitudinal studies with ecosystem-level studies. It also means that studies designed to capture outcomes, such as patent applications, investment funding, and students' career choices, risk being conducted without a coherent theory of action to trace *how* participation yields particular outcomes.

An opportunity to find such a home may be evident from the 2019-2025 literature review, which revealed attention to the iterative design and contextual evaluation of pedagogical approaches supporting inventions and inventiveness. Such emphases are aligned with the values and assumptions found within the learning sciences (Nathan & Alibali, 2010), a subdiscipline within the field of educational research that is aligned with both the theoretical approach of constructivism that permeates IvE research and the design-based and partnership-oriented approaches to knowledge building described in in this paper in Section 6 (Research and Evaluation Methodologies).

7.2 Recommendations for Enhancing Invention Education Research

7.2.1 Support Research as a Core Component of Invention Education Funding

Although a substantial amount of funding has been allocated to invention education programs, grants and initiatives have tended to prioritize implementation of interventions over research and program evaluation. Requiring IvE practitioners to work with educational researchers or program evaluation providers during the conceptualization or planning phase of their work could greatly increase the quantity and methodological diversity of IvE research. In turn, high-quality research will improve the quality of the body of knowledge that is accessible to educators, researchers, and policymakers.

7.2.2 Coordinate the Creation and Implementation of a Strategic Plan for Invention Education Research

It is evident from this review that field-initiated research efforts undertaken since 2019 have varied in approach, scale, and focus. This has created opportunities to explore different research questions in diverse IvE contexts, but it has also produced findings that are uncoordinated and diffuse. Creating a cohesive plan for IvE research, initiated and updated by a Research Advisory Committee, could support collective action around high-priority questions and challenges facing the field. Such a committee could also serve in an advisory role to IvE researchers to support their alignment with the strategic plan.

7.2.3 Support the Invention Education Research Pipeline

As discussed in Section 3 of this paper (Research on Invention Pathways), there are numerous existing sites that implement IvE in some form. IvE programming now includes options for teachers to embrace classroom-based invention curricula, for schools to adopt commercially available after-school and summer enrichment programs, and for students to participate in invention competitions run by regional and national nonprofit organizations. Because these sites and programs illustrate the diversity of forms that IvE can take, they offer rare opportunities for research investigating transdisciplinary, meaningful learning by both small and large numbers of students over varying periods of time. If supported, research that is embedded in the variety of IvE implementation contexts could result in the continued improvement of IvE programs and the production of a rich body of coherent learnings that can move the field forward.

Like the development and diffusion of inventions and innovations, however, the IvE research process is a multi-component, long-term, collaborative endeavor. At this time, there is a need to support the development and continuation of partnerships among trained researchers, IvE practitioners, and program designers. Partnerships might be formed through diversified sources of funding, including research grants, graduate assistantships, and post-doctoral appointments supported by foundations, federal and state agencies, and private or corporate sponsors. The research pipeline may also be strengthened by policy work to bring IvE competencies and skills to the center of the K-12 core subject-area curriculum standards and career and technical education competencies. This is needed in order to incentivize teacher and school district participation in IvE research.

7.2.4 Support the Dissemination of High-Quality Invention Education Research

The Background section in *Researching Invention Education:2019-2025* identifies working definitions used by IvE researchers. Variations likely reflect the researchers' different contextual and theoretical emphases. However, variance may also reflect the range of publication outlets and audiences to which the research was disseminated, as researchers often tailor the disciplinary presentation of their work to suit the scope of particular journals. It is therefore recommended that the field of IvE research attend to the consensus definition of invention education in *Researching Invention Education: A White Paper (2019)*, and include a description of alignment with or divergence from it. A second recommendation is for IvE researchers to be consistent in the key terms that they assign to their work and to use these terms throughout the dissemination process. This will increase the likelihood that similar work would be found when searching databases for IvE research. A third recommendation is that the field consider creating its own journal to serve as a common and cohesive repository for scholarly work on invention education. A journal with a diverse and multidisciplinary editorial board would also promote coherence and communication among a scholarly community that is currently dispersed across different subdisciplines of educational research.

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[2] The researchers strive to be culturally respectful. However, diacritical marks have been omitted from references to increase searchability of authors' names.

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