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Systematic review of invention education research landscape: state of the discipline and future directions

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Invention and innovation education and its associated practices (e.g., problem-finding, problem-defining, learning from failure, iterative problem-solving, innovation-focused curricula, collaboration, and maker spaces) are moving from the periphery to the center of education at an ever-increasing pace. Although the research and literature on invention and innovation education, collectively termed as Invention Education (IvE) in this research, is on the rise, to our knowledge no attempt has been made to systematically review the literature available on the topic. To address this gap, we identify, collect, and systematically review scientific literature on IvE. We conduct Bibliometrix-based and targeted analysis to identify the topics, sources, authors, and articles most cited, as well as prominent countries publishing IvE literature. Another objective of this research is to uncover the intellectual, conceptual, and social structures of IvE. A third objective is to identify the progress made and the challenges being faced in furthering IvE and propose future directions. Our review shows that the field has seen substantial growth, especially in recent years particularly in the United States. Research shows IvE's importance in nurturing a well-rounded, innovative, and skilled future workforce, emphasizing creativity, critical thinking, collaboration, adaptability, and problem-solving skills. Although with a plethora of curricula and K-20 programs in United States, followed by South Korea, and China, IvE lacks unifying conceptualization, definitions and frameworks. The lack of commonly accepted terms and theoretical bases, and difficulties integrating invention into STEM coursework, are compounded by barriers like resource limitations, curriculum constraints, and the need for teacher training and support. The review underscores the need for IvE to address and dismantle inventor stereotypes and cultivate a diverse and inclusive generation of innovators. It points to the impact of gender and stereotypes on participation in IvE programs and the importance of promoting equity and access to IvE opportunities for all students. The article concludes with a discussion of challenges and future research directions to address them.

KEYWORDS

invention education, innovation education, systematic literature review, Bibliometrix, problem-solving

Introduction

The decline in entrepreneurship, invention, and innovation within the United States has spurred a range of initiatives aimed at boosting inventiveness among young people (Arora et al., 2019). Recent efforts to promote Invention Education (IvE), featuring targeted programs designed to teach individuals how to identify, comprehend, and solve problems effectively "in ways that reflect the processes and practices employed by accomplished inventors" (Skukauskaite et al., 2019, p. 1), highlight the initiative's scope. The importance of inventors and IvE in building economies, creating active academic and entrepreneurial ecosystems, and fostering start-ups is well established (White and Burg, 2019). In K-12 and college settings, IvE and its associated practices (e.g., problem-finding, problem-defining, learning from failure, iterative problem-solving, innovation-focused curricula, and collaboration) are beginning to move from the periphery to the center of the curriculum. Set against this context, we follow Aria and Cuccurullo (2017) to conduct a Systematic Literature Review (SLR) of the academic literature relating to invention and innovation education.

IvE supports the curiosity and inventiveness of young people, and explicitly teaches them novel applications of ideas and tools, mimicking the practices used by accomplished inventors (Garner et al., 2021). IvE is vital for nurturing a well-rounded, innovative, and skilled future workforce who can make meaningful contributions to society. IvE is also important to modernize STEM coursework that fosters creativity, critical thinking, collaboration, adaptability, and problem-solving skills. Through hands-on experiences, students learn practical applications of STEM concepts, while collaborative projects build teamwork and communication abilities. Moreover, IvE nurtures an entrepreneurial mindset, encouraging students to identify opportunities and take calculated risks. Making STEM relevant and engaging, IvE enhances technological literacy and inspires a passion for lifelong learning. Students develop confidence, resilience, integrity, and social responsibility as they address real-world challenges and work toward sustainable solutions. Overall, IvE empowers students to become innovative thinkers, well prepared to make significant contributions to society through their future careers.

Enabled by the widespread availability of academic research databases, SLR offers a highly efficient and effective way to deeply understand the theoretical approaches, reported outcomes, research methodologies, key concepts developed, geographical areas of focus, and research networks in the scientific knowledge of a specific field, as well as identifying gaps that indicate future research opportunities (Aria and Cuccurullo, 2017). Although the research and literature on invention and innovation education, collectively termed as IvE in this study, is on the rise, to our knowledge, no attempt has been made to empirically review the knowledge available on the topic. With the objective of identifying, collecting, and systematically reviewing the scientific literature on IvE, we conducted a bibliometric analysis using two studies to discover the topics, sources, authors, most cited articles, and prominent countries in the IvE literature. Another objective of both the studies was to analyze the intellectual, conceptual, and social foundations of IvE literature. This analysis was designed to map out the main ideas, key topics, and areas of research within the field of IvE. Additionally, our review sought to track advancements and challenges in IvE, suggest prospective paths for future investigation, and highlight areas where forthcoming IvE research could bolster both practical applications and the field's knowledge base.

Our research was guided by these three key questions.

i. What are the key characteristics and trends in the IvE literature, including dominant themes, influential authors, and geographic contributions?
ii. How do the intellectual, conceptual, and social foundations of IvE literature contribute to the understanding and advancement of the field?
iii. Based on existing research, what future directions and opportunities exist for IvE research to address current challenges and enhance both theoretical knowledge and practical application?

We did two studies, each of which contributed to comprehensively answering the research questions stated above.

Methodology

We conducted two studies to investigate the IvE landscape. The first study searched for IvE research from the heavily used database, Web of Science (WoS). The second study gathered additional IvE research from Scopus and Google Scholar. Thereafter, targeted searches for the works of notable authors in the field were conducted to obtain a comprehensive dataset of IvE research. We now discuss the methodology for the two studies here.

Bibliometric analysis using web of science

Study 1 uses bibliometric analysis (Pritchard, 1969), a technique that quantitatively tracks and analyzes scholarly literature through key information, such as authors, journals, methodologies used, contextual focus, and co-occurrence of terms (Durán Sánchez et al., 2014; Roemer and Borchardt, 2015; Gokhale et al., 2020). Methodically obtained metadata and bibliographic material from the WoS database gives a systematic overview of journals (Martínez-López et al., 2018), the field of research (Blanco-Mesa et al., 2017; Milian et al., 2019), and countries of publication (Mas-Tur et al., 2019).

Metadata generation and selection process

In Study 1, we used WoS to obtain an exhaustive inventory of articles related to K-20 IvE. Given the lack of universally accepted terms for IvE and its transdisciplinary nature, we conducted several searches to identify the best combination of terms that would result in comprehensive metadata. We started with a combination of invention or innovation + learning, education, or teaching in the abstract, which resulted in less than 30 relevant articles. Notably, because IvE strategies and programs are also referred to as design thinking or problem-solving education and are conducted in programs like Dare2Design, Destination Imagination, InvenTure Prize, and Project Lead the Way (PLTW), we added these terms to the search. However, this resulted in many unrelated articles and over two thousand results. Finally, searching for "invention education" in all fields, or "learning invention," "innovation education," and "design thinking education" in the abstract led to a set of 115 most relevant articles from WoS. The search was not bound by a set time period, was performed in English, and included articles, review articles, open access, early access, editorial materials, and enriched cited references. The selected WoS categories limited the results to education/educational research, business, psychology, engineering, and economics. Specialized areas, such as medicine, nursing, etc., were excluded from the search.

To determine the relevance of the resulting 115 articles, the authors individually reviewed the titles and abstracts and identified articles that were directly relevant to IvE. An agreement on relevance (irrelevance) led to the inclusion (exclusion) of each article for subsequent analysis. In case of disagreement, the articles were examined by a third expert. This process led to a bank of 50 articles, published 1987–2023 in 31 sources, predominantly journals. For Study 1, we used Bibliometrix to analyze the landscape of IvE research through this relevant collection of 43 articles, two reviews, three editorial materials, and two uncategorized publications (Figure 1).

Data analysis process

Biblioshiny software was used to systematically analyze the final dataset obtained from the search in Study 1 (Huber, 2002). Biblioshiny is the web interface for Bibliometrix V3.0 (Aria and Cuccurullo, 2017) and supports extremely sophisticated visualization of statistics by providing the data in a graphical format. In this study, the tables and figures obtained through Biblioshiny analysis answer research questions 1 and 2.

Study 2: Scopus, Google scholar, and targeted search

The WoS metadata in Study 1 brought up limited IvE research. Significant research and authors were missing from the obtained dataset, which motivated Study 2. To ensure the inclusion of comprehensive data in IvE research, we first searched for IvE articles on Scopus using the same search terms as in Study 1. Thereafter, we searched Google Scholar for IvE research. A Scopus search yielded 178 articles, conference papers, books, and book chapters. Google Scholar search resulted in 28 articles, conference papers, books, and book chapters. The next step was to identify duplicates and irrelevant results. We found 31 duplications in WoS and Scopus results, seven in WoS and Google Scholar, and four in Scopus and Google Scholar, with only one article common across all the three databases. Eliminating duplicates and irrelevant articles finally led to 107 relevant results from Scopus and 17 from Google Scholar. One surprising finding was the continued absence of the works of some notable authors, such as Adam Maltese, Joanna Garner, and Ruth Small, which led us to conduct a targeted search for notable authors. We obtained the list of notable authors from a recent white paper on IvE (Skukauskaite et al., 2019).

The following sections combine the results from Studies 1 and 2 to offer a comprehensive picture of IvE research as we answer research questions 1 and 2. In the next section, *IvE Research Landscape,* we answer research question 1 as we present the existing landscape of the knowledge base through an analysis of the sources, authors, and documents. Thereafter, *Structures of IvE Knowledge* answers research question 2 through an analysis of the metadata's conceptual, intellectual, and social structures. The structures led to a systematic understanding of the diverse programs and curricula, curricular perspectives, interdisciplinarity in IvE, assessment of IvE, as well as inventor stereotypes, identities, and equity, topics that emerged from the review of IvE literature. Finally, in response to research question 3, we present the challenges identified from the study and directions for future research in order to enhance theoretical knowledge and practical applications.

IvE research landscape

We now discuss the IvE research landscape that emerged from the findings of studies 1 and 2 and informs the first research question. Findings from the WoS bibliometric analysis (Study 1)- sources, authors, and documents-reveal that in the time span of the data (1987–2023) 113 authors published 50 documents in 34 sources (journals, books, conference proceedings, etc.). Eight of the 113 authors have produced single-authored documents. Besides the single authors, the average of 2.6 authors per document reflects a high level of collaboration in research on the topic.

Study 2 included findings from Scopus and Google Scholar. Findings from the Scopus search were very broad, with a total of 107 relevant articles, conference proceedings, books, and book chapters. The earliest document was published in 1999 (Plucker and Gorman, 1999), and there were 12 relevant publications in 2023. This supports the Study 1 finding that research on IvE has increased substantially in recent years. In addition, the targeted Google Scholar search generated 26 non-duplicated articles. Combining the searches from studies 1 and 2 yielded 183 articles, conference proceedings, and books on IvE.

An in-depth qualitative analysis of the sources, authors, documents, and topics offers a comprehensive understanding of how the IvE landscape evolved, the geographic differences in the global evolution of IvE as reported by the researchers, and the range of program researched. These findings are presented below.

Brief history of invention education research

A bibliometric analysis synthesizes how a research field evolved over time and reveals its key characteristics, which informed research question 1. Bibliometric analysis of articles in both the studies illustrates the connections between different research topics, specific studies, the authors who wrote them, and the countries they come from Small (1999). We followed recommendations by Cobo et al. (2011) to produce maps of the research topics and the different structures in Study 1 dataset.

To determine the genesis of academic research on IvE, the search was not bound in a time period. From the bank of articles obtained, it can be determined that the first mention of the term "invention education" was made in an article co-authored by Perusek and Shlesinger (1987) who, as early as in 1979, reported examples of inventions by children. Following a two-decade-long absence of research, IvE literature has grown since 2007, gaining a significant boost since 2015 (Figure 2A).

Excluding duplicates, an analysis of articles generated in Study 2 (Figure 2B) shows a consistent increase in the research since 2017, with a prominent increase in 2022. Further, the analysis of words'

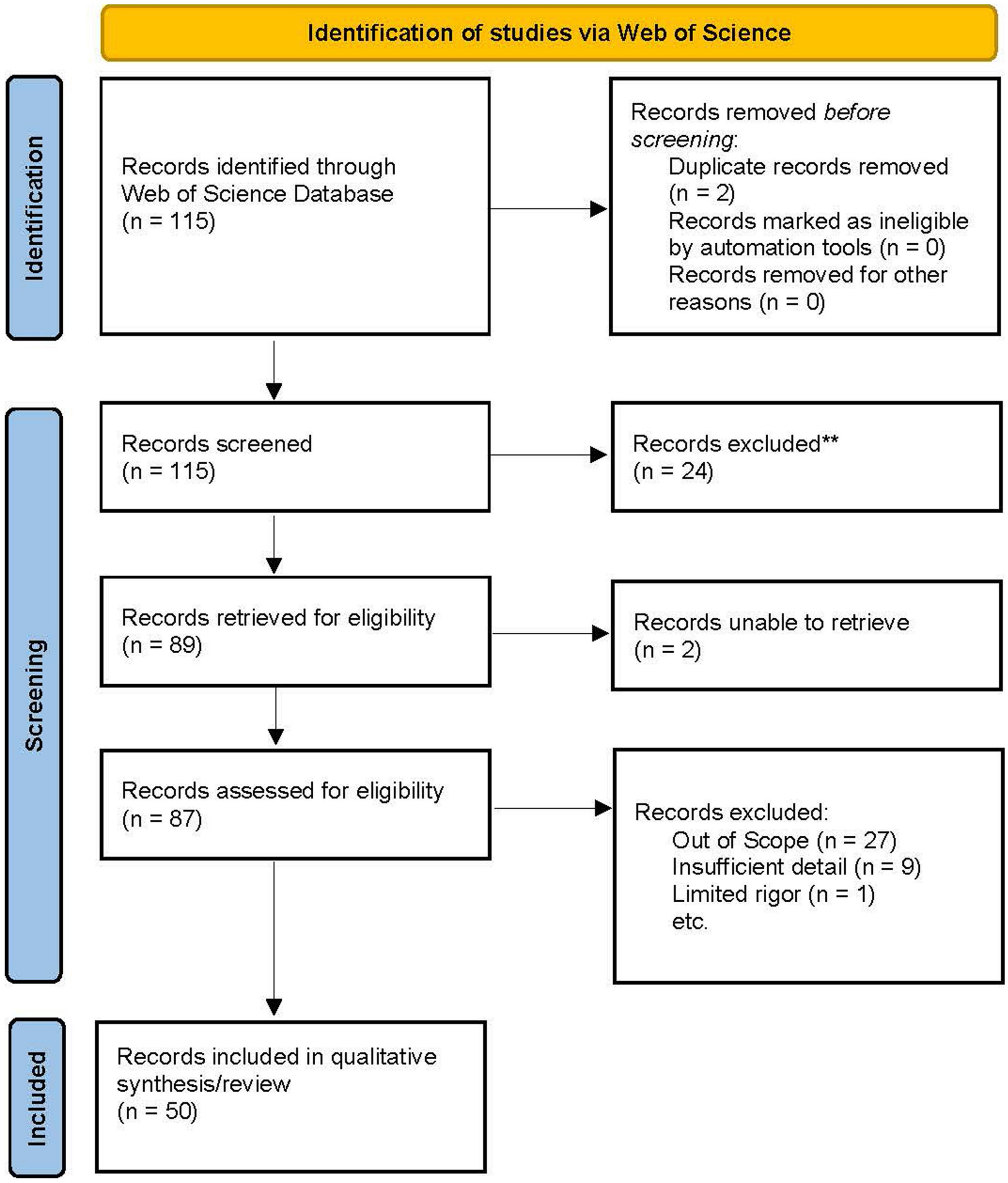

FIGURE 1
PRISMA flow diagram of search. Adapted from: Page et al. (2020).

frequency demonstrates that the majority researches focused on the impact of IvE on its students (Figure 3).

A review of the WoS-based sources' production over time (Figure 4) corroborates that IvE is considered an important topic primarily in science and technology, with Technology and Innovation being the most frequently used channel for disseminating research in this area. Two education journals (International Journal of Engineering Education and Journal of Baltic Science Education), which are making increasing contributions in the field, are also focused on STEM.

As seen in Figure 4, the second most productive journal, Frontiers in Psychology, made its foray into IvE research in 2019 but has had more articles since then, highlighting the increasing interest in the subject in the field of humanities and social sciences.

Further analysis of sources over time in Study 2 added other significant outlets for IvE research not captured in Study 1 dataset. This includes nine conference papers in the American Society of Engineering Education (ASEE) Annual Conference and Exposition. The first of these papers was presented in 2012. Since 2020, the frequency of IvE research in ASEE has increased, with a maximum of four relevant papers in the 2022 ASEE proceedings. Another significant source of IvE research were the chapters in the Routledge International Handbook of Innovation Education which was published in 2013. Together, the two studies compile a comprehensive dataset of IvE sources. Both studies show few IvE articles in business journals, with these articles generally appearing later than those in engineering. This suggests that consideration of innovation as a research topic in business is relatively new. Drucker (2002) and Sołek-Borowska (2018) note that innovation in recent years has become essential for entrepreneurship, therefore appearing frequently in recent entrepreneurship literature. However, Duval-Couetil and

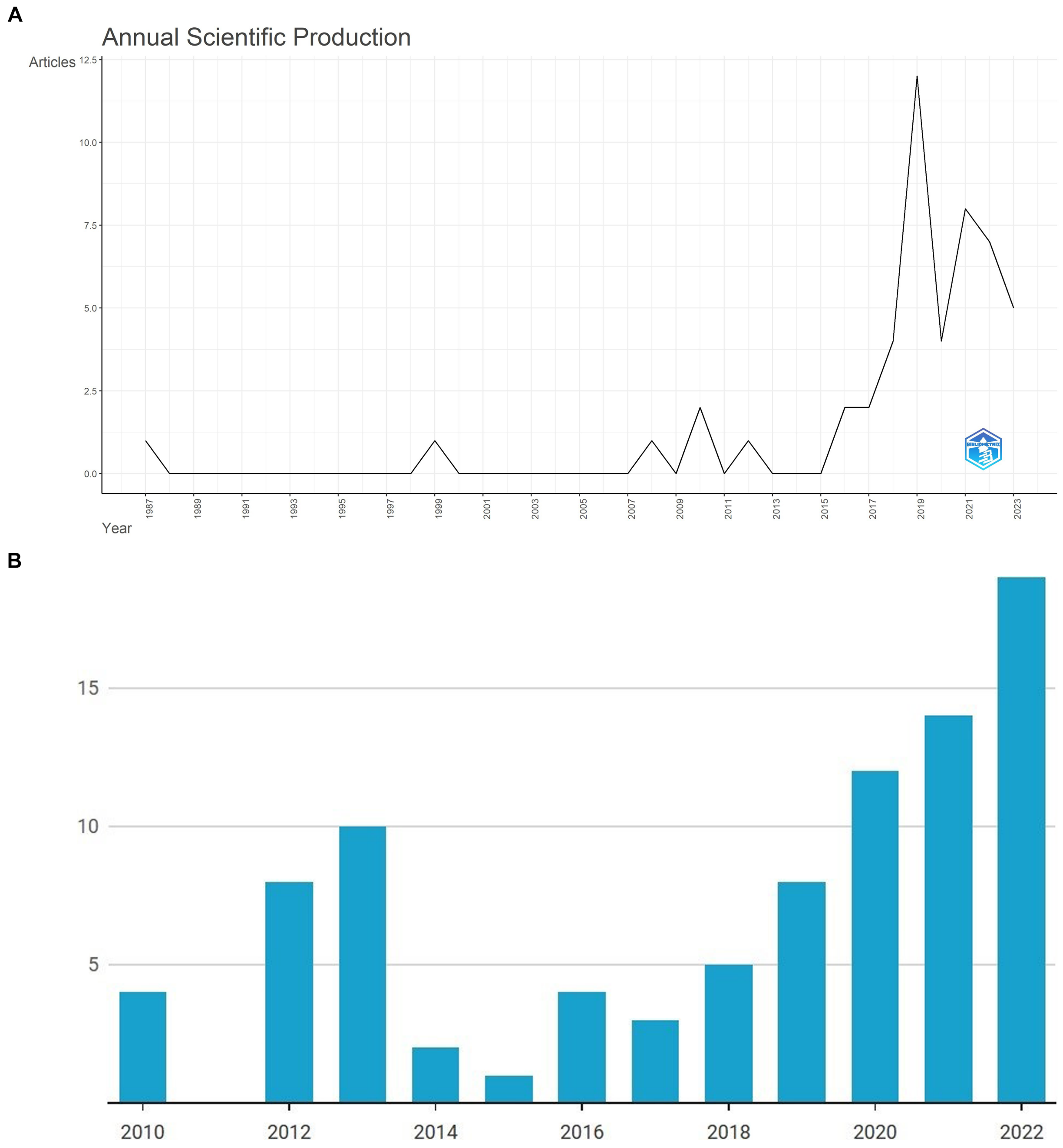

FIGURE 2
(A) WoS annual scientific production. **(B)** Scopus annual scientific production.

Dyrenfurth (2012) and Maritz and Donovan (2015) highlight that innovation and entrepreneurship have also begun to emerge as distinct fields in recent years.

Based on the early efforts in IvE, Perusek and Shlesinger (1987) introduced the benefits, challenges, opportunities, and the need to educate young inventors in systematic problem-solving. This was followed by a gap in publications where only five more studies were reported in the following two and a half decades before IvE publications started to increase in 2015. The few publications in these two intermediate decades included studies that measured the longitudinal benefits of a summer invention course for adolescents (Plucker and Gorman, 1999); reported the blend of online and in-person learning as a pedagogical approach used in European InnoEd project (Page et al., 2008); raised the urgent need to train student engineers to design to "minimize the footprint of stuff on our world" (Lande and Leifer, 2010, p. 9); and put forth the results of an experiment in extra-curricular design-based learning in higher education (Gerber et al., 2012).

Annual IvE publications increased in 2013 with the Routledge International Handbook and two publications in 2015, which increased to 10 in 2019. Kwon et al. (2016) gathered 37 studies on IvE in South Korea to synthesize and report its impact on grade

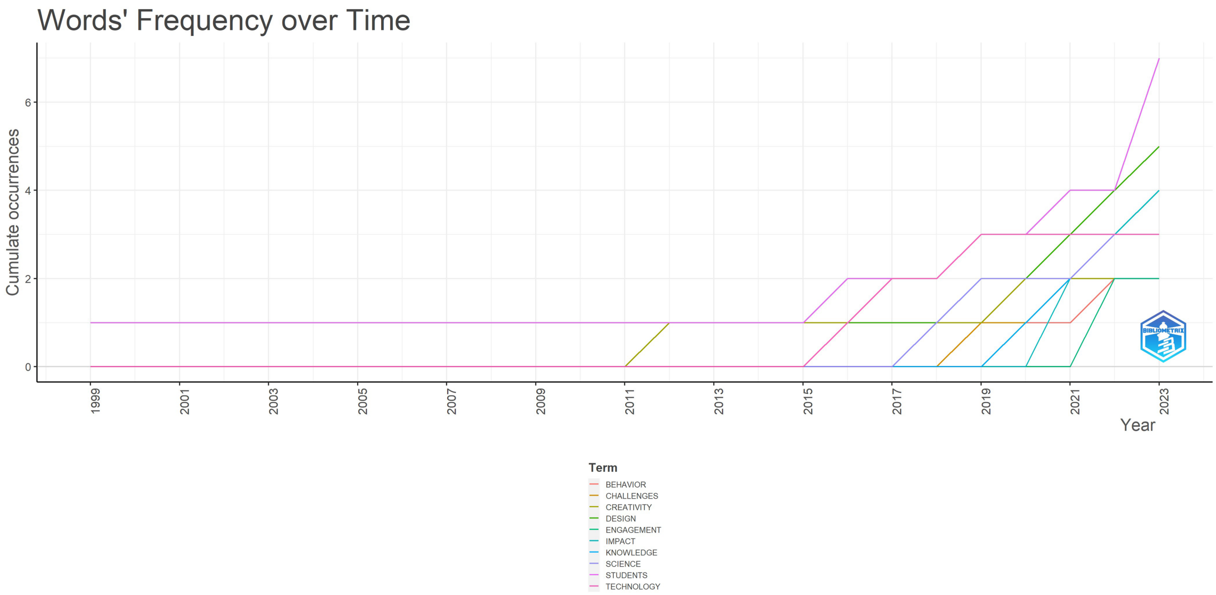

FIGURE 3
Word's frequency over time.

school student creativity, attitudes toward science and invention, and the ability to solve technological problems. Their meta-analysis underscored the value of IvE in fostering important skills and attitudes among students. The analysis found the greatest effect of IvE on creative capacities, followed by attitudes toward invention, attitudes toward science, and tendency for technological problem solving, respectively. Despite the widespread belief that practical activities enhance inventing skills, Kwon et al. (2016) discovered that invention programs focusing more on reading, writing, and thinking strategies also yield comparable educational outcomes. These benefits from IvE are independent of the number of participants or sessions in a program.

Concurrently, based on the syllabi of 29 innovation education courses in graduate schools, Kars-Unluoglu (2016) discovered that innovation education encompasses a diverse mix of exploration, theory, and skill development, spanning opportunity identification, design, and commercialization. Usually influenced by the teacher's expertise, each course has a combination of exploration (of problems), iteration (of designs), collaboration through teamwork, and reflection to reinforce learning of how theories, tools, and methods work. The author recommended four benchmarks for innovation education. The pedagogy cycles between theories (cognition) and doing (construction); learning objectives and content include conceptual and meta-theoretical aspects, as well as skills development; teachers act as mediators, facilitators, or coaches in an active learning, small-group collaborative environment; and assessment involves immersive, collaborative and innovative tasks that stimulate learning and understanding.

In addition to tracking the time-period over which IvE research has increased, we examined variations in the global points of origin of the research. Significant reports of IvE implementation in the USA and South Korea were followed by an increasing interest in IvE programs in the Middle East, North Africa (Abdulwahed, 2017), and China, mostly in higher education. Around the same time, South Korean and USA-based research started investigating gender gaps (Couch et al., 2018) and gender-related stereotypes (Lee and Kwon, 2018), a theme that recurred in subsequent years. In a later section, we discuss the stereotypes in detail.

The 2019 issue of Technology & Innovation dedicated to invention education highlights a maturing field, evidenced by a growing body of empirical research on the impact of exposure on students and the emerging trend of integrating IvE into traditional educational settings, like science classes for English Language Learners. This integration fostered iterative learning, identity formation through invention, discursive IvE processes, and reflexive mentoring by student inventors (Couch et al., 2019a). Reporting on the long-term effects of Camp Invention, Hosler (2019) emphasized the need for repetitive experiences in building, intellectual property, creative problem-solving, and collaboration, to gain experience in the practice of invention.

As the field expanded across various educational tiers, researchers explored numerous methods and tactics to activate IvE effectively. While Kars-Unluoglu (2016) first introduced the idea of innovation's interdisciplinarity, Swayne et al. (2019) and Chandra et al. (2021) later contended that crafting the transdisciplinary framework essential for proficient IvE necessitates teaching these programs independently of any single disciplinary context. Given the inherently multidisciplinary nature of invention and innovation, "a complex phenomenon (spanning diverse processes and environments)… can make it challenging to provide these opportunities and frame them within appropriate learning contexts." (Fila et al., 2020, p. 633). Similarly, Newton et al. (2020) reported the results of efforts at combining innovation and entrepreneurship through partners in remote and rural areas.

Post-pandemic, IvE related publications decreased slightly but have increased again since 2022. Winch (2003) established early that the constructivist approach, emphasizing learner autonomy in building and hypothesis testing, plays a significant role in modern educational practices, challenging traditional notions of truth and knowledge acquisition. More recent authors have begun to study, critique, and evaluate the effectiveness of IvE programs (e.g., Zhang,

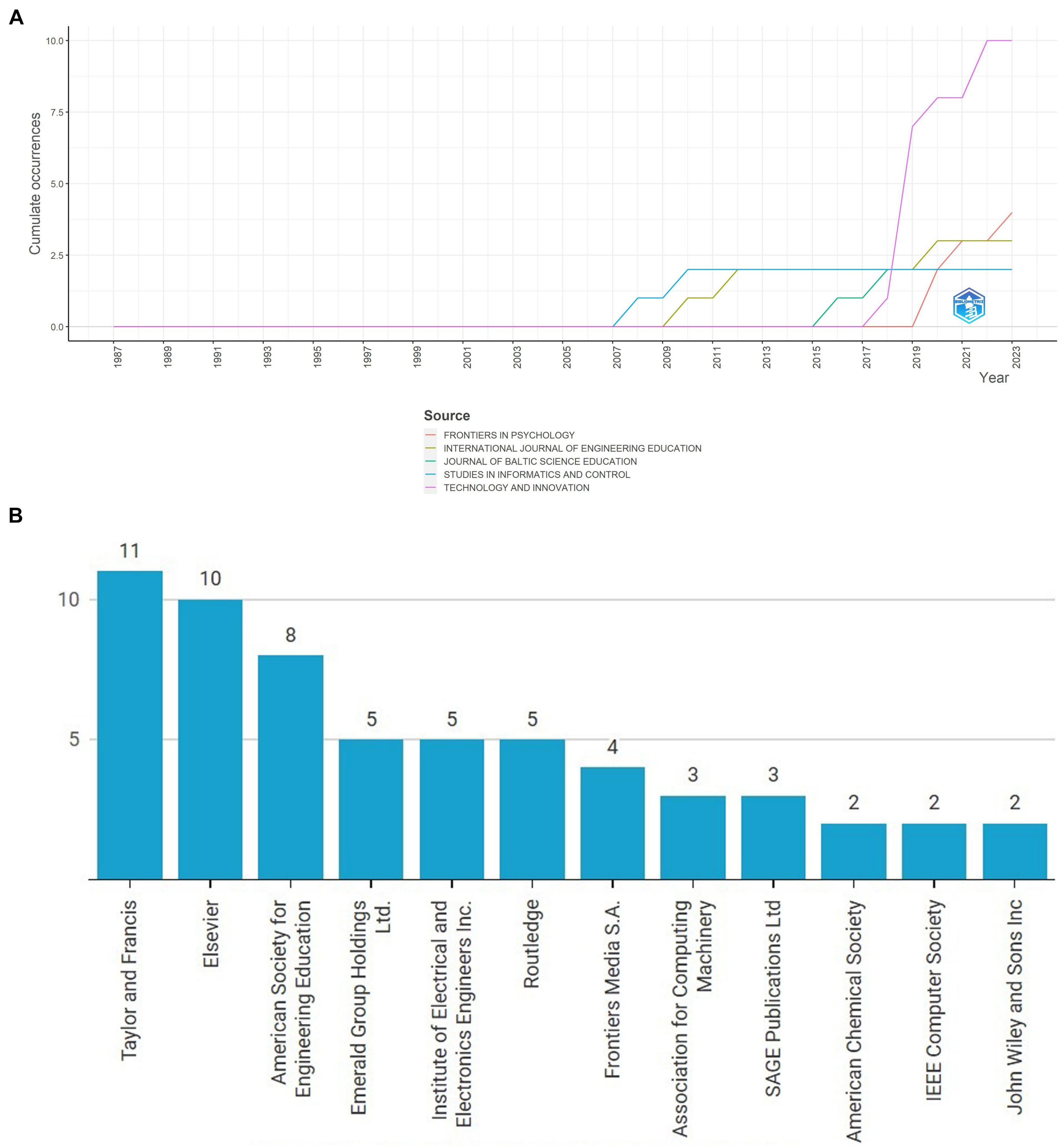

FIGURE 4
(A) WoS sources production over time. **(B)** Scopus sources production over time.

2020; Novak and Mulvey, 2021; Garner et al., 2023). For example, Garner et al. (2023) noted that invention education, when deeply intertwined with STEM/STEAM curricula, nurtures students' inventive thinking and problem-solving skills and can act as a context for the development of an inventive identity.

Geographic differences in the evolution of IvE

Geographic characteristics of IvE research further informed research question 1. We examined the affiliations of the researchers to determine regions with the highest research activity on the subject. According to Study 1-WoS dataset, only eight countries have contributed more than one article in this domain. The majority of research produced and referenced by authors originates from the USA, with China being the second leading contributor. However, as the later sections show, most programming cited in the studies was conducted in the USA and in South Korea (Figure 5A).

An analysis of countries in the second dataset in Study 2 (Figure 5B) corroborates the dominance of USA and South Korea-based researchers in the field, although recent IvE research is emerging from multiple regions across the world.

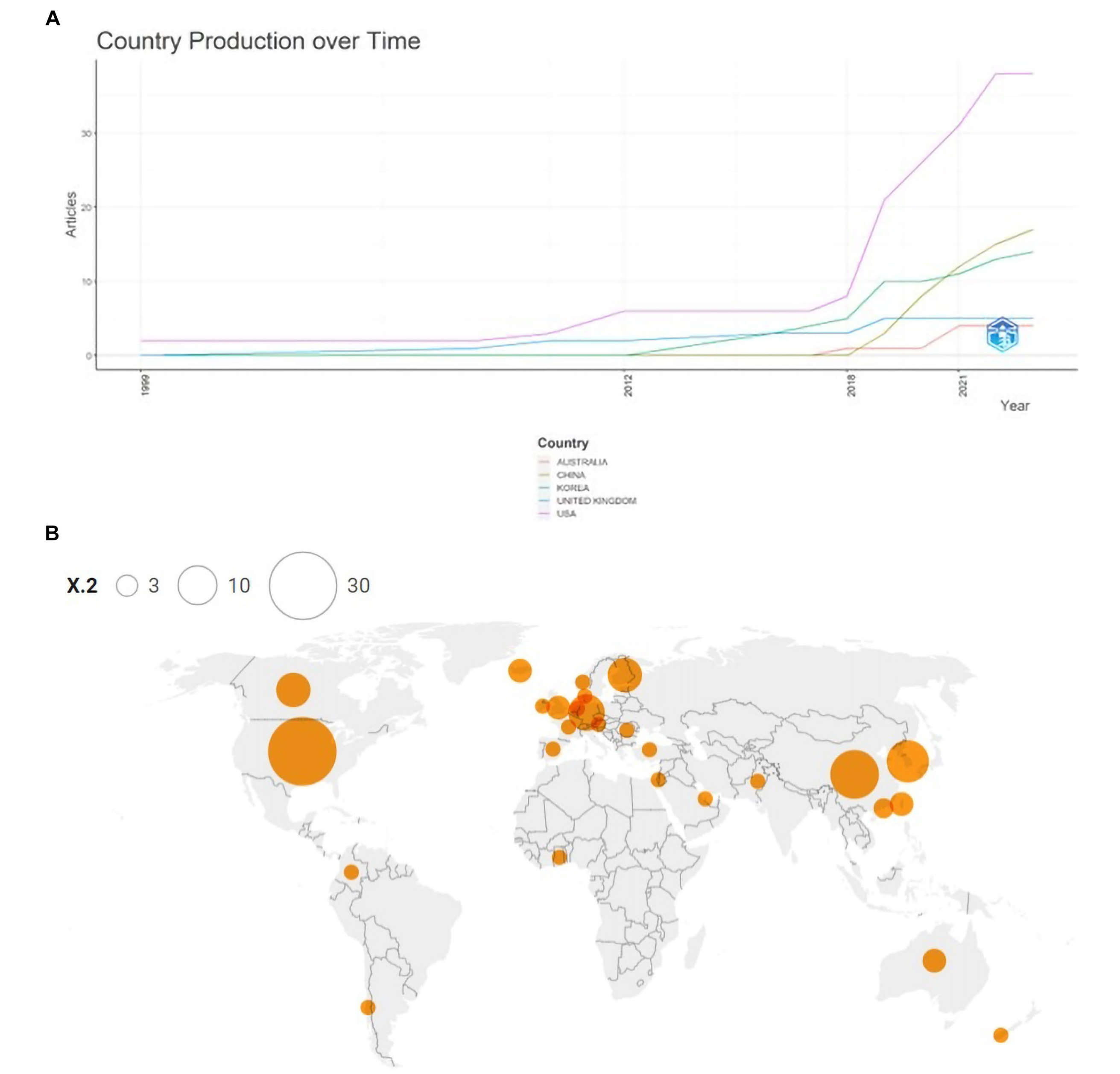

FIGURE 5
(A) WoS Country production over time. **(B)** Scopus Country production over time.

Pioneering authors in any field are known to have the most significant influence on the field's evolution, practically and scientifically, making it essential to identify the most published authors. Study 1 identifies Skukauskaite, A. (2018–2022) as the most published author, followed by Couch, S. (2018–2020), both based in the USA. Study 2 generated more work from South Korean author Kwon, H. (2016–2023), followed by Moore, R. (2014–2022) and Garner, J. (2021–2023) from the USA.

Scopus and Google Scholar search results identified Garner, J.'s (2021–2023) contributions to IvE research, particularly in the areas of identity exploration (2021, 2022) and inventive mindset (2023). Moore, R. (2014–2022) emerged as the most cited author, with her co-authored work (Forest et al., 2014) generating over 190 citations. This was among the first seminal articles, published in USA, that advocated fostering an open-ended design-build environment.

This data captures the geographical diversity of the IvE efforts and experimentation informing research question 1. Overall, USA and South Korean research is more focused on K-12; Mediterranean countries, North Africa, and China were looking at higher education to spread IvE; Europe was pioneering the use of Information and Communication Technologies to create open innovation platforms that triangulated innovation, education, and research in search of new solutions for the living urban environment (Raunio et al., 2018).

Structures of IvE knowledge

The structures of IvE knowledge drawn from studies 1 and 2 informed our second research question. The links between the authors, authors' keywords, and sources in the three-field plot (Figure 6) illustrate the network between concepts (as keywords) explored, the most impactful references, and the most frequent authors. The more links one element had, the taller the rectangle representing it.

Figure 6 from Study 1 illustrates that five top authors are linked to two top references (Nager et al., 2016; Skukauskaite et al., 2019) and an untitled paper that has been cited at least once by each of these authors. However, Study 2 places Moore, R. as the top author with Forest et al. (2014), the most cited article, advocating open-ended design-build environment in engineering education. Besides invention education, invention, and innovation, which appear among the top keywords, seemingly because they were included in the search terms, gender gap is the second largest keyword (7 counts), followed by South Korea, abductive reasoning, science education, and blended learning (4 counts each). This points to considerable research emphasis on gender-based diversity and equity in IvE. Science education and blended learning point to the curricular aspects of IvE. Finally, abductive reasoning in research indicates the overarching presence of qualitative observations and logical reasoning used by researchers in current IvE literature.

While Study 1 findings focus on gender gaps and abductive reasoning research, the results in Study 2 focus on resourcefulness, narratives, and inventive identity. A review of identity-focused research in Study 2 indicates equal emphasis on inventors' technical and professional identities, as well as identity exploration among young inventors (Garner et al., 2023). Study 2 findings also bring up the expansive research on design, innovation, and invention in South Korea, followed by China and Iceland.

Generating the graphical parameters of authors' keywords and word occurrence frequency in a word cloud, Figure 7 highlights the most frequently used keywords: innovation, followed by design thinking, education, entrepreneurship, and creativity.

Further, the cumulated occurrences of keywords plus (Figure 8) present a clearer picture of the breadth of areas as they evolved in IvE.

Despite differences in overall values, the keywords' focus in Study 2 aligns with the keywords in Study 1. Students was the top word which started increasing in frequency a decade ago, followed by design, impact, science, and entrepreneurship. This indicates an increased focus on the impact of IvE on students in science disciplines. The word generation also highlights the bridges between innovation research-primarily conducted in business and entrepreneurship-and design research in engineering. A notable illustration of this concept is provided by Moore et al. (2022), who contend that inventiveness—defined as "a mix of novelty, unpredictability, creativity, and individual uniqueness" (Moore et al., 2022, p. 9)—exists on a spectrum where entrepreneurship and engineering design intersect, leading to varying degrees of inventiveness across different curricula.

To answer research question 2, the following sections discuss IvE programs and curricula, interdisciplinarity, assessment, and inventor stereotypes and identities that make up the intellectual, conceptual and social foundations of IvE. We reference literature from both studies, 1 and 2, for this purpose.

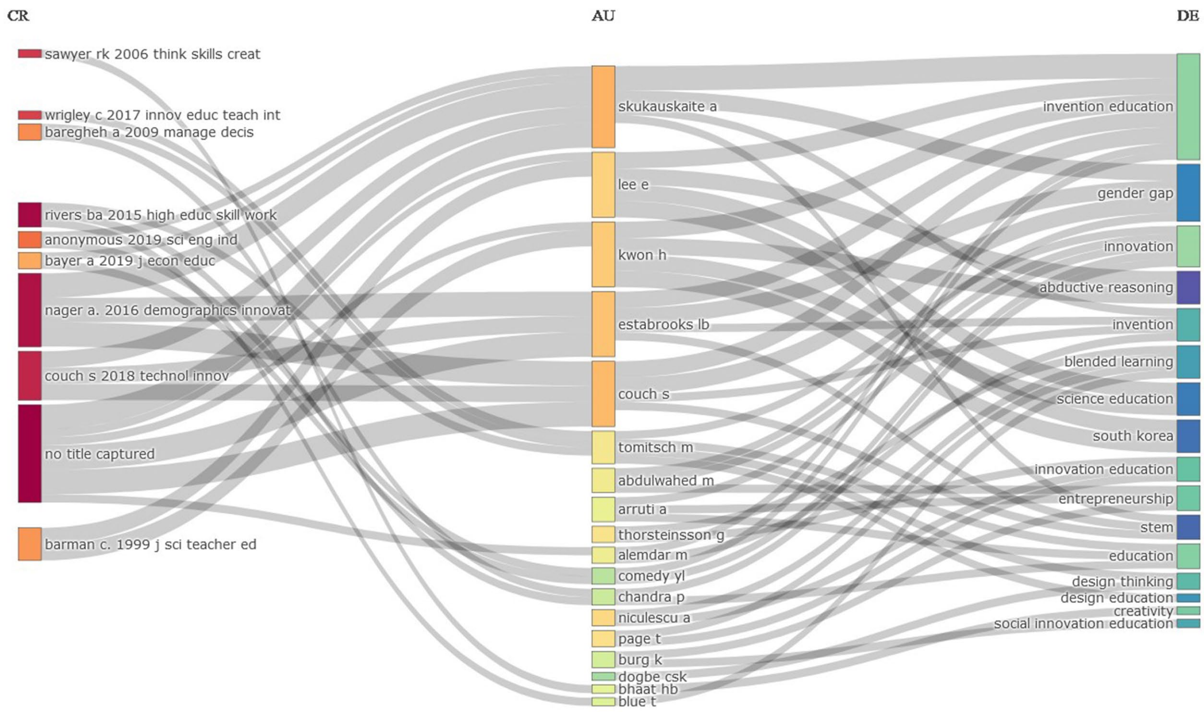

FIGURE 6
Three fields plot.

IvE programs and curricula

Understanding the structures, designs, achievements, challenges, and outcomes of IvE program can uncover the intellectual, conceptual, and social foundations of IvE, thus answering research question 2. Research generated in studies 1 and 2 describes many IvE programs, ranging from PreK through universities. This section reviews that to understand the intellectual and social foundations of IvE.

Offering 29 uniquely themed modules packed with hands-on challenges that encourage problem-finding and solving, risk-taking, and exploration, the National Inventors Hall of Fame website describes how the Invention Project STEM Curriculum helps transform PreK-8 students into innovators (NIHF, 2020).

Camp Invention, a hands-on creativity and science day and summer camp for K-6 students, offered in different formats at more than 400 schools in USA, integrates science, history, mathematics, arts, and fun — promoting creative learning and teamwork through interactive activities (Hosler, 2019). Studying Camp Invention, Garner et al. (2023) integrate these diverse perspectives and components into Inventive Mindset Development through a curriculum that fosters ingenuity, creativity, curiosity, resilience, and solution-seeking.

FIGURE 7
Author keywords' word cloud.

The Dare2Design summer and after-school program at Eastern Michigan University goes beyond the STEM fields and includes entrepreneurship and arts to teach systematic problem-solving to K-12 grade students using a project, place and problem-based methodology. The student learning-centered approach uses individual student strengths to introduce them to the invention ecosystem and inventor as well as integrity competencies (Ahmed et al., 2023). The program not only attracts students interested in technology, but also those interested in art, literature, sciences or any other field (Ahmed et al., 2023; Dalela et al., 2023).

The K-12 InVenture Prize competition, run by Georgia Institute of Technology's Center for Education Integrating Science, Mathematics, and Computing, challenges students to identify real-world problems and design novel solutions through analysis, creativity, and the scientific method. Focused on making IvE accessible to all, InVenture Prize trains teachers to offer IvE and develop the next generation of engineers and entrepreneurs. Students' progress from problem identification to prototyping over multiple months and finally enter a competition (Moore et al., 2019).

Zhang et al. (2019) reported on the Junior Varsity InvenTeams Chill Out, where 7th-grade students learned heat transfer and applied their knowledge to create lunch boxes. The Junior Varsity Chill Out flexibly adjusts to teacher schedules, each unit needing approximately 9–12 h. Talamantes et al. (2022) described a similar initiative called iINVENT that offers invention education for upper elementary, middle, and high school students through a scaffolded pathway. It included in-class invention activities for elementary students, summer mobile camps for middle school students, and a hybrid program for high school students varying in duration. The program utilizes college

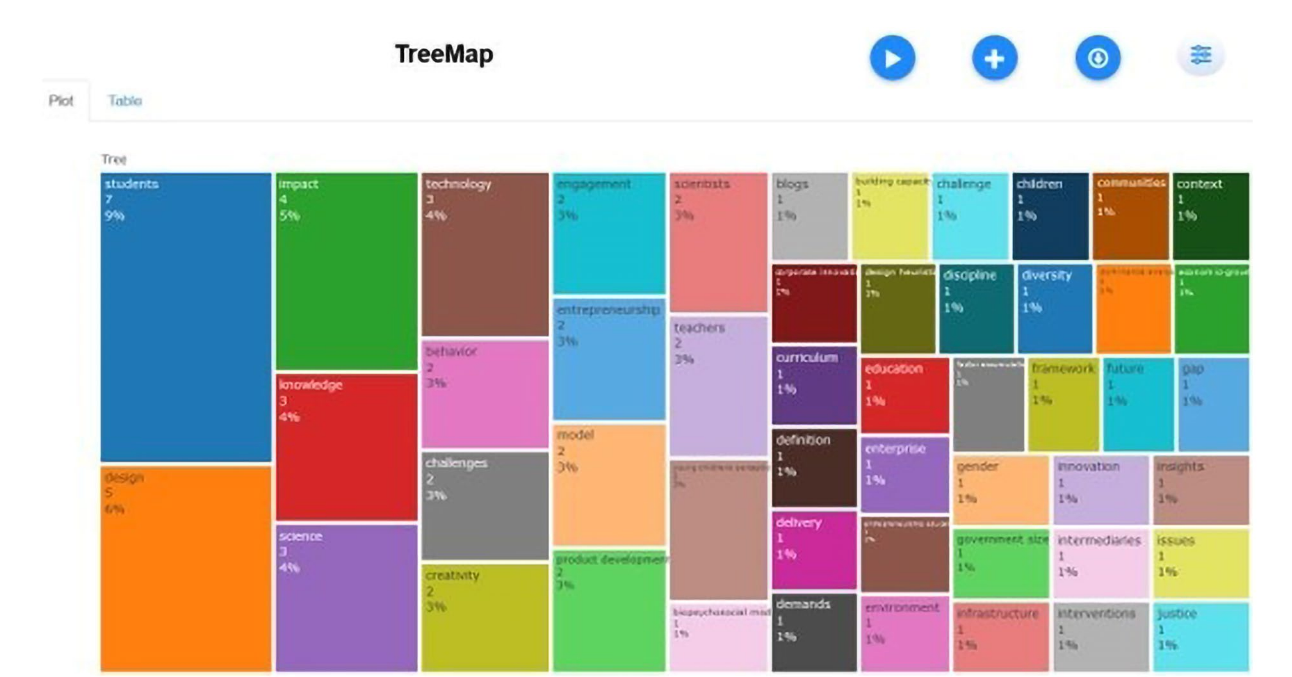

FIGURE 8
Cumulate occurances of keywords plus.

students as mentors and focuses on human-centered design themes. Similarly, Kalemaki et al. (2021) reported that a social innovation education experiment, the European H2020 NEMESIS project, led to positive emotional, cognitive, behavioral, and agentic engagement of the students and increased their social innovation competencies.

The Lemelson-MIT InvenTeams program immerses high school teams and their teachers over an academic year in the collaborative problem-solving processes utilized by inventors, providing an in-depth experience. Program staff works with student teams remotely and in-person during an academic year. Each team identifies a problem within their community, conceptualizes, designs, and builds a working prototype of a technological solution that is useful, and uniquely (i.e., an invention) solves the problem. The program follows flexible schedules with broad timelines, with the process being student-led and flexible. Through its innovative process, the program also teaches leadership, community building, and creative problem-solving.

Page et al. (2008) studied the InnoEd project funded by the European Union. Originating in Iceland, this project studied student problems and focused on implementing new or existing solutions to pedagogical issues. The resulting blended learning model improved in-service IvE teachers' teaching skills and students' ideation skills using a virtual reality learning environment. The virtual environment was a pedagogical tool that supported ideation and hosted online course materials, facilitating innovation. Tailored virtual workshops informed by the underlying database facilitated the formation of online communities of teachers and students.

Authors have reported IvE programs in higher education as early as 2012. Gerber et al. (2012) implemented an extra-curricular design-based learning model for higher education in the Design for America program at Northwestern University. The program strengthened self-efficacy in innovation-related tasks through mastery experiences, vicarious learning, and social persuasion in regular feedback sessions with stakeholders. Raunio et al. (2018) reported the results of a European experiment where open innovation platforms were used to facilitate university-industry-government knowledge triangles that could boost policymaking for IvE. Selznick et al. (2021) discussed some global institutions (e.g., University of Twente, Netherlands and an unnamed Canadian university) as early adopters in IvE. They are developing and sustaining campuswide innovation efforts, such as offering innovation fellowships and organizing research groups, with courses focused on transdisciplinary problem-solving, incentivizing collaborative and interdisciplinary faculty–student research, and close engagement with real problems in a region or nation (Selznick, 2019).

Articles yielded from both studies describe various aspects of IvE curricula. Most of these are case studies, such as the study of Junior Varsity InvenTeams Chill Out. This middle school program presents the potential for broadening youth participation in IvE (Zhang et al., 2019). The After School EdVentures program focuses on making and tinkering (Simpson et al., 2020). Similarly, Moore et al. (2019) summarize years' worth of information relating to the teachers' experiences in the InVenture Prize program. Well-designed components of the IvE curricula lead to high level of teacher self-efficacy, motivation to participate, and enjoyment in teaching IvE. Teachers also agree that IvE participation positively impacts student communication and teamwork skills, enthusiasm for learning about engineering and entrepreneurship, and knowledge of the engineering design process.

IvE curricula are often integrated with STEM (Science, Technology, Engineering, and Mathematics) and STEAM (STEM + Arts) subjects (Garner et al., 2023). Moore et al. (2022) further argued for infusing entrepreneurship with engineering to promote inclusive inventiveness. This integration has the potential to ground the invention process in technical and creative skills, enhancing students' understanding and application of these subjects in inventive contexts. Talamantes et al. (2022) focus on user-centered invention and culturally responsive teaching practices, ensuring that learning experiences are relevant and relatable for students from diverse backgrounds. User-centered design practices have also been shown to effectively enhance students' learning in invention (Dalela and Ahmed, 2023).

Some after-school programs, for instance, Georgia Institute of Technology's InVenture Prize (Moore et al., 2019), Lemelson-MIT's InvenTeam (Couch et al., 2019a) and Eastern Michigan University's Dare2Design (Ahmed et al., 2023) provide invention opportunities to students of all ages, backgrounds, and geographies as they are offered during the school day, as after-school programs, or as summer camps (Skukauskaite et al., 2019). It is important to note that most IvE students perceive inventors as highly gifted individuals, not as teams of motivated individuals with average skills and capabilities who combine knowledge and skills to solve problems. When provided in-class, IvE programs are predominantly offered to gifted and advanced students across various subjects, primarily in STEM areas, though not exclusively.

Variations in IvE approaches and curricula

Perusek and Shlesinger (1987) highlighted five key components of IvE programs, emphasizing that a methodical teaching approach can facilitate a systematic process of invention. This begins with identifying the problem, followed by researching the background, collecting data, applying imagination, and finally recognizing limitations. These components are similar to those identified by Talamantes et al. (2022), who also emphasize real-world problems and user-centered design solutions, which involves an empathetic understanding of user needs and iterative design processes. Fila et al. (2020) examined 55 innovation course design heuristics to contextualize, situate, guide, support, challenge, motivate, and enhance expert reasoning, creativity, and efficiency in IvE and innovation courses, facilitating new approaches to experiencing innovation. Further emphasizing the complexity of learning the innovative thinking process, Wrigley et al. (2018) argue that to develop students' notional understanding and practical thinking, design thinking needs to scaffold in complexity, starting with addressing lower-order thinking skills and progressing to higher-order thinking skills. The application also needs to move from foundational to professional skills.

Almost all IvE curricula intended for K-12 education are designed for hands-on engagement and open-ended exploration, empowering students and teachers alike (Gale et al., 2020). Programs might encourage an open-ended selection of problems (e.g., InVenture Prize, Dare2Design) or define an area, such as social innovation, sustainability, or community-based problems (e.g., InvenTeams).

Maynard et al. (2023) recently reviewed 17 social innovation programs in adolescent education in six countries. The programs varied across delivery methods, length, setting, age, facilitators, and techniques. Lande and Leifer (2010) introduced the concept of integrating sustainability thinking into design education to help students better conceptualize green products. By documenting a higher education engineering course, they demonstrated the benefits of providing technical students with a broad, liberal education that includes a foundation in social and economic insights. This approach, by raising awareness of planetary and societal concerns, can enhance the development of sustainable inventions.

IvE curricula often employ project-based and experiential learning strategies, where students actively engage in hands-on projects, such as building prototypes and participating in invention competitions or challenges (Moore et al., 2022; Talamantes et al., 2022). Despite the potential benefits, Fulgham et al. (2012) draw attention to the need for students to learn how to use information reliably. Small (2014) emphasized that libraries can create innovation spaces for young inventors and motivate them as their information mentors. This will encourage young inventors and ensure that students learn the value of reliable sources of information. These innovation spaces can foster curiosity and exploration through the process of innovation. Skukauskaite et al. (2019) concluded that schools rarely offer the kind of creative, open-ended problem-solving required for real-world challenges. This gap leaves learners without the necessary support to integrate information across disciplines.

Following the Dynamic Systems Model of Role Identity (Kaplan and Garner, 2017) and analyzing data from Dare2Design, an IvE curricular pilot by Ahmed et al. (2023) demonstrate the benefits of emphasizing the journey and the process of learning in IvE. Accurate recording of the experiences, absence of judgments and evaluation during the process, coupled with giving students autonomy, ownership, and accountability of the invention process, develop their integrity capacity, the quality of moral self-governance (Petrick and Quinn, 2000). Integrity capacity includes the ability to distinguish right from wrong, analyze situations truly, adhere to anchoring principles, and readiness to act ethically when tempted, such as readily accepting shortcomings in the concepts and designs. The study confirmed the findings of Garner et al. (2021) that when students are offered autonomy to choose their preferred problems and process steps, they demonstrate high confidence and are engaged by the novelty. Further, building autonomy and freedom from evaluation offers psychological safety to the young inventors which boosts integrity capacity.

A source of variation and a determining factor in the success of IvE programs relates to how the students join the program. Yoon and Kim (2019) found greater enthusiasm for learning when the students volunteered to join the program. These students understood inventions and games better than those studying under the general curriculum. Yoon and Kim (2019) and Lau (2023) investigated a curriculum-based serious game content design and development program. To make learning engaging, the program successfully combined complex learning in IvE with amusement.

Faludi and Gilbert (2019) interviewed teachers and administrators to investigate best practices in curriculum, delivery methods, and administrative leadership, particularly in order to foster environmental consciousness among IvE students. Hosler (2019) conducted a longitudinal assessment of the impact of Camp Invention and emphasized the need for children to learn to invent, particularly for building STEM skills, collaborating, understanding intellectual property, and developing creative problem-solving skills. In another study, Simpson et al. (2020) provide a working model of how young minds are engaged through active listening and communication, developing models, carrying out investigations, designing solutions, analyzing and interpreting data, and constructing explanations. Hosler (2019) also reiterated the importance of incorporating repeated learning and experiential opportunities in the invention process, emphasizing how these experiences can become personally meaningful to children.

Researchers have also studied the effects of different learning formats in IvE. Page et al. (2008) and Thorsteinsson et al. (2010) reported the results of the European InnoEd project's blended learning experiment, which integrated lectures, visuals, assessments, and activities in some combination of in-person and virtual environment and on-demand, synchronous, and asynchronous online learning options.

Liu et al. (2019) experiment focused on the effectiveness of virtual (e.g., augmented reality) and physical learning aids (e.g., 3D printers) in enhancing the learners' product innovation capability, including design experiences and domain knowledge. The authors report that while both types of aids are helpful in enhancing design experiences and domain knowledge, physical aids improve divergent search for ideation. Moreover, learning motivation was found to be lower when using virtual aids.

Interdisciplinarity in IvE

Uncovering the disciplinary links in IvE research informed its conceptual and intellectual foundations, thus answering research question 2. Based on the journals of publication, Table 1 highlights IvE research by domain and ranks the top 10 sources using different impact measures (Aria and Cuccurullo, 2017). According to the WoS dataset, while Technology and Innovation has the highest number of publications (10), the four publications in the journal Frontiers in Psychology have had the most impact in the subject area. The H index also points to the highest local impact of publications in Frontiers. A Scopus search in Study 2 brought up additional sources of significance to IvE knowledge. In recent years, significant contributions to IvE research have come from publications within the American Society of Engineering Education (ASEE) Conference and Exposition Proceedings, and the 2013 Routledge International Handbook of Innovation Education. Notable works include those by Newton et al. (2020), Moore et al. (2022), Talamantes et al. (2022), and Garner et al. (2023), highlighting the ongoing development and exploration in this field.

The top 10 publications highlight the expanding scope of research within the domains of science, engineering, and technology, as shown in Table 1 . Conversely, IvE in non-science fields such as business and non-technology areas, including social sciences (with the exception of Frontiers in Psychology), natural sciences, and humanities in innovation education, remains largely unexplored, except for the work by Moore et al. (2022). Incorporating IvE into non-science and non-technology fields could help normalize it among students who identify as "artists" or "entrepreneurs."

Researchers differ in their understanding of the disciplines that IvE transcends. While some researchers limit their scope to "unique

TABLE 1 Frequency and impact of sources from all databases.

Journal	# pubs.	h_index	g_index	m_index	TC	NP	PY_start
FRONTIERS IN PSYCHOLOGY	4	3	4	0.75	16	4	2020
INTERNATIONAL J. OF ENGINEERING EDU	3	2	3	0.143	43	3	2010
J. OF BALTIC SCIENCE EDU	2 + 1	2	2	0.25	4	2	2016
STUDIES IN INFORMATICS AND CONTROL	2	2	2	0.125	8	2	2008
TECHNOLOGY AND INNOVATION	10	2	3	0.333	13	10	2018
ASIAN J. OF TECHNO. INNOVATION	1	1	1	0.143	1	1	2017
CREATIVITY RESEARCH J.	1	1	1	0.04	11	1	1999
EDUCATION AND INFO. TECHNOLOGIES	1 + 1	1	1	1	1	1	2023
EUROPEAN J. OF INNOV. MGMT	1	1	1	0.333	4	1	2021
EUROPEAN J. OF SUSTAINABLE DEVE	1	1	1	0.333	1	1	2021
ASEE ANNUAL CONF. AND EXPO.	0 + 9						
ROUTLEDGE INT. HANDBOOK OF INNOVATION EDUCATION	0 + 10						

h_index, Source's number of published articles cited in other journals at least h times; g_index, h_index improvement to measure the global citation performance of a set; m_index, h_index/n, or number of years since the first published paper in the journal. TC, total citations; NP, net production; PY start, production year start.

design considerations needed when developing invention curriculum for science classes" (Zhang et al., 2019, p. 235), others refer to the "marked dominance of this subject in traditional domains such as engineering, business, medicine and little or no presence in nontraditional domains such as humanities or social sciences." (Chandra et al., 2021, p. 1268).

The complexity of teaching IvE is linked to the description of the ill-defined problem that may not have the right solution and require knowledge of various disciplines. In an opinion article, Cavagnaro and Fasihuddin (2016) argue that IvE instructors should act as guides to the innovation process instead of as keepers of knowledge. Based on the articles in the special issue on Invention Education, published in Technology and Innovation, Couch et al. (2019b) underlined the need for IvE's interdisciplinarity. However, despite the field's transcendence of disciplinary boundaries, the invention curriculum remains predominantly confined to STEM classes.

Paños-Castro and Arruti (2021) note connections between innovation and entrepreneurship curriculum. Their research demonstrates that entrepreneurship education not only encompasses innovation but goes further to commercialize and spread the use of that innovation. Reporting the results of a European pilot that used open innovation platforms to facilitate university-industry-government knowledge triangles, Raunio et al. (2018) advocate open innovation as both a knowledge triangle and a policy tool that facilitates the convergence of agile and user-driven innovation with education and research. They emphasize the use of urban environments as living labs to orchestrate joint innovation efforts. Lee and Jung (2021) discuss the paucity of open innovation programs in STEM high schools. Their research paves the way for integrating innovation programs in entrepreneurship with STEM education, which can open the doors for civic virtue-driven, arts, cultural, daily life-based, and community service-driven open innovation. They also underline the need for the government to expand and strengthen the design and operation of open innovation education programs in STEM high schools, thus creating a path to true interdisciplinarity. Combining entrepreneurship education with engineering design prompts students to consider the practical applications and commercialization potential of their inventions, merging business, economics, and marketing concepts with their technical and design expertise. This strategy equips students not only to innovate but also to assess the market readiness and societal implications of their creations (Moore et al., 2022).

Almost four decades ago, Perusek and Shlesinger (1987) mentioned that universities are lagging in substantially offering IvE. This call seems to have finally brought a change as at least five higher education institutions mentioned in this study (Massachusetts Institute of Technology, Georgia Institute of Technology, Northwestern University, Eastern Michigan University, and University of Twente) are actively offering IvE as a regular outreach program. Nevertheless, given their vast resources and experience in higher education courses that contribute to IvE, higher education institutions are positioned well to play a pivotal role in bridging disciplinary divides. This effort can make IvE interdisciplinary and enable it to transcend numerous fields, as proposed by Abdulwahed (2017).

Some IvE programs require collaboration with partners as diverse as industry, community organizations, and higher education institutions (Talamantes et al., 2022). These partnerships highlight latent perspectives and contribute expertise into the educational process, exposing students to various disciplines and professional practices. This network extends learning beyond the traditional classroom setting, connecting it with real-world applications and community needs (Ahmed et al., 2023).

Selznick et al. (2021) highlight numerous administrative challenges in advancing IvE, emphasizing that IvE across all grades encounters issues akin to those prevalent in K-12 schools. These include the multifaceted organizational and structural challenges that require us to reimagine the administrative structure for such transdisciplinary endeavors. Selznick et al. (2021) emphasize that innovation presents a distinctive set of complications for institutional stakeholders as they empower students with the tools needed to build creative regional economies. The institutional leadership must navigate multifaceted organizational and structural challenges within the tension between isomorphic patterns and innovative practices to establish legitimacy. Abdulwahed (2017) proposed a comprehensive multidisciplinary department in engineering schools of higher education focused on technology innovation, engineering education, and entrepreneurship to resolve the administrative complexities. Such a department has the potential to serve as an academic integrative platform, attracting multidisciplinary faculty who will be instrumental in advancing transdisciplinary technology innovation, design, entrepreneurship, engineering education practices and scholarship, as well as sustainable development.

Assessment of IvE programs

Reviewing how IvE programs are assessed and what is measured through the evaluations further informed the second research question. Some researchers have analyzed IvE program structures and their impacts. Maynard et al. (2023) found that most social innovation programs in adolescent education in six countries utilize stages to map the process with a primary focus on assessing skill development, civic engagement, civic commitment, and social & civic responsibility.

Garner et al. (2023) gathered data in the context of Camp Invention, a national-scale IvE program for elementary and middle school students. They validated and confirmed a measure of *Inventive Mindset* designed to evaluate children's self-perceptions of their inventive capacities and the effectiveness of IvE programs. This tool assesses how students view their abilities in terms of ingenuity and solution-seeking, which are crucial components of inventive mindset.

Talamantes et al. (2022) *Self-Efficacy and Engagement Evaluation* investigated changes in youth learners' self-efficacy and engagement with STEM concepts after participating in IvE programs. This type of assessment typically involves pre-and post-program surveys to gauge changes in students' confidence and interest in STEM areas following their involvement in IvE activities.

In a mixed-method assessment of an IvE camp, Jackson (2022) found statistically significant increase in cognitive self-efficacy with technology in middle school students, along with their perceived agency for inter-disciplinary and trans-disciplinary approaches to inventing, social engagement, and student participation. They also discovered progression in individuals' and teams' emotional, behavioral, and cognitive engagement. Such research informs future avenues for designing more effective IvE programs and comprehensively assessing the effectiveness of loosely structured paths to invention.

Dreamson and Khine (2022) argue in favor of integrating abductive reasoning in IvE because of its deductive validity and inductive strength. They propose using six abductive reasoning strategies to assess design thinking: questioning socially given identities, restructuring a hierarchy of values, perspective-taking, being intersubjective through body swapping, and developing imaginative empathy for compassion.

Acknowledging challenges in evaluating the impact of invention education programming, Moore et al. (2022) and Talamantes et al. (2022) emphasize the need for more research to investigate and seek a better understanding of how such education impacts long-term engagement in STEM fields and entrepreneurial activities. As we show above, although researchers have assessed and reported IvE programs, there are challenges with reaching an agreement on what to assess and how to evaluate IvE's educational gains.

Inventor stereotypes, identities, and equity in IvE

Stereotypes, identities, equity, and inclusion stand out as central IvE themes. Reviewing these themes will inform the social foundations of IvE research (research question 2) and pave the way for dismantling inventor stereotypes and cultivating a diverse, inclusive generation of innovators. Traditional stereotypes often depict inventors as solitary geniuses from specific demographics or fields, predominantly male figures. Analyzing surveys and interviews with high school inventors in the USA, Couch et al. (2018) reported that organization and processes of invention programs, resources, collaborations, inventor personal qualities, values, and beliefs facilitate learning from failure, self-confidence, and persistence among females, more than males. However, time constraints, stereotypes, lack of prior knowledge, exposure, understanding, and engagement can constraint girls more in the process of invention.

In South Korea, a comprehensive study by Lee and Kwon (2018) revealed that elementary students predominantly perceived inventors as male. When prompted to illustrate an inventor, boys tended to depict male inventors, while girls often portrayed female inventors. Interviews with the participants revealed that such stereotypes were strengthened by the depictions in books and media. Although the above two studies were done in different geographies, the gender implications seem universal, indicated by the presence of stereotypical symbols, such as beard, and males in lab coats.

Iddris et al. (2022) found that the participant's gender even affected the extent to which IvE improved their perception of innovation competence and subsequent entrepreneurial intentions. Moore et al. (2022) highlight IvE's role in broadening these perceptions by showcasing a diverse range of inventors, thereby affirming that innovation can originate from anyone, irrespective of their background. This initiative is critical, as Voiklis et al. (2020) observed in South Korean elementary schools that inventor stereotypes tend to lean toward male associations, influenced by gender, media habits, and personal histories. These stereotypes, which blend the identities of scientists and inventors, solidify with age, suggesting a deep-rooted bias that IvE programs struggle to amend, even at the collegiate level.

The stereotypes and identity perceptions regarding inventors are not uniform across ages, genders, and races, indicating a significant variance in how inventorship is viewed (Zhang et al., 2019). Participation in IvE has been shown to alter gender-related stereotypes significantly, especially among women, transforming girls' perceptions of themselves as leaders and innovators (Couch et al., 2018). However, as students progress in their education, the stereotypical views of inventors as white, male, intellectual geniuses become more entrenched (Saenz and Skukauskait, 2022), often depicting them as secluded figures in lab coats, which affects diversity and participation in STEM and invention programs (Lee and Kwon, 2018). This stereotyping particularly discourages girls, who feel they are not "supposed to be interested" in these fields, underscoring a broader issue of representation and inclusion in STEM (Couch et al., 2018, p. 745).

Researchers show that these stereotypes also influence diversity and participation in IvE and STEM fields. Lee and Kwon (2019) report that breaking the stereotypes will require more foundational efforts, such as replacing the photos and figures in textbooks with more relevant images and even changing teachers' recognition of invention. Skukauskaite et al. (2019) argue for historical accounts of inventors to show a wide variety of personal backgrounds and knowledge sources.

Institutions and programs with extensive experience in offering IvE started focusing on the diversity and equity issues in the field. For example, in their review of IvE programs, Holly and Comedy (2022) emphasized the importance of acknowledging sociopolitical factors, such as urban divestment, unequal educational opportunities, and narrow definitions of innovation. Similarly, Couch et al. (2019a, 2020) argued for the crucial role of access to STEM-rich settings and community engagement in shaping students' self-perception as inventors and nurturing a creative persona, which Zhao et al. (2020) identified as a key trait among enduring inventors.

The necessity of repeated exposure to IvE for developing invention competencies and fostering entrepreneurial intentions becomes evident through some studies (e.g., Iddris et al., 2022). Continuous and repeated engagement helps students identify more closely with the inventive process, encouraging them to see beyond mere leadership roles (Couch et al., 2019a).

Efforts to ensure that IvE is inclusive and accessible are pivotal, involving the integration of culturally responsive teaching practices and the development of programs that cater to a wide range of learning needs and interests (Talamantes et al., 2022). These efforts aim to guarantee that all students, regardless of socio-economic, racial, or cultural backgrounds, have equal access to IvE opportunities. By promoting equity and engaging community and industry partners, IvE initiatives strive to create a more inclusive educational landscape.

Conclusion, challenges, and future directions

We now address our third research question by discussing the current challenges and recommending future directions and opportunities that could spur substantial advancements within the field. A significant uptick in IvE research in recent years demonstrates the field's burgeoning interest and development globally. This growth underscores the expanding reach of interdisciplinary IvE initiatives. Although limited, the early integration of IvE into educational settings has been pivotal in initiating diversity and preparing a well-versed workforce in innovation. Highlighted by programs like the InVenture Prize and Dare2Design, these initiatives have significantly improved engagement and outcomes for both teachers and students, showcasing the potential and effectiveness of targeted IvE efforts.

Despite the substantial interest and the critical role IvE plays in modernizing STEM education and fostering essential skills like creativity, collaboration, and problem-solving, this study identifies several areas needing further exploration and development. The field suffers from limited access to relevant literature, perhaps exacerbated by the lack of universal terminologies and definitions, hindering comprehensive development and a unified understanding of IvE. A notable absence of commonly accepted terms and theoretical foundations complicates matters further, especially when integrating invention into STEM coursework. This challenge is compounded by various barriers, including resource limitations, curriculum constraints, and the need for extensive teacher training and support.

The call for teacher training as a crucial future research direction resonates deeply within the culmination of preceding sections. Each citation echoes a distinct facet of the imperative: interdisciplinary skills demand attention (Chandra et al., 2021); resources must be harnessed to foster effective IvE delivery (Page et al., 2008); a systematic invention process, guided by proficient educators, is essential (Hosler, 2019); and cultural responsiveness is paramount in IvE pedagogy (Talamantes et al., 2022). Moreover, the current landscape reveals a significant obstacle: the self-selection of IvE education by both teachers and students, hindering the broader dissemination of this discipline. Evidence suggests that IvE instructors may inadvertently prioritize certain curricular aspects due to limited expertise (Kars-Unluoglu, 2016). These challenges underscore the urgent need for comprehensive teacher training initiatives, aiming to democratize IvE education and empower educators to contextualize opportunities within diverse learning environments (Fila et al., 2020). Meticulously planned training programs not only equip teachers with essential skills but also furnish them with the resources necessary for effective IvE implementation (Perusek and Shlesinger, 1987; Page et al., 2008; Moore et al., 2019). Through strategic investment in teacher development, IvE education can transcend its current limitations, reaching beyond self-selected participants and instructors to enrich a broader educational landscape. Broad access to IvE pedagogical and content training can be instrumental in broader integration of IvE in current educational environment, as well as overcoming of entrenched stereotypes associated with inventors and innovation, which complicates the adoption and integration of IvE.

Looking forward, the future of IvE research lies in addressing these challenges. Establishing a unified theoretical framework for IvE and linking it more closely to established learning theories will be crucial. Researchers could build on Lemelson Foundation and Coy (2020) which proposes six tenets of context, empathy, problem-solving, continuous learning, iterations, and sustainable innovations. Skukauskaite et al. (2019) list empathy, creativity, resilience, calculated risk-taking, passion, resourcefulness and tolerance for ambiguity, and complexity as the attributes of this framework. Given the shared interdisciplinarity between Computer Science and IvE, Skukauskaite et al. (2019) argue in favor of drawing from the computer science framework for adoption and implementation of IvE.

Expanding IvE's integration across educational curricula to enhance inclusivity and diversity within the field also presents a significant opportunity. Overcoming resource availability challenges and improving teacher preparedness necessitates forging robust partnerships across educational institutions and industry to develop comprehensive support systems for educators. Furthermore, investigating the dynamics of self-selection by teachers and students into IvE programs will provide deeper insights into factors affecting participation, aiding in the development of strategies to broaden the appeal and impact of IvE. Additional research exploring the distribution of IvE literature, its integration at various educational levels, and a more global view of IvE's development will enrich the field's knowledge base and practical applications.

By addressing these areas with improved clarity and methodological rigor, the IvE research community can further validate and support the endeavors of practitioners and scholars in the field, paving the way for a future where innovation and invention education are integral components of a well-rounded educational experience.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SD: Conceptualization, Data curation, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. MA: Conceptualization, Data curation, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing, Formal analysis, Resources, Software, Supervision, Visualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1284442/full#supplementary-material

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