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iINVENT pathways and practices: prizing the process over the product

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Rural communities need skilled innovators who engage as community members, support economic opportunities, and develop novel ways to solve local problems. Through innovation, Invention Education (IvE) is one way to promote the creativity and problem-solving needed to restore economic vitality to regions of the rural US. IvE pathways support a skilled workforce that communities can draw upon to solve complex problems. Introductory IvE experiences can begin to bolster rural recovery and open prime grounds for innovative solutions. The Office of Precollege Programs at Oregon State University established the iINVENT Program for upper elementary, middle, and high school learners to engage in IvE and act as inventors. In this study, we describe the iINVENT pathways resulting from 8 years of curriculum design and iteration guided by engaged scholarship practices and robust evaluation. Program data from 2019–2023 was collected via learner, educator, community partner, and parent surveys, as well as through observations conducted by program staff and partner instructors. Results from qualitative content and thematic analysis demonstrate the value of introducing learners to IvE and how iINVENT practices support invention educators in impacting youth learners. The findings demonstrate essential practices, successes, and challenges that have shaped the iINVENT pathways and IvE curriculum delivered. Based on these findings and current discourse unfolding throughout the IvE professional community, the authors suggest that a process-oriented invention framework focused on inventiveness and the ways learners can act as inventors is pivotal to broaden access and participation in IvE, providing learners with a more applicable and relatable learning experience to cultivate inventiveness mindsets and skills transferable to all parts of life.

KEYWORDS

process-based, invention, STEM, K-12, guided participation, rural learners, qualitative

Introduction: background and rationale

The revitalization of rural communities lies in the next generation of learners and leaders becoming skilled innovators who can engage with their communities, support regional economic development, and create novel ways to solve local problems relevant to their place and people. In Oregon, rural learners account for 38% of the K-8th graders (ECONorthwest, ND) and 42% of the 9–12th grade population (Riggs, 2021), considerably more than twice the national average of 14% and 19%, respectively (Drescher and Torrance, 2022). Weakening economies and declining job opportunities have forced many residents to relocate to urban centers, effectively shrinking the rural workforce (US Department of Labor, 2019). In Oregon, jobs that remain often require higher education as a result of technological strategies adopted by the wood products and agricultural industries. Rural environments are consistently underserved by initiatives that support innovation; hence, the revitalization of rural economies and reduction of poverty will require the next generation of innovators and entrepreneurs to be inspired and creative. A skilled workforce needs a support pathway that communities can draw upon to solve complex problems. For this purpose, almost a decade ago, the Office of Precollege Programs at Oregon State University (OSU-PCP) established iINVENT, an Invention Education (IvE) Program originated to offer mobile middle school summer camps across rural Oregon communities. Currently, iINVENT offers three introductory invention pathways for (1) upper elementary learners via in-school instruction, (2) middle school learners via community-based summer mobile camps, and (3) high school learners via participatory projects with community partners. In general, program evaluation has documented that it increases learners' self-efficacy as inventors and exposure to STEM careers and majors and meets the needs of parents, teachers, and community members seeking STEM education experiences for youth while providing a unique connection to college student mentors and near-peers (Talamantes, 2020; Talamantes et al., 2022).

Because of iINVENT's explicit design focus on opportunities at each level for participatory appropriation (Wertsch, 1997; Engeström, 2000; Rogoff, 2003; Gee, 2015) of inventiveness skills and dispositions through apprenticeship (Engeström, 2000) and guided participation (Rogoff et al., 2003), the authors undertook a qualitative evaluation to understand how the participating iINVENT educators drew upon explicit teaching practices to engage learners, as well as the challenges they encountered while implementing invention activities.

Rural needs and invention pathways

A variety of factors including low learner academic engagement, low income, and geographical isolation result in a broad rural-urban education disparity across Oregon and the nation. High school graduation rates in remote Oregon communities are some of the lowest in the state (Pierson and Hanson, 2015) with an average of 76.9% (25.5% low to 96.5% high) for rural counties as a whole compared to 80.1% for urban counties (Oregon.gov, 2019). The enrollment rate of rural learners in postsecondary education institutions is lower (55% compared to 63% for non-rural learners), and persistence to their second year is also lower (78% vs. 83%) (Pierson and Hanson, 2015). Similarly, there is an acute disparity in college achievement between rural and urban Oregonians. As of 2018, only 26.2% of Oregonians living in rural counties held a four-year degree, far below the Oregon urban county average of 44.4% and below the overall national average of 37.7 % (Oregon.gov, 2019; US Census, 2022). Finally, youth from populations traditionally underserved by or underrepresented in science, technology, engineering, and mathematics (STEM) learning and IvE (especially LatinX and Indigenous) are overrepresented in rural Oregon counties. At the same time, rural schools and communities offer unique opportunities for innovations that bridge engaging out-of-school activities with school learning goals in ways that help learners develop an interest in academic achievement and long-term career success (Wai et al., 2010; Couch et al., 2019).

A review of the literature shows that exposure to innovation during childhood has a significant impact on youth's likelihood to engage in invention activities (Bell et al., 2019). IvE engages youth learners and broadens participation in STEM, positioning youth to act as and to become inventors (Zhang et al., 2019). Bell et al. (2019) point out that the top one percent of youth in high-income families are ten times more likely to become inventors than youth from below-median-income families, demonstrate gaps by race and gender, and exposing the skewed nature of financial returns to inventions as they correlate with scientific impact. The authors suggest that increasing exposure to innovation in childhood may have larger impacts on the industry than increasing the financial incentives to innovate.

Pedagogical frameworks

IvE builds from and adds to the solid foundation underlying STEM education efforts to promote creativity, problem-solving, and innovation skills (Couch et al., 2019; Talamantes, 2020; Talamantes et al., 2022). The primary mission of the iINVENT program is to provide introductory invention experiences to rural Oregon youth by engaging them in real-world problem-solving. iINVENT uses cross-disciplinary lenses (STEM-focused, hands-on, and community engaged) and diverse pedagogical practices (e.g., learner centered, experiential, art integrated) to support inclusivity and guided participation in relevant contexts for learning by intentionally leveraging community-based problems, near-peer mentorship, thematic instruction, and a collaborative approach to inventing (Talamantes, 2020; Talamantes et al., 2022). By focusing on a community-based approach, iINVENT becomes relevant to rural Oregon communities by identifying community needs rural learners are familiar with and further exploring those needs through interviews with users, videos with community members, and critical analysis. By leveraging thematic teaching and OSU-PCP college student staff as near-peer mentors, the program situates inventor mindsets, skills, and content within learner-led invention projects with collaborative teams. In doing so, we strive to support learners to generate ideas about their inventions, share those ideas, and revise them to create invention prototypes, positioning youth as agents who can identify a community need and collaborate with others taking the steps to solve real problems (Talamantes, 2020; Talamantes et al., 2022).

Learning environments

iINVENT brings introductory IvE curricula to in-school and out-of-school settings throughout rural Oregon. Learning pathways for elementary, middle and high school learners generate impact inventors via innovation, community engagement, and problem-solving reaching learners in four ways: iINVENT in the

Classroom, iINVENT Mobile Summer Camps, iINVENT Youth as Inventors, and iINVENT Integrations. Table 1 provides a summary of these program pathways and the professional development offered to educators within each when applicable.

Educators receive professional development, support the delivery of invention-specific activities, have OSU-PCP learner staff interact with youth as near peers, and stay in regular communication with OSU-PCP staff. iINVENT also provides a stipend for participating classroom educators as well as curricular materials for all program activities. Table 2 shows the invention attributes embedded within each pathway and the associated program supports provided by OSU-PCP iINVENT structure.

Methods

Theoretical framing

The authors view IvE as embodied in cultural and social practices (Rogoff, 2003; Rogoff et al., 2003) and rooted in cultural, historical, and social contexts and activities (Engeström, 2000; Stetsenko and Arievitch, 2004; Roth et al., 2009), which are then mediated by iINVENT activities. We conceptualize and include all invention educators, classroom educators, and college student mentors as partners who work to revise and co-create programming elements, activities, and goals, and enact community involvement to create a mutually beneficial partnership, making the IvE pathway possible for youth learners (Beaulieu et al., 2018).

Data collection and analysis

The participants in this study were purposefully sampled in alignment with the iINVENT program they led (Maxwell, 2004). Each participant completed an end-of-year survey or a semi-structured focus group interview following their participation in an iINVENT program. The sample includes 14 elementary school educators, 8 college learner mentors, and 2 high school educators who facilitated an iINVENT program between 2018 and 2023 (Pandemic years data were removed from the dataset due to the challenges and pivots needed during the COVID-19 Pandemic). Data was collected and analyzed to (1) describe how participating iINVENT educators describe IvE, (2) what practices educators use to engage learners in IvE, and (3) the challenges that come with doing IvE in their learning spaces. Table 3 summarizes how many educators participated in each program, when, and the data collected.

Responses were transcribed (where necessary) and entered into online qualitative data analysis software (Dedoose). Relevant text was broken into excerpts ($N = 250$) and analyzed using content and thematic analysis (Auerbach and Silverstein, 2003; Berg et al., 2004). An initial codebook was developed by two of the authors to reflect the structure and design of the program, and these codes were applied by the same two authors in a top-down fashion with other codes developed *in vivo* as part of analysis. This resulted in 43 separate codes. After reviewing for redundancy and eliminating unused codes, 25 codes remained, 18 of which were included in the data reported here. Table 4 summarizes the final codes and frequencies of application.

Acknowledgment of constraints

The authors acknowledge the constraints of the study related to participant representation, dynamics of working within a university-community partnership, funding, and pandemic impact. First, elementary and middle school educators were more represented in this study than high school educators by virtue of the size and pilot limitation of the high school *Youth As Inventors* as a new program. This may have skewed the results of the practices identified as being more representative of what occurred at the elementary and middle school pathways. Additionally, the nature of the high school curriculum is largely different with over 60 h of learning time and in-depth engagement of youth with community partners, hence there will always be a smaller number of high school educators and learners involved in iINVENT.

Second, the 2018–2019 pre-pandemic *iINVENT Summer Camp* data was used as a more accurate representation of program impact than 2020–2022, which suffered changes from mitigating COVID-19 impact and adapting back to in-person instruction. The *iINVENT in the Classroom* elementary program was revamped post-pandemic, hence the use of data from 2022–2023 program. As we sustain these pathways in a post-pandemic world, we will be aligning our data collection efforts to the emerging process-based inventiveness framework.

Third, the iINVENT pathways operate as part of a university-community partnership within Oregon State University's Office of Precollege Programs with the concert of multiple internal and external partners. Due to this relationship and the importance for learners to interact with near-peers, iINVENT pathways utilize university students as mentors and university resources that may have influenced participants to answer survey questions in an overly positive way, possibly due to eagerness to support the overall program as invested participants and lifelong learners.

Lastly, this study was conducted using stipends for elementary and high school educators and paid university student mentors. The funds for stipends, payments, programming, and evaluation were provided by the Lemelson Foundation. The authors feel that these constraints did not significantly impact the validity of this study hence the educator and student experiences in the program are distant from their knowledge and understanding of the program funding structure and sources.

Results

The focus of the analysis was (1) to understand how educators working within an explicitly guided, participatory, apprenticeship-based, program engaged in the iINVENT IvE program, (2) the teaching practices educators used to engage learners in IvE and acting as inventors, and (3) to understand the challenges educators perceive in doing IvE with learners. As Table 4 shows that participants identified ten practices essential to describing what IvE is, and four practices that are essential to engaging learners in invention. All practices identified supported positive learner

TABLE 1 iINVENT program pathways by denomination, description, and professional development offered to educators.

Pathway denomination	Pathway description	Educator professional development
iINVENT in the Classroom (Elementary Level)	Elementary learners participate in a 6-lesson invention project focused on inventing something for their school. Classroom educators facilitate lessons and OSU-PCP student staff video-call-in to provide near-peer mentorship, feedback on projects, and participate in a panel for college preparation and career awareness.	Elementary school educators receive 2 h of professional development where facilitators cover content about IvE, the program pathway curriculum, as well as common pitfalls and tips to implementation and support their learners as facilitators.
iINVENT Mobile Summer Camps (Middle School Level)	Middle school learners gain skills related to the IvE toolkit and apply these skills through community-focused invention case studies via a 5-day summer camp invention project. Camps are led by OSU-PCP college students as near-peer mentors.	OSU-PCP student mentors receive 40 h of professional development and in-person training including program pathway curriculum content, youth engagement, youth safety protocols, etc. As a team of mentors, they lead and deliver eight or more summer camps annually.
iINVENT Youth As Inventors (YAI) (High School Level)	High school learners participate in a 3-week hybrid invention project focused on inventing something to address a local community issue (e.g., marine debris, tsunami awareness). Lessons are led by high school educators, OSU faculty, OSU innovation lab interns, and OSU-PCP college student mentors.	High school educators receive 2 h of professional development on the curriculum and focus of the projects surrounding the community problem of choice, which they help select with their learners. They recruit participants and facilitate the development of their inventions.
iINVENT Integrations	Short IvE activities are incorporated into another PCP existing program, Campus Field Trip, hosting K-12 students, teachers, and families in hands-on activities during their campus visit.	No professional development occurs in these short integrations for teachers leading visiting groups. The curriculum is directly delivered by OSU-PCP student staff conducting these alternative programs as integrations with IvE.

*Because there is no educator development in this pathway. Data is not included in this study analysis. See Talamantes (2020) and Talamantes et al. (2022) for a summary of the iINVENT Mobile Summer Camps and iINVENT Youth as Inventors Activities.

engagement and outcomes. Some of these were purposefully built into the curriculum while others emerged from implementation. These practices are briefly described. The frequency of mention of some practices differed by grade level, a finding consistent with the intentional design of the three-level curriculum.

Essential practices of IvE

Educator indicated that they saw IvE as something more than a traditional subject, like reading or math, because learners focus on applying what they are learning to solve a problem, because of the unique structural aspects of their invention projects, and value the people and resources around them. The codes that emerged when educators were describing invention were: *Project Framing, Solving Everyday Problems, Interviewing Others, Prizing the Process over the Product, the Roles of Feedback, Sharing, Presenting, Representations of Invention and Technology Use, and the Role of the University and Mentors*.

Project framing

The curriculum of each program pathway carefully frames projects for learners in terms of scope and seriousness. The importance of how a project is framed was not mentioned by elementary educators, but it was the second most highlighted practice for high school educators and was also mentioned in multiple ways by middle school educators. This suggests that it might be more necessary to have learners develop a well-framed problem as learners become more deeply involved in the invention process at the middle and high school levels. This finding goes hand in hand with the fact that a focus on metacognition was also mentioned frequently by middle and high school-level educators and not at all by elementary.

Solving everyday problems and interviewing others

While not mentioned by middle or high school level educators, the program focus on invention as a way to solve everyday problems, especially in one's local community, school, or family was called out as important by all participating elementary school educators as was the related activity of interviewing others, whether it be other learners, the school custodian, community members, university college learners, or even each other. A key component of the invention process is the development of empathy for end users or clients, and interviews are built into the curriculum at each level to help learners learn how to take end-user ideas, needs, and feedback into consideration during the ideation and prototype development processes. Elementary educators also discussed the importance to learners of seeing the everyday problems of their lives, schools, or communities as being tractable spaces for creating learner-driven inventions. It is important to note that the places, people, and problems learners address at the elementary level are considered every day because the place, problem, and people impacted are easily accessed by the learners—meaning that people they know, or possibly they themselves, encounter this problem in a place that is familiar to them as learners, who are also possible users, and, now, inventors.

Prizing the process over the product

The importance of emphasizing the invention process rather than the actual inventions that result from the projects and related activities and skills was recognized as an important element of the programming by all educators. There was an explicit emphasis by the educators to call attention to what learners were learning, doing, and sharing rather than making a working prototype. This is an important finding because the curriculum is geared toward introductory invention experiences with an explicit focus

TABLE 2 iINVENT program attributes and structural supports.

Program attributes	*iINVENT in the Classroom*	*iINVENT Mobile Summer Camps*	*iINVENT Youth as Inventors*
Lead educators	Classroom teachers and college student mentors.	College student mentors.	Classroom teachers, innovation lab instructors, and college student mentors.
Support professionals	PCP Program coordinator and team members, OSU program partners	Program coordinator, collaborative PCP team members, OSU program partners	Program coordinator, collaborative PCP team members, OSU and community partners
Program resources	OSU-PCP offers the invention curriculum and its pedagogical materials (kits, presentations, books, and other supplies) provided to teachers.	OSU-PCP offers the invention curriculum and its pedagogical materials (kits, presentations, camp materials and other supplies) to each cam.	OSU-PCP offers the invention curriculum and its pedagogical materials (kits, presentations, books, and other supplies). The innovation lab provides expertise, technology, and resources for prototypes.
Community partners	Classroom teachers and their community partners.	Community camp hosts and their community partners.	Innovation labs and community partners experts solving local problems.
Learning context	Learners participate in an 8 h in-school IvE unit where they work in teams to solve a problem for someone they know or about something in their school community.	Learners participate in a 5-day 30 h Summer IvE camp working in teams to solve a problem for a peer or a college student, or to work on a problem presented to them.	Leaners participate in an 10hr hybrid program that spans their high school and a local innovation laboratory solving a community identified problem.
Invention specific content	Delivered through lessons, hands-on activities and a variety of media, such as videos and books to engage learners with introductory steps in the invention process.	Delivered through lessons, daily hands-on activities and a variety of media such as videos to engage learners with human centered design and the invention process.	Delivered through lessons, experiential activities and variety of videos, readings, activities to engage learners with inventor mindsets, human-centered design, and the invention process.
Essential practice - identifying a user and empathizing	Learners interview someone they know, such as a parent or a school staff member, to inquire about the problems they are facing and understand their point of view.	Learners interview someone at camp, such as a peer or a college student mentor, to inquire about the problems they are facing and learn their point of view.	Learners watch videos and read testimonials about problems their local community is facing (e.g., marine debris) to learn the partners' point of view.
Essential practice - problem solving	Learners engage in various activities to generate, develop, and evaluate their ideas.	Learners engage in various activities to generate, develop, and evaluate their ideas.	Learners engage in various activities to generate, develop, and evaluate their ideas.
Essential practice - continuous feedback	Learners share their project ideas and prototypes with their users, teachers, each other, and via zoom with college student mentors to get feedback.	Learners share their project ideas and prototypes with their users, each other and the college student mentors to get feedback	Learners share their project ideas and prototypes with each other, their users, teachers, innovation lab staff, and college student mentors to get feedback.
Essential practice - presentations	Learners present their prototypes to each other in the form of a pitch presentation.	Learners present their prototypes to each other and parents at the end of the 5-day camp.	Learners present their inventions to family and community at a research symposium.
Example inventions	Learners have developed inventions to make their school a better place, supports for custodial staff, and new playground ideas.	Learners have developed inventions to support college students such as planners, lunch boxes, and personal organizers.	Learners have developed inventions to solve a local problem such. One example is a tsunami cache that opens and directs people to it in case of an emergency.

on engaging in the process of inventing rather than the need to create a fully operational prototype.

Feedback, sharing, and presenting

The importance of learning to give and receive feedback especially related to the design of inventions was highlighted as an essential practice across age levels more or less equally. While receiving and giving feedback was equally represented across participants, the important role of sharing each other's ideas, plans, and prototypes and presenting those to multiple audiences was only highlighted as an essential principle by elementary-level educators. It was not mentioned at all by either high school or middle. This may be because general presentation skills, such as audience considerations, are more explicitly emphasized at the elementary level than at the middle and high school levels.

Representations of invention and technology use

Invention and inventors are purposefully represented across the curriculum in multiple ways and through multiple types of media. The curriculum uses books and short videos at the elementary level to show learners what an inventor is, and similarly, the middle and high school curricula use short videos of similar-aged youth sharing their inventions. Having materials that engaged learners in seeing themselves as inventors was frequently mentioned by elementary and middle school educators as important. In addition, the use of technology is also purposefully woven into the curriculum. Technology use was the most mentioned essential practice important to the high school and middle school level educators, only being mentioned once by an elementary level educator. This finding may reflect the fact that elementary learners use arts and crafts materials (e.g., pipe cleaners, hot glue, felt, foam, and balloons) to represent their invention. Middle school uses the same materials with additional access to more technology-driven

TABLE 3 iINVENT participants by programs and data collection methods.

iINVENT program	Grade level	Participants and data collection
iINVENT in the Classroom	Elementary School	14 educators completed the post-activity survey after each lesson in 2022–2023 (post-pandemic revamped program).
iINVENT Mobile Summer Camps	Middle School	8 College student mentors facilitated 16 summer camps and completed post-program surveys in 2018–2019 (pre-pandemic).
iINVENT Youth As Inventors (YAI)	High School	2 High school educators facilitated an invention project with a high school team utilizing the Hatfield Marine Science Center's Innovation Laboratory. They were interviewed following their 2022 participation in the pilot program.

activities that utilize iPads, electrical motors, and programmable robots to spur their invention along. High school learners access a working innovation laboratory with various equipment, such as 3D printers, to represent an invention, and the people (e.g., mentors and university staff) who can teach the learners how to use the available equipment the moment a learner needs to use it for their project. While this finding may reflect the curriculum design, it also infers that utilizing and accessing technology is very important to educators and learners at the middle and high school levels.

Role of the university and mentors

Educators highlighted in many ways the value of the university partnership. Most commonly at the elementary level, this was represented by the relationship and importance of the college learner mentors who visited the learners. Their role is to provide expertise related to entrepreneurship and innovation, define invention, and provide feedback to prepare learners for a pitch presentation to the class, family, and/or community members. Additionally, both the college mentors and the educators pointed out the importance of making connections between college youth and elementary school youth such that the former serve as both role models and representations of paths to college experience for youth, many of whom in the project geographical areas come from communities that are highly underrepresented at regional universities. Beyond the mentors, middle and high school level educators pointed to the important role of the university in providing educator training, introductions to invention processes and resources, and community partners. Finally, middle and high school educators also discussed the access to maker spaces, technology, tools, and laboratory equipment that the relationship with the university made possible.

TABLE 4 Final list of codes and frequency of application.

Name of code	Total number of applications
Essential practices of IvE	
Project framing	16
Solving everyday problems	10
Interviewing others	8
Process over product	24
Role of feedback	22
Sharing/presenting	21
Representation in/of the invention	27
Technology use	7
College mentor	25
Relationship with OSU	22
Essential practices for engaging learners in IvE	
Iteration	30
Ideation	29
learner project ideas	13
Metacognition	10
Challenges	34
Small groups	18
Pacing of program	13
Open-ended	7
Totals	**336**

Essential practices for engaging learners in IvE

The following practices emerged as researchers sought to describe how educators were inviting learners to think about their invention projects and the strategies that they used to direct learner thinking and activities to create a prototype of their invention. Hence, the practices below are referred to as a “Focus on...” since they detail intentional instructional strategies to direct learner thinking. The codes and practices that were useful in describing the ways that educators engaged learners were a focus on learner Project Ideas, Ideation, Iteration, and Metacognition.

Focus on learner project ideas, ideation, and iteration

All three levels highlighted the important place of learners' ideas for projects as being significant motivators of engagement, sharing, and fun. Following learners generating project ideas, these project ideas were then ideated on as intangible inventions and then iterated on as physical prototypes. Iteration was the most common essential practice reported followed by ideation, both practices were most often mentioned by elementary and middle school educators. Ideation and Iteration are stressed particularly in activities that encourage youth to imagine new uses for everyday products (e.g., pencils) or new designs for existing inventions. Iteration is also built into the process of developing and testing prototype inventions as well as practicing presentations and pitches and incorporating feedback from audiences into those presentations.

Focus on metacognition

This practice includes the use of questioning strategies to push learners to evaluate their own or other learners' design ideas, inventions, or prototypes, cycling through groups or among individuals to assist them in thinking critically about their approaches, their thinking, or potential areas for prototype or presentation improvement. As mentioned previously, both high school and middle school level educators highlighted the focus on learners' thinking as a key element of guiding learners through the invention process. This code often co-occurred with codes for Ideation and Iteration as educators talked about challenging learners to do more, reflect on their thinking/ideas, and challenge the stereotypes of inventors and invention.

Challenges

The participating educators encountered several challenges to engaging youth in IvE. Some stem from a lack of awareness of what IvE is and how it is executed. These sentiments became apparent in the codes related to the open-ended nature of the activities, deciding on ideas, and incorporating feedback. While educators voiced these challenges, their overall sentiment toward the program was positive.

Open-ended nature of the activities, invention process, and the program itself

Throughout the programming at all levels, invention is presented in an open-ended way, a feature of the curriculum that educators see as both a positive and a challenge. Specifically, they point out that the open-ended nature of the programming helps focus learners on asking and answering questions of each other in ways that support their processes. However, for educators themselves, the open-endedness is something of a challenge, especially in terms of overall pacing and timing. Educators often point out that lessons take much more time than they anticipated. While this is not necessarily discussed as a drawback or problem, it is a challenge for educators and mentors who may be experiencing IvE themselves for the first time.

Deciding on ideas

A second challenge for all the educators was watching learners struggle with developing initial ideas and then working in small groups to decide on which ideas to see through to production. Educators often relied on small group strategies suggested by the curriculum or from their own experience to either guide groups or to self-select by interest as a way of winnowing down possible invention ideas. At the same time, they recognized the importance of learner buy-in developed when one's idea goes from ideation through iteration, to production and presentation. Discussion about the difficulty learners had in deciding on ideas was often related to the difficulty learners had receiving and incorporating feedback.

Incorporating feedback

All educators recognized the importance of feedback in the process, but across all levels, they called out the challenge of youth learning to give and receive feedback in positive ways AND taking it seriously enough to incorporate feedback into design changes at every stage of the process. Elementary-level educators stressed the need for more time in the curriculum for learners to practice giving and receiving feedback.

Discussion

This study aimed to document and distill how educators describe IvE, to document the practices educators use to engage learners in IvE, and to understand the challenges educators perceive in doing IvE with learners. Many of the themes described above, from the joy of working with learner ideas to the challenges of open-ended projects, resonate with the pedagogical approach of Problem-based learning (PBL). Similar to IvE, PBL approaches rely on an invested learner having a high level of choice in what the project is going to be, how the project is going to be conducted, and what the learning outcomes of the project will be (Hmelo-Silver, 2004; Falk, 2005; Couch et al., 2019; Talamantes et al., 2022). Furthermore, educators who engage in PBL may often feel uncomfortable with the ambiguity of where a learner-driven project may take them. Within the context of an AP project-based government class, for instance, Parker et al. (2011) describe this sentiment as a tension between the breadth of knowledge learners need to complete the project and the depth at which learners need to know that knowledge to complete the project well. In IvE, this tension may be felt when educators need to teach a learner how to 3D print something on the fly—how much about 3D printing do learners need to know—or when trying to plan for what a user may say is the problem they would like the learners to address, or when groups are deciding on what ideas to pursue, and, lastly when wondering how much time a specific project may take compared to other groups completing very different projects. For invention educators to recruit other educators to their cause and to promote learner learning, finding ways to navigate these tensions is important.

Inherent in iINVENT's approach to IvE is an emphasis on the practices of invention that seek to encourage youth to act as inventors as a way to engage them in introductory invention experiences (Talamantes, 2020; Talamantes et al., 2022). To move this vision forward we seek to strengthen our view of IvE to specifically focus on *process-based inventiveness*. While working toward an end goal or prototype is necessary for learners to act as inventors to begin with, focusing on what happens along the way (the process) develops the agency necessary for young inventors to become agents of change and impactful innovators.

To inform our focus on *process-based inventiveness*, we draw on the practices previously described and Gee's (2015) framework on how identity is shaped by discursive interactions individuals have with the world around them. Gee (2015) notes that while some

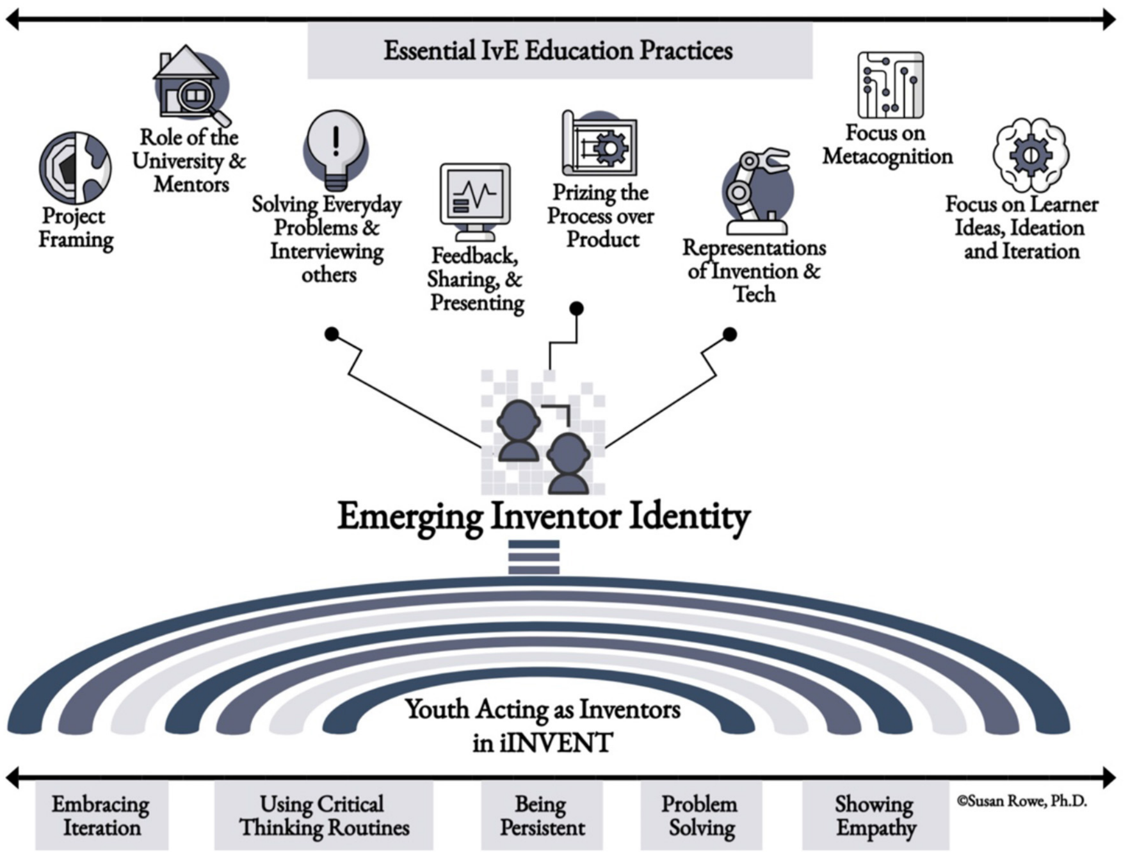

FIGURE 1
Conceptual model of the relationship between identity, essential IvE practices and youth acting as inventors within the context of iINVENT.

aspects of a person's identity are not easily changeable, others can be malleable and fluid. In the context of invention and inventiveness, Gee's (2015) framework would view someone who held the identity of an inventor as a function of that individual doing things that would count as inventing and other folks calling attention to them as doing things an inventor would. We operationalize invention and inventiveness utilizing Gee's (2015) identity framework as an "inventor is someone who acts in inventive ways" to study how youth navigate learning experiences specifically designed to promote traits valued in IvE (e.g., inventiveness) and broadly valued in STEM-fields (e.g., empathy, problem-solving, technology use, ideation, iteration, and creativity). To say someone is acting inventive, and therefore as an inventor, could mean they think creatively about tasks, solve problems in novel and unique ways, organize group ideas effectively, and efficiently navigate a community of experts to find out needed information. Thus, the IvE practices described earlier should prompt learners to act as inventors and promote a broad sense of inventiveness by positioning youth to utilize traits that are valued in IvE and elsewhere with agency (Gee, 2015; Talamantes et al., 2022). See Figure 1 for a conceptual model of the relationships between the essential practices identified above, the activities of youth made possible by those practices, and identity as inventors. The figure shows the discursive relationship between teaching practices that prompt learners to act as inventor to develop an inventor identity.

The distinction between inventiveness and invention has been discussed by multiple scholars in the field (e.g., Moore et al., 2022) as a relationship between entrepreneurship and engineering education as a function of creativity, novelty, unpredictability, and uniqueness to the individual(s) who created a product. The authors used their definition as a lens "to analyze existing curricular elements and to assess the likelihood of those elements promoting and encouraging inventive outcomes" (Moore et al., 2022, p. 17) and found the curricular elements of problem-finding, testing a solution, creating a value proposition, ideating on a solution, and pitching an idea to a customer as being activities likely to promote inventiveness. They assert that promoting inventiveness in a broad sense across multiple disciplines may allow learners to leverage the assets they bring to the classroom and allow for greater engagement of youth underrepresented in invention, entrepreneurship, and STEM fields.

Process-based inventiveness recognizes that the creative process itself holds intrinsic value and can lead to new insights, breakthroughs, and inventive solutions. By nurturing a mindset of curiosity, flexibility, and persistence, process-based inventiveness unlocks the potential for transformative and meaningful innovation. Each step in the invention process informs the next, with failures and unexpected discoveries serving as valuable learning opportunities. Process-based inventiveness activities may be a solution to encourage learners to try out aspects of invention, take risks, and step outside their comfort zones, without the commitment of a long-term project. Current efforts to pilot specific evaluation methods to further analyze process-based inventiveness are underway in the forms of exploring the dynamic between learners' own ideas, creativity, ideation, and iteration in the forms of coding, dance, and instructional practices that explicitly promote learners generating, sharing, and developing their ideas as a function of their interests (Kong et al., 2018; Flesch et al., 2021; Renzulli et al., 2022). The primary author of this paper (Susan Rowe) is a member of a Lemelson funded Sprint group of professionals in IvE currently creating an inclusive and accessible survey tool with aligned metrics as a formative assessment of inventiveness in education pedagogical practices (Livingood et al., 2024). With this emerging set of evaluation metrics and tools, it will be possible to test four hypotheses regarding Processed-Based Inventiveness as represented within iINVENT programming:

1. Process-based inventiveness is positively impactful because process-based activities allow for more opportunities for learners to work on their ideas during the learning experience.
2. Process-based inventiveness is inclusive and relevant because focusing on parts of the invention process (e.g., ideation or iteration) rather than a final product allow for more modalities of engagement in IvE and more opportunities to bring learner ideas, interests, and cultural capital into their learning experience.
3. Process-based inventiveness is broadly accessible because inventiveness can be tied to numerous learning contexts and disciplines once the emphasis on completing a project is lessened for educators and learners.
4. Process-based inventiveness is broadly applicable because learners can see how the skills they use for inventing are used in STEM professions and their daily lives, and vice versa.

iINVENT has become a protagonist in broadening K-12 participation in Rural Oregon, introducing IvE to multiple stakeholders and intentionally linking schools and communities by growing a successful framework and pathway for learners to act as inventors. Participating educators have noted several essential practices for promoting IvE and engaging learners, shining light into how those practices can be further developed into a process-based inventiveness framework we can use in future research. These educators described the joy of working with learners' ideas and their efforts in ideating and iterating, as well as the challenges of leading an open-ended team-based learner-driven project within the context of IvE. In alignment with emerging scholarship within the IvE community, we intend to move this work forward by focusing on *a process-based inventiveness* framework to make "acting as an inventor" more accessible to learners and more potent in promoting the transferable skills that are valued within IvE and STEM careers. Not every learner will become an inventor, but all learners can develop inventiveness mindsets and skills applicable to solving problems in their communities and become agents of change.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The Oregon State University Institutional Review Board deemed this study exempt for studies involving humans as program evaluation. The evaluation was conducted in accordance with institutional requirements. Participants were informed that the results of the evaluations would be used for program evaluation and might be reported as such.

Author contributions

SuR: Writing – original draft, Investigation, Funding acquisition, Conceptualization. AT: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. JW: Writing – review & editing, Project administration, Funding acquisition. RO'N: Writing – review & editing, Supervision, Project administration. EN: Writing – review & editing, Project administration. ShR: Writing – original draft, Methodology, Formal analysis, Data curation.

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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.

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