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Supporting teachers to lead invention education with high school students

Audra Skukauskaite
Learning Sciences and Education Research, University of Central Florida, Orlando, Florida, USA, and

Stephanie Renee Couch
Lemelson-MIT Program, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Abstract

Purpose – The purpose of this study was to examine ways high school educators new to invention education (IvE) pedagogy can develop confidence in their ability to facilitate high school students' work as part of this transdisciplinary (STEM+) problem-based approach to teaching.

Design/methodology/approach – This focused ethnographic study traced participants' interactions across a three-day event that included professional development for 36 educators. The authors documented the discourse, actions and broader social context in which the interactions took place between the educators and others. Ethnographic fieldnotes, interview transcripts and pre- post-experience surveys were analyzed to determine ways the professional development opportunities shaped the educators' perspectives on their confidence to facilitate IvE with their students.

Findings – Many different types of learning opportunities were afforded across the three days, including lectures by professor-inventors, seminars, talks with experienced educators, hands-on activities and engagement with high school students. The 36 educators indicated they were more confident in their ability to lead invention projects (55% more confident, 41% much more confident) due to participation.

Originality/value – IvE is an emerging form of problem-based learning in which educators engage learners in the identification of problems and the design and development of new, novel, useful and unique technological solutions (i.e. inventions) that help people. The study responds to the need for research on ways educators learn how to take-up IvE pedagogy.

Keywords Invention education, Transdisciplinary, STEM, Ethnography, High school students, Professional development, Pedagogy, Confidence

Paper type Research paper

"Invention education" is an emerging field focused on the development of the next generation of inventors and creative problem solvers. We define invention education (IvE) in accordance with a consensus document produced in 2019 by 39 educators, education

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researchers and educational program providers with expertise ranging from the early years of schooling through college [Invention Education Research Community (IVERC), 2019]. The consensus document describes IvE as:

> A deliberate effort to engage learners in the identification of problems and the design and development of new, novel, useful, and unique technological solutions (i.e., inventions) that contribute to the betterment of society (Committee for the Study of Invention, 2004; Couch *et al.*, 2019) (IvERC, 2019).

Additional perspectives can be found in an edited volume produced by Finnish educators and researchers, entitled *Invention Pedagogy – The Finnish Approach to Maker Education* (Korhonen *et al.*, 2022). A meta-analysis of IvE in K-12 schools in South Korea also demonstrates positive effects of invention pedagogy in developing "student creativity, attitudes toward science, and tendency for technological problem solving" (Kwon *et al.*, 2016).

Elements common to descriptions of IvE pedagogy as described by the researchers from the USA and Finland include a focus on *problem finding and defining, developing prototypes of unique and novel technological solutions* that *address a need of intended beneficiaries* and *ongoing engagement of the intended users over time* as the inventor(s) goes through *the nonlinear, iterative process of discovery, designing, building and (re)testing of a* prototype (IVERC, 2019). The process underlying the work of invention educators reflects accounts of the work of inventors and their understandings of ways of developing inventiveness (Committee for the Study of Invention, 2004; Johnson, 2014; Petroski, 1996; Weightman, 2015; Wiener, 1993). Component parts of the invention process also intersect with work in innovation (Perez-Breva, 2016), creativity (Daly *et al.*, 2014), maker movements (Blikstein, 2013; Martin, 2015), project-based learning (Beier *et al.*, 2019) and integrated STEM initiatives (Cajas, 2001; National Academy of Engineering and National Research Council, 2014). IvE is a pedagogical approach that also aligns with inquiry-, problem- and project-based models of education (Gijbels *et al.*, 2005; Lu *et al.*, 2015; Skukauskaitė *et al.*, 2023a, 2023b). What makes inventing and IvE unique is its focus on problem-finding and ideation phases of inquiry as well as teamwork in developing technological solutions to learner-identified, community-grounded problems (Couch *et al.*, 2018; Skukauskaitė *et al.*, 2023a, 2023b). The uniqueness of IvE also stems from the belief that everyone can create new, novel, useful, unique and nonobvious technical solutions to problems (an invention) if provided the opportunities and support in a collaborative environment which welcomes continuous learning, values creativity and embraces productive failure (Bell *et al.*, 2018; Committee for the Study of Invention, 2004; Couch and Kalainoff, 2024; Novy-Hildesley, 2010).

Educators taking up IvE organize instruction around the invention process as they help students learn ways inventors find and solve problems that matter and improve lives. Knowledge and inquiry practices are based on strength-based approaches to education (Couch and Kalainoff, 2024; Saenz and Skukauskaitė, 2022) and draw from many different disciplines, depending on the nature of the problem being solved. Students and teachers, therefore, are enacting a transdisciplinary approach to problem-based learning that is recognized as being especially useful in solving complex real-world challenges (National Science and Technology Council, 2022).

Making IvE available to all students across grade levels and communities requires more teachers who are prepared to facilitate students' work in transdisciplinary environments where the invention process structures the opportunities for learning. Teachers also need to be prepared to collaborate with students and members of the larger community as both

teachers and students seek to acquire the knowledge, skills and capabilities needed for their invention projects (IvERC, 2019).

This paper reports findings from our reexamination of archived records to explore ways of orienting educators to IvE pedagogy and preparing them to facilitate transdisciplinary IvE projects in which teachers work alongside students developing invention prototypes. The Lemelson-MIT (LMIT) Program, which has a 20-year history of helping educators and students learn to invent, served as our site of study. We focused on the archived records from 2018 since that was the year LMIT had hired an external ethnographer (first author) to supplement efforts by the internal ethnographer (second author) to document the program (Couch and Kalainoff, 2024). The external ethnographer conducted interviews with educators participating in LMIT's summer IvE professional development opportunity. The external ethnographer also generated research records by observing, recording, interacting, interviewing and surveying attending educators. Staff researchers at LMIT have been collecting data and studying LMIT's programs since 2017 (Couch and Kalainoff, 2024).

The external ethnographer coming alongside the ethnographer who is on-staff (an insider) helped ensure that the internal ethnographer avoided ethnocentrism (Green and Bridges, 2018; Green *et al.*, 2017). The support of external ethnographers and researchers as part of the design and implementation team also increased the capacity for generating robust data sets and for generating new analytic insights (Couch, 2012). Creating internal, program-owned archives (Sullivan, 2023) and accessing them later enabled researchers to explore the records in new ways. With the distance of time, the researchers had opportunities to step back from prior knowledge or assumptions to construct data and conduct analyses on topics that were most salient to questions LMIT practitioners posed in relation to their work to grow the emerging field of IvE (Green *et al.*, 2017; Punathil, 2021; Sullivan, 2023; Roulston and deMarrais, 2021).

Entering the archived 2018 ethnographic records, we asked two research questions:

RQ1. What opportunities for learning about IvE did the LMIT program provide for teachers participating in a professional development program intended to help educators learn about IvE?

RQ2. How did the opportunities for learning about IvE impact educators' perspectives about their take-up of IvE with the students they serve?

To explore these questions, we first provide a brief review of the context in which this study took place, including the way teacher professional development sessions were embedded into the larger IvE grants initiative, known as InvenTeams. We then provide an overview of our research approach. The following sections demonstrate analyses of the data for the two research questions. We end with reflections on the implications of the research findings.

Context: the Lemelson-MIT InvenTeams grant process and EurekaFest as a telling case of supporting teachers in leading invention education initiatives

This study is part of a continuing program of research on IvE conducted by internal and external ethnographers supported by the LMIT Program (Couch and Kalainoff, 2024). The LMIT Program, funded by the Lemelson Foundation and housed within MIT's School of Engineering, works to ensure that all students have opportunities to learn to invent (Lemelson-MIT Program, 2024). In this paper we focus on the program's Excite Awardees, or educators deemed to have met the initial qualifications for the eventual submission of a final InvenTeam grant application for funding and support from LMIT for an invention project with their students.

Excite awards and the InvenTeams grant cycle

InvenTeam grants provide funding and staff support to teams of high school students (grades 10–12) and their teachers as they explore a real-world problem they have identified in their communities and develop a working prototype to solve that problem. Since the creation of InvenTeams twenty years ago, 296 teams from around the USA have received grants and support from LMIT as well as from their local communities. The teams have produced working prototypes of their inventions at the end of a 14- to 18-month grant period. Eighteen teams have secured U.S. design and utility patents for their work and many more have patents pending, although patenting is not an expectation of the InvenTeams program.

The InvenTeams grant initiative includes three phases. Phase I focuses on the initial InvenTeam grant application in the Spring in which a teacher and a team of students submit a proposal for their invention project. In 2018, the year in which the data for this study were collected, 36 teachers were selected from the pool of applicants to receive an Excite Award (referred to hereafter as Excite Award Recipients or EARs). The 2018 award, announced in April, consisted of an all-expense paid trip to MIT in June to attend a three-day annual event known as EurekaFest. EARs participated in a programmatic strand specifically designed to help the teachers learn about IvE and ways of preparing a final InvenTeam grant application. Activities for EARs included sessions on IvE and facilitating student invention teams, and one-on-one meetings with the Expert Teachers who provided feedback on the InvenTeam project proposed in the initial application. The EARs also had opportunities to interact with current InvenTeam students, teachers and collegiate inventors, to observe or participate in a design challenge and to engage in other social events.

The larger 3-day EurekaFest event, in which the professional development program for EARs was situated, included K-12 educators with different lengths of experience with IvE, high school and collegiate student inventors, MIT professors who are prolific inventors and LMIT staff, as shown in Table 1.

The focus of our study and this paper is on the ways LMIT oriented EARs to IvE through the professional learning strand offered during EurekaFest at MIT in mid-June, after the teachers' initial InvenTeam applications were chosen. We begin by tracing the opportunities for learning offered to the EARs at the beginning stages of taking up IvE that were intended to educate EARs about ways of initiating, facilitating and supporting the transdisciplinary work of teams of high school students. We then provide an overview of the EAR's perspectives on their confidence in taking-up IvE with their students after the professional development experience.

Research approach

The larger program of research of which this study is a part is guided by an interactional ethnographic perspective and its goal to understand people's practices, processes and perspectives from their points of view, within situated groups and events embedded in the larger sociocultural contexts. In studying IvE, we draw on scholarship that conceptualizes ethnography as epistemology (Anderson-Levitt, 2006; Green and Bridges, 2018; Green *et al.*, 2012; Skukauskaitė and Green, 2023b) and a way of thinking (Agar, 2006; Atkinson, 2017) rather than a method or a set of techniques (Bloome *et al.*, 2018; Heath and Street, 2008; Skukauskaitė, 2023). This epistemology enables researchers to conduct full scale ethnographies or develop smaller-range studies that adopt an ethnographic perspective to investigate particular phenomena and areas of interest (Agar, 2010; Skukauskaitė and Green, 2023a). A study that utilizes an ethnographic perspective, like all ethnographies, can draw on a variety of methods and tools to explore the complex in-time and overtime processes,

Table 1. IvE network members participating in EurekaFest and EAR professional development

Type of member	Description
Ethnographers	Education researchers, including a researcher on the LMIT staff (internal) and a researcher working on contract (external)
Excite award recipient (EAR)	Educators who met the initial qualifications for an InvenTeam grant
Expert teachers	Teachers who had facilitated the work of an InvenTeam in prior years. They receive stipends to mentor EARs and support educators who receive an InvenTeam grant across the year
High school and collegiate inventors	High school students who were members of an InvenTeam in the prior school year, and undergraduate teams and graduate students from colleges and universities across the U.S. who had won the Lemelson-MIT student prize for their creativity and inventiveness
InvenTeams	Teams of high school students (grades 10–12) and their teachers (former EARs) who received a grant and support from LMIT
Invention education officer	A member of the LMIT staff who had the lead responsibility for EAR selection, professional development and InvenTeam grant cycle
Lemelson foundation	Funder of LMIT and its program offerings
Lemelson-MIT program (LMIT)	The invention education program administered by the school of engineering at MIT. The LMIT program has several initiatives including Excite Awards and InvenTeams
Professor/professors	MIT faculty members who were guest speakers

Source: Created by authors

practices and consequential progressions (Putney *et al.*, 1999) of human activity and interaction (Atkinson, 2017; Skukauskaitė and Green, 2023b; Walford, 2018).

This study began with our examination of the professional learning sessions for EARs documented by the external ethnographer. Ethnographic fieldnotes, audio and/or video recordings of the sessions, on-site feedback questionnaires administered to the teachers, and materials provided for the teachers as part of the professional learning opportunity were collected and analyzed to examine the opportunities for learning about IvE afforded to the teachers (*RQ1)*. Program records, emails, one-on-one interviews and post-EurekaFest EAR surveys were utilized to explore the educators' reflections on the professional learning sessions (*RQ2)*. Table 2 provides an overview of the records and corpus of data utilized for this study.

The records generated as part of this study provide an evidence base from which we explored our two research questions about the EARs who are taking up IvE for the first time.

Participants

A total of 36 EARs attended EurekaFest in 2018. They came from 22 states and represented 13 urban, 5 rural and 17 suburban schools. 56% came from schools that offered free and reduced lunch to over 40% of the school students, a measure used across the U.S. to determine the students' and community's socioeconomic level. 16 of the educators were female and 20 were male. Their teaching experience ranged from one to over twenty years, with the majority (72.6%) falling into the 1–15-year K-12 teaching experience bracket. All EARs were sent the university Institutional Review Board (IRB) approved consent forms electronically, inviting them to participate in the study. The email and subsequent introduction of the research project in person on the first day of EurekaFest emphasized that the participation was voluntary and had no bearing on their final application. Final applications would be evaluated by external judges who were not part of the ongoing research. All 2018 EARs signed IRB-approved consent forms to participate in this study.

Table 2. Records for studying Excite Award recipients' professional learning opportunities about IvE at EurekaFest (EF)

Source of information	Administered by	# responses & kinds of documents	Intent
Documents			
Initial applications for EARs	LMIT staff, online on SlideRoom	63 submitted, 36 accepted	Examine backgrounds as represented in CVs and interest statements; explore reasons for non-acceptance
Materials shared with EARs at EF	LMIT staff and guest speakers	Folder of documents; book; slide handouts	Explore opportunities for learning about invention education provided at EF
Interviews/conversations			
Pre-EF phone interviews	External ethnographer	2, 35–45 min	To pilot the questions for the pre-EF survey and to learn about teacher experiences with the initial application
Interviews with EARs at EF (audio records and fieldnotes notes)	External ethnographer	2 interviews; multiple informal interactions	Learn what brought them to invention education
Interactions with expert teachers, LMIT program staff	External ethnographer	Multiple, over 5 days of EF and post EF	Listening to expert teachers and program staff insights about what makes a good invention education teacher/ facilitator
Fieldnotes			
Fieldnotes of EF events	External ethnographer, Internal ethnographer, Researcher on contract	Notebooks, electronic files, pictures and drawings of seating and room layout	Record and explore the primary ethnographic question: what is happening here?, including what opportunities are provided?
Surveys			
Pre-EF survey to EARs	LMIT research team through survey monkey	33, 92% response rate	Learn teacher backgrounds, reasons to apply, and hopes for EF
EARs at EF wednesday	LMIT program staff	35, 97%	Learning and impact of professional development at EF
EARs at EF thursday	LMIT program staff	28, 78%	Learning and impact of professional development at EF
EAR post EF survey	LMIT staff and external ethnographer via survey monkey	23, 64%	Impact of professional development and attendance at EF
EAR experiences in preparing the final InvenTeam application	External ethnographer via survey monkey	30, 83%	Explore processes, practices and experiences in preparing the final application

Source: Created by authors

Analyses and findings

Methods of analysis were grounded in the interactional ethnographic epistemology and research practices (Skukauskaitė and Green, 2023a). The first step in analysis involved creating an event map (Table 3) – a sequential record of events, situated in time and marked by transitions in participant actions and/or topics (Green and Kelly, 2019; Green and Wallat, 1981). The second step involved identifying key events, or rich points, which have the potential to reveal the underlying language, knowledge and cultural practices being cocreated within the event and community in focus (Agar, 2006; Skinner, 2023). Transcribing in message units as an analytic process (Skukauskaitė, 2014) and discourse analysis of participants' language (Bloome *et al.*, 2022) enabled us to see what the first speaker signaled as important for IvE (Table 4). We then identified the next rich point, the lecture by a guest professor, as an event which covered more information about IvE and in step three created an event map of that event (Table 5), noting discursive markers and identifying ideas about IvE signaled through the discourse. The fourth step involved conducting a domain analysis in which we worked with the key ideas signaled to identify how they interrelated. Using Spradley's (2016) semantic relationship of "x is a kind of y", which helps researchers identify aspects of an idea or phenomenon, we noted the kinds of ideas (included terms) that were kinds of aspects of inventing (Table 6). Noticing that the professor also talked about ways of teaching, we also constructed a domain of ways of teaching (Table 7). These two domains enabled us to show what was taught as IvE and its pedagogy to educators (EARs) participating in the professional development strand. These steps of analysis were iterative and recursive, and not as linear as presented here since each informed the prior and subsequent steps, which required us to go back to what was already done to seek further evidence or clarify meanings through discourse analysis.

Once we analyzed the video and audio data and checked it against ethnographer fieldnotes and the documents provided at the event to ensure the accuracy of our representation of opportunities for learning, we turned to question 2. To answer the second question pertaining to the program's impact of educators' confidence, we utilized participants' open-ended survey responses, constructed a table based on the Likert scale from the survey and entered all self-reported ratings of confidence educators identified for themselves at the end of the professional development. For this paper, we selected responses that were representative for each scale on the survey and created (Table 8). This analysis is an overview of participant responses, which could be analyzed in more depth in future studies. Below we unfold these analyses and discuss how they answer the two research questions we posed for this study.

RQ1. What opportunities for learning about IvE did the LMIT program provide for teachers participating in a professional development program intended to help educators learn about IvE?

EARs attending EurekaFest in June 2018 were provided an opportunity to participate in professional learning sessions at MIT, to view the prior year's InvenTeam projects, receive feedback on their students' proposed projects for the following school year and review and ask questions about the requirements for the final InvenTeam application due in September. Our documentation of the opportunities afforded EARs at EurekaFest began with the construction of an event map – a record of the shifting events over time (Green and Kelly, 2019; Green and Wallat, 1981; Skukauskaitė *et al.*, 2023a, 2023b). The EurekaFest schedule served as a starting point for the construction of the map. Table 3 shows the activities designed by the program staff for EARs across the four days.

Constructing the event map represented in Table 3 and aligning activities by day and time made visible two kinds of events that provided opportunities for teacher learning and interaction: seminars and lectures, and InvenTeam events. The seminars and lectures primarily took place

Table 3. Event map of opportunities for excite award recipients at EurekaFest

Time slots	Day 1, 6/19	Day 2, 6/20 Invent	Day 3, 6/21, Teams	Day 4, 6/22 Final application
8–8:45 am	A	Breakfast	Breakfast	Breakfast
9–10 am	R	9–10	9–9:50	9–9:50
	R	InvenTeams welcome	Invention is a team sport	The final application
	I			
	V	10:15–10:55	10–10:50	10–10:50
	A	Getting to know you	Communication is key	The final application – judging criteria
	L			
	S			
11 am–noon	and	11–noon	11–noon	11–noon
	Settling	Teaching innovation	Hands on activity	The final application experiences
12–12:45 pm	Into	Lunch	Lunch	Lunch
1–2 pm	Next house dormitory	1–2:15	1–2	1–5
		What's an invention?	Invention and innovation	Individual feedback on the initial application
2–5 pm		2:30–4:30	2:15–5	Observe InvenTeam Design Challenge
		InvenTeam presentations	InvenTeams showcase of inventions	
5–6 pm	5–5:45 Orientation for ALL educators: InvenTeams (1 per team) and EARs			
6–8 pm	6–7	6–8:30	6–8	6
	Dinner	Dinner: student prize award ceremony	Teacher appreciation dinner	Goodbye InvenTeams! dinner
Evening		8:30–10	8 pm	7:30
		Video game truck	Ice cream truck	Popcorn and movie

Source: Created by authors

Table 4. Analytic notes on introductory comments for excite award recipients

Fieldnotes	Analytic notes about professional development opportunity for EARs
10:00 am. LMIT IvE Officer	
1. Now I believe we have a full house	1. "we" as a group opportunity
2. we have a folder full of goodies	2. "we" as LMIT staff offering resources
3. For wednesday and thursday we are on the right side of the folder	3. Resources organized by day "we" – collective learning
4. For friday – on the left	4. Friday as slightly different
5. On the right, blue sheet, is the schedule you will follow	5. Schedule is color coded and specific to EARs
6. Your schedule will be in and out of the InvenTeams schedule	6. Connection of EAR events with InvenTeams
7. We'll be giving hints of what you might want to see	7. "We" people as resources; hints to listen for as guides
8. Who to talk to	8. Talking to others
9. What types of questions to ask	9. Asking different types of questions
10. So you come from EF knowing why you were here	10. Expected outcome – knowing
11. What InvenTeams do	11. Understanding what ITs do
12. Knowing the impact of InvenTeams on students and the teachers	12. Understanding the impact on students and teachers
13. And figuring out if it is in fact something you want to do next year or if you can do it	13. Making an informed choice whether to participate in the next stage

Source: Created by authors

before noon, while events involving the InvenTeams occurred in the afternoons. Each type of event provided opportunities for professional learning and interacting in multiple ways.

Seminars or lectures: learning from experts

The formal professional learning programming for EARs at EurekaFest included seminars, participation in dialogues and hands-on activities with the LMIT IvE Officer and/or Expert Teachers, and lectures by MIT professors. On the first day of the professional learning seminars, when EARs arrived in the room where all formal programming for EARs took place over the next three days, the LMIT IvE Officer distributed folders and introduced the schedule. A book about team building was given to all EARs.

Analysis of fieldnotes and the audio recording of the introduction made visible how, from the first moments of the formal gathering and seminar with EARs, the IvE Officer emphasized key ideas and values related to invention. These first moments of interaction on Day 2, the first formal event of the day taking place from 9 to 10 a.m., provided a rich point (Agar, 2006) that reveals cultural patterns being co-constructed in the group. Table 4 includes an excerpt from the researcher's fieldnotes and analytic notes of what was signaled to EARs during that first formal interaction (line numbers added for analysis purposes).

In the 13 phrases of the LMIT IvE Officer's presentation, she signaled key values of IvE: materials and people as resources (2, 3), learning as a group undertaking (1, 3, 7 "we"), and EAR opportunities purposefully linked with InvenTeam activities to enable EARs to learn from those who have completed the InvenTeam process, which EARs had initiated for themselves with their application (6). The IvE Officer also signaled expected actions and outcomes. The actions she and "we" (Expert Teachers and LMIT staff implied) expected the EARs to engage in included talking to others (8), asking questions (9) and listening (7).

Table 5. An event map of the MIT professor's lecture, including analytic notes about opportunities for learning about innovation and invention

Event	Subevents	Discursive markers from the professor's talk (captured in the researcher's fieldnotes)	Insights about innovation/ invention reflected in the professor's talk
Introduction	Opening	- Will talk about teaching innovation - We are trying to set people up to have careers for stuff like this - More than anything is to create a desire to create as an innovator	- Learning principles of innovation sets people up for careers - Teachers can help students create a desire to innovate
	3 examples	- Braille labeler - Helmet vending machine - LED microfilm projector slide	- There are multiple examples of where innovation is needed - Inventions solve real problems
	Discussion	- What's in common? - *EAR responses:* • *Real world problem* • *Student driven* • *Need* • *Impact* - "Real users"… students worked with real people - "Can't underestimate the value of having real users to help you"	- Learning involves engagement and reformulations of ideas - Real users are key to invention
	Examples	- Examples	- Examples provide inspiration and make learning relevant
Lecture: Framing	Presentation start	- Teaching innovation slide - To inspire students - History "we've been working for a while: 23 years of refinement"	- Innovation can be taught - The goal of teaching is to inspire students - Developing innovation culture takes time and is historical
	"recipe"	- What is the recipe? - "Motivation + creativity + informed craft + process"	- There are common processes/values involved in inventing
	Teaching quiz	- "Which object is different from the others?" answer on an index card - "Short quizzes are unexpected and you don't know it's coming up" - "Turns challenge into a kind of game"	- Unexpected challenges may be helpful - Challenges can become a kind of game

(*continued*)

Table 5. Continued

Event	Subevents	Discursive markers from the professor's talk (captured in the researcher's fieldnotes)	Insights about innovation/ invention reflected in the professor's talk
	Discussion Summary/ embedded lesson	- All answers are acceptable - "Discovery consists of looking at the same thing as everyone else and thinking something different" Aleber Szent-Gyorgyi	- Variety of ideas is important - Divergent thinking is necessary - Others have conceptualized and talked about these ideas over centuries
Lecture: Creativity	Framing the importance of creativity	- Why do you think so few people think differently? - We are taught - We stop when we think something works – that is dangerous; in a competitive situation if you are doing the first thing you can think of, that's probably what other people are doing also, so you won't have a competitive advantage - Believe there are more ways to do things - Know how much time you have to explore and use it to explore	- Thinking differently is challenging because we have been taught to conform - Considering competitive situations to find an advantage - Important to remember that there are many ways to accomplish things - Allotting time to explore within time available
	Strategies to foster innovation	- Look for the next right answer - Look from multiple viewpoints - Defer all judgments (tell the left side of your brain to be quiet) - Challenge assumptions (question assumed boundaries or norms)	- Looking from multiple points of view - Deferring judgments - Challenging own assumptions
	Summary/ Embedded lesson	- "The best way to get a good idea is to get a lot of ideas" Linus Pauling - There is a correlation between how many ideas you come up with and how many good ones are there - The best ideas can be first, last, you don't know the order - If you have certain amount of time to explore, use it to explore - We'll generate a lot of garbage but we'll find one idea	- Generating many ideas - More ideas can lead to more good ideas - There is no sequence of when good ideas develop - Use time to explore - Generating "garbage" is a necessary part of the process to find the one good idea

(*continued*)

Table 5. Continued

Event	Subevents	Discursive markers from the professor's talk (captured in the researcher's fieldnotes)	Insights about innovation/ invention reflected in the professor's talk
Lecture: Informed craft	Framing informed craft	- Knowing stuff and knowing how to work with it - "To invent, you need a good imagination and a pile of junk" Thomas A. Edison - Being able to work with what you have - You will see something you didn't see that will carry you forward - You get to get real - "Fail fast to succeed sooner" – learn from our failures - Rapid cycles: idea, test, learn	- Knowing is not enough; invention requires hands-on engagement - "Junk" and "imagination" can lead to invention - Invention requires being able to work with resources available - Ideas for the next steps will be generated in the process of doing - Failure allows to learn and to "get real" - Crafting involves iterative cycles of generating ideas, testing, learning
	Example	- Sketching, visual modeling, soft modeling by hand - This model at Phillips, my vision of what a computer may look like 1984 - Digital, more refined	- Modeling helps develop the ideas - Current digital possibilities enabled more refined modeling
	Framing the need for craft	- Craft: We are good at what we practice - In education – it's testing, taking notes - We need to give people a chance to practice	- Craft develops through practice - People need opportunities for hands on building
	Guiding through the crafting process in his course	- We talk and have them tear the product down - we talk about what a tear down is, then students have 45 mins to tear down, look at parts, document them, figure out what they are made of - Parts, labeled, estimated price - Students see that you can do a lot in a short amount of time	- Tearing apart products and labeling the parts can foster innovation - Engaging students in hands-on activities - Much can be learned and done in even a short time - Understanding of parts and costs is part of crafting/creating
	Examples	- Videos from the classes	- Multiple modes of presentations and examples can inspire or provide ideas
	Synthesis	- Craft is a process - Contextualize it as fun, students remember - Take products apart and talk about design	- Crafting/ innovation develops through a process of doing - Contextualizing doing and learning as fun helps students engage and remember

(*continued*)

Table 5. Continued

Event	Subevents	Discursive markers from the professor's talk (captured in the researcher's fieldnotes)	Insights about innovation/ invention reflected in the professor's talk
		- What do I want teams to master? – learn by doing (slide title) - Learning by fun	- Design can be taught by examining parts of things - Learning should be fun
Lecture: Process	Discussion	- Something I think is important. Why? - *EARs: repeatable* - Imagine if you are making a career of this if you get lucky once, it won't get you far - *EARs: safety* - Prof: Yes - *EARs: Cost effectiveness* - Prof: related to time - Rigor and breadth	- Discussion and generating ideas is part of learning - All ideas are valuable - Process relates to time, rigor, and breadth of innovating
	Framing process as part of invention	- Rigorous and thorough about exploring options - We have to be rigorous in depth - Typically we spent about ½ of the process exploring options, preliminary prototyping, and then committing	- Rigor develops through exploring options in depth - Half of the allotted time can be spent on exploring options and prototyping - Committing to an idea follows the process of exploration and trying out idea
	Importance of feedback	- We are doing the reviews every 3 weeks - Reviews provide feedback, rank order concepts - Teams have different ideas, we discuss what one does better - What's the least useful idea in feedback? "looks good" - The point of doing reviews and feedback, to change your thinking - Want to create a culture where people discuss pros and cons of ideas openly	- Multiple reviews are necessary - Reviewers provide valuable feedback - Reviews foster discussion and development of ideas that are good and can lead to innovation - Reviews that say "looks good" are useless - Reviews should influence and change thinking - Important to create a culture where honest debating is possible
Lecture: Motivation	Framing the importance of motivation	- Motivation is the most important, without it you can't get to innovation - "How many of you in your career want to do nothing of value?- no one"	- Motivation is the driving force - Motivation as part of a meaningful career - Important to make things that matter - Working with real users

(*continued*)

Table 5. Continued

Event	Subevents	Discursive markers from the professor's talk (captured in the researcher's fieldnotes)	Insights about innovation/ invention reflected in the professor's talk
		- If we do things that make it matter, making it real, solving things, - Working with real users makes it matter	
	Examples	- Example slide: elderly care facility, device to read–don't go to restaurants because they can't read menus	- Problems to solve can be observed in everyday encounters
	Experiential story: immersion in narrative	- Act 1: setup - Act 2: journey. Product development process - Act 3: resolution. Product launch. - Video	- Process has three major parts: setup, journey, and resolution - Motivating by sharing video examples
	Synthesis	- Key is to create a motivational environment so students push themselves and do great stuff - Anonymous peer reviews are important and motivational - Knowing that we'll be discussing in an open way also motivates	- Important to create an environment in which students are motivated to push themselves and engage in doing - Open discussion and dialogue can be motivational
Summary	Summary	- In summary: motivation, creativity, informed craft, process	- Invention "recipe"
	Resources	Link to the course website	- Sharing knowledge and resources publicly

Notes: Quotation marks indicate direct quotes, as captured by the ethnographer at the time. Italics represents the ethnographer's synthesis of the key foci in EAR responses
Source: Created by authors

Table 6. Domain analysis: X is an aspect of inventing

X (included terms)	Semantic relationship	Y (cover term)
- Learning innovation principles and common processes - Seeing relevance for careers - Solving real-world problems - Interacting with real users - Generating many ideas - Understanding that there are many ways to solve things - Receiving and providing honest feedback - Engaging in divergent thinking - Understanding the history of field and inventiveness - Considering competitive situations to find an advantage - Allotting time for exploring - Engaging in the process hands-on - Taking things apart, learning how things work - Working with resources available - Learning from failure - Creating models, testing ideas - Engaging in iterative and recursive process - Motivating and inspiring others - Challenging own assumptions - Deferring judgments during idea generation phases	Is an aspect of	Inventing

Source: Created by authors

By mentioning the outcomes right after the presentation of expected actions, the IvE Officer made visible that learning from these opportunities was dependent on the actions EARs undertake during the EurekaFest. Expected outcomes included: "knowing why you were here" (10) and understanding the purposes of the intended professional learning as well as understanding what InvenTeams do (11), and how they impact teachers and students (12). In the last line, the IvE Officer made clear that ultimately the EARs will need to make an informed choice whether they want and/or can proceed to the next step – the final application and, if selected, undertake the complex work of InvenTeams. As she articulated the resources, expectations and possible outcomes for the EAR participation in EurekaFest, the IvE Officer also emphasized the collective "we" and "full house" engagement necessary for learning to take place.

After the overview of the EAR EurekaFest schedule and the time for everyone to introduce themselves, a lecture by a MIT professor took place. In the post-EurekaFest survey and during many informal conversations, EARs talked about the impact this lecture had on them. Two primary themes were mentioned: the dynamic personality of the professor as an inspiration, and the message about what constitutes invention and how anyone can be inspired and supported on the journey to inventing. The professor, a distinguished member of one of the MIT's engineering departments, introduced his talk as focusing on "teaching innovation" and invention as consisting of "motivation + creativity + informed craft + process." Table 5 provides an event map analysis (Green and Kelly, 2019; Skukauskaitė *et al.*, 2023a) constructed from the researcher's fieldnotes and supporting information from the lecture (pictures of slides and the website the professor shared). We include this long table here not only to make visible what is signaled about IvE by this distinguished professor through his lecture, but also to demonstrate how researchers can capture key information when video or audio recording is not possible.

Table 7. Domain analysis: x is a way of teaching invention

X (included terms)	Semantic relationship	Y (cover term)
Creating a desire to invent		
Teaching principles of inventing		
Sharing many examples of inventions that solve real problems		
Engaging students in generating many ideas		
Having students consider and talk to real users		
Teaching about invention processes and practices (knowing)		
Focusing on engaging in invention processes and practices (doing)		
Providing many ongoing hands-on opportunities for learning	Is a way of	Teaching invention
Inspiring students		
Developing an innovation culture in the school or classroom		
Providing challenges		
Encouraging divergent thinking		
Accepting all ideas		
Engaging students in honest dialogues and feedback of each others' work		
Fostering failure as a learning opportunity		
Breaking norms, challenging conformity		
Allotting time to explore ideas		
Engaging students in iterative and recursive processes of hands-on doing		
Allowing students to take things apart		
Developing tasks that help students learn how things work and are built		
Establishing parameters of boundaries – time, available resources		
Creating an environment in which students push themselves		
Sharing own developing knowledge and not knowing		
Sharing resources		

Source: Created by authors

Constructing the event map of the professor's lecture to the EARs made visible that the opportunities for learning were constructed not only through the content shared, but also through his demonstration of ways to engage in learning. During this one-hour lecture, EARs had opportunities to listen, respond to questions verbally, share their ideas, do a surprise quiz, check their answers and see multiple examples on the slides, on video, and in the actions of the professor. The professor also demonstrated one way of structuring a lesson as an interactive opportunity for learning, rather than an hour-long lecture. In this process of dynamically sharing ideas and engaging the participants, the professor shared a variety of ideas about invention. We included the possible opportunities and ideas for learning about invention in the right-hand column of Table 5. Further analysis of these ideas led us to construct a domain of *x is a kind of y* (Spradley, 1980/2016), an aspect of inventing, represented in Table 6.

In addition to highlighting many aspects of inventing, the professor also modeled and talked about ways of teaching invention. Using the notes in the last column of Table 5, we constructed an additional domain analysis, *x is a way of y*, for teaching invention (represented in Table 7).

The two domains generated through the analyses of the professor's lecture made visible how an experienced educator taught invention by engaging his own students in invention processes and practices. In sharing his knowledge and teaching practices, he also demonstrated an approach for lecturing and engaging audiences in ways that motivate and inspire them. As many EARs mentioned in conversations and on the surveys, this lecture was one of the most impactful learning opportunities for them at EurekaFest.

Table 8. Representative explanations of increased confidence to lead invention projects in response to the survey prompt: "explain what contributed to the change (or no change) in your confidence"

Confidence expressed	Response from the survey
More confident	Seeing for myself that anyone can be an inventor. Hearing success stories, challenges that were overcome and disasters (some that could have been prevented) made it more real for me and I see myself as someone who can guide students on the invention process. I am not afraid of hard work and that is a main ingredient of an invention. I now feel I can better inspire, motivate, give feedback, and embrace failure
More confident	I feel that after seeing and hearing how many hours of planning and building these projects really helped me understand the pathway that provided a better understanding of what is involved in building a team
Much more confident	Participating in training sessions of EurekaFest gave me more confidence in leading my team in their invention project. The training sessions, allows me to see and weigh things whether my students could do the project or not and assessed the strength and weaknesses of my team in terms of manpower (skills and talent), resources (financial, equipment and other logistics) and time. Seeing my team's strength and weaknesses this early, allows me to make some adjustment, seek help and devise a way to improve my team. Having the chance to evaluate my team's capacity and find solution this early, gave me much more confidence in leading my team for their project
Much more confident	I have always felt I can do this, but it helps to talk to the InvenTeam educators about their triumphs and woes. Lets me know that I too can overcome obstacles and help the students do the same
Much more confident	I think networking with my peers within the context of the training was most helpful. I have some great strengths, but also some weaknesses and sharing those with my peers helped us learn from each other. Everyone at EurekaFest has the ability to lead a team and knowing I was among that group increased my confidence in my own abilities. I did learn a lot but there was also a great deal that I was already familiar with, so that also gave me confidence to believe that we can be successful

Source: Created by authors

In addition to the lecture by this distinguished professor, EARs had opportunities to participate in presentations by two other professors-inventors, including an author of a book on innovation, and attend talks by leaders of the Lemelson Foundation (a key supporter of IvE and sponsor for the EurekaFest). These presentations provided the EARs with opportunities to learn about the values, processes, practices and impacts of inventing and IvE. As the event map of the four days represented in Table 3 demonstrates, EARs participated in seminars focused on conceptualizing invention, engaging in the processes of invention, and idea generation as well as seminars and hands-on activities focused on team building. The LMIT IvE Officer and Expert Teachers led the seminars and modeled many of the activities the teachers could use with their own students.

Following lectures or seminars as venues for EARs' professional learning and networking, interactions with InvenTeam students and educators provided additional opportunities for gaining insights into invention processes and practices. Each day of EurekaFest included a programmed opportunity for EARs to interact with InvenTeam students and/or educators. On Day 2, EARs participated in InvenTeam presentations in which the high school teams presented their inventions. On Day 3, EARs attended the InvenTeams showcase where the teams' working prototypes were on display. The showcase event on Day 3 was the primary venue for EARs to engage with InvenTeam students and

their educators to learn about individual InvenTeam's processes, practices, impacts and to explore any questions EARs had. The showcase event involved all 15 InvenTeams from the prior year. Teams were situated in a large tent and an adjacent auditorium, and all team members were available to discuss their prototype and invention processes with anyone who approached their stand and engaged in a conversation. On Day 4, InvenTeam students participated in a Design Challenge and worked in new configurations across teams to construct a solution to a given problem. As students engaged in the design challenge, all educators, including EARs and InvenTeam teachers, had opportunities to talk with each other and the students about their journeys in invention

RQ2. How did the opportunities for learning about IvE impact educators' perspectives about their take-up of IvE with the students they serve?

After leaving EurekaFest, all 22 EARs who responded to the post-EurekaFest survey stated they felt much more confident (50%) or more confident (50%) about preparing the final InvenTeam application. In responding to the next survey question, "As a result of your participation in training sessions at EurekaFest, how confident do you feel in leading invention projects?" 55% of the respondents indicated they were "more confident" and 41% "much more confident" while one indicated "no change." The one teacher who marked "no change" on the survey explained, "I was already pretty confident that I will be able to act as a mentor and guide as this is my model for teaching anyway."

In Table 8, we offer five representative explanations the teachers provided for their increased confidence in facilitating IvE projects in their schools.

The first two explanations were offered by educators who indicated they were "more confident" to lead invention projects. The first teacher explained that "seeing that anyone can be an inventor" and understanding the process from the perspective of the InvenTeams made the InvenTeam possibility "more real" for her. The educator said she was not afraid of hard work and now was more confident in leading IvE projects through inspiring, motivating, embracing failure, and providing feedback for the students. The second "more confident" respondent echoed the "more real" idea of the first educator and explained that he was more confident because now he had a clearer vision of the invention pathway and work involved.

The three teachers who expressed they were "much more confident" to lead invention projects illuminated the impact of information offered during the EurekaFest and the programming for Excite Award Recipients. The first respondent wrote about the different elements of the program that helped her understand the processes and elements of an invention project and to identify her and her team's strengths and weaknesses. She commented on the importance of feedback provided and remarked that "Having the chance to evaluate my team's capacity and find solution this early, gave me much more confidence in leading my team for their project."

The second educator who marked "much more confident" emphasized the importance of talking with others and understanding "their triumphs and woes" as factors in increasing his confidence. He expressed that while he was confident he could lead invention projects before attending EurekaFest, the learning and conversations during the event boosted his confidence to lead invention even further. The importance of talking with others and networking was emphasized by the last participant whose comment we included in Table 8. She noted that becoming part of the IvE network was instrumental in her reflection about her own strengths and her ability to lead IvE projects.

Throughout EurekaFest, many educators expressed the importance of meeting like-minded people, connecting and understanding they could be leaders in IvE individually and collectively. EARs left EurekaFest with affirmations of their ways of working with students, of their knowledge and of their capacity to lead invention projects. Most commented that

they "learned a lot" and a few, in interviews and conversations, shared that participation at EurekaFest was "a life changing experience."

Conclusions

Participating in professional development opportunities for learning about invention and IvE processes and practices influenced educators' ways of thinking and increased their confidence in their own ability to facilitate students' learning through invention projects. The educators interacted with other IvE educators from across the nation, MIT professors, LMIT staff and other IvE leaders, and high school and college students who had invented novel solutions to real world problems. The ideas heard, shared and developed inspired and supported the educators and provided a foundation for their future work with students. The EAR professional development opportunity was a multifaceted introduction to the IvE ways of thinking, the language and practices educators could implement with their students, as well as the larger support network consisting of IvE leaders, teachers and students from around the nation. The repeated and iterative exposure to IvE ideas for teachers, like the early and repeated exposure to invention for students (Bell *et al.*, 2018), contributed to teachers' growth in awareness, confidence and capacity for engaging in transdisciplinary IvE efforts.

After the EurekaFest professional development opportunity, the EARs we studied in 2018 had opportunities to apply what they learned by working with their team of students to revise and resubmit the InvenTeam grant application to LMIT in September. Whether they applied or received the InvenTeam grant or not, all EARs, by virtue of their participation in the professional development had opportunities for obtaining the knowledge and skills needed to guide their students to find problems in their local communities and develop technological solutions that are new, novel, useful and unique (IvERC, 2019). Differences in how EARs took up IvE practices after participating in the professional development program (with or without an InvenTeam grant) is beyond the scope of this study and a topic for future research.

The educators attending EurekaFest as EARs had met the initial requirements for a grant to lead a year-long invention project, which was an indication the educators had already opened their minds to the possibility that their students could invent solutions to real world problems. The teachers' awareness of their students' capabilities aligns with a growing body of research in the field of IvE which demonstrates that everyone has the capacity to invent, and that early and repeated exposure enhances such possibilities, especially for diverse learners from marginalized and under-resourced communities (Couch *et al.*, 2018; Couch *et al.*, 2019; Saenz *et al.*, 2024). LMIT's continuing research, growing awareness of educators' openness to the take-up of IvE, conviction and research-based evidence that all students can learn to invent if opportunities for learning are afforded across time, along with developing understandings of how to help educators enter the emerging field, have led to substantial changes in LMIT's initiatives. LMIT's Partners in Invention Education (PiE) program, for example, now offers professional development and support to educators new to IvE across all grade levels (see https://lmit-pie.mit.edu). Professional development participation is available to educators at all grade levels as opposed to being limited to high school educators seeking an InvenTeam grant. Research, including the findings reported in this paper, has helped LMIT evolve its programming, grow the number of educators taking up IvE and reach diverse educators and students around the USA and internationally.

In submitting our work to the journal focused on *Quality Education for All*, we invite readers to reflect on the words and experiences of the people who participated in our study and to consider ways the accounts of other educators may influence their own perspectives on who can invent, how one learns to invent, and ways the open-ended, inquiry and project-based approach to learning known as IvE can enhance teaching and learning for all.

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Corresponding author
Audra Skukauskaite can be contacted at: audra@ucf.edu