JSO JOURNAL of STEM OUTREACH

Vol. 4, Issue 1, August 2021

Invention Education as a Context for Children's Identity Exploration

Joanna K. Garner[1], Erica Matheny[2], Alaina Rutledge[2], and Melissa Kuhn[1]

[1]Old Dominion University, Norfolk, VA and [2]National Inventors Hall of Fame, Alexandria, VA

Keywords: Invention education, identity, assessment, STEM outreach

Publication Date: August 11, 2021

DOI: https://doi.org/10.15695/jstem/v4i1.07

ABSTRACT: Generating solutions for society's complex problems will require the development of a diverse workforce that is committed to technological and social innovation. In the United States, this need is being addressed by the invention education movement, a goal of which is to promote the adoption of an inventive mindset among K-12 students through outreach and out-of-school time programming that promotes habitual problem finding, creative problem solving, collaboration, and persistence (Lemelson Foundation, 2020). In this study we examined a STEM-based invention education program, Camp Invention®, for its potential as a context for inventive mindset development. Our analysis of pre- and post-camp questionnaire responses from 108 upper elementary and middle school-aged children generated a measure of inventive mindset which was stable over time but largely independent of children's identification with three STEM subjects typically encountered in school. In alignment with prior studies examining features of educational contexts that support identity development (Kaplan et al., 2014), we found that children's most preferred activities supported perceived confidence, task novelty, and task utility, and least preferred activities received lower ratings on perceived autonomy and psychological safety. We consider theoretical and practical implications for the design and evaluation of STEM-based invention education programs.

INTRODUCTION

The complex problems our society faces will require technological and social innovation by individuals with diverse perspectives and experiences. Increasingly, the need for this capacity in the workforce has been identified by employers, who have highlighted the importance of invention and innovation skills such as problem finding, creative thinking, teamwork, and persistence. At the K-12 level, this need has also been recognized by a cross-sector movement known as *Invention Education*, through which various groups of educators, nonprofit and government agencies, and social science researchers strive to understand and support young people's curiosity and inventiveness, and explicitly teach the novel application of ideas, objects and tools that mimic the practices and habits of mind of accomplished inventors (Lemelson Foundation, 2019, 2020). A small number of research and evaluation studies have investigated the impacts of invention oriented after-school STEM programs and summer camps, and interactive museum exhibitions and outreach events that encourage tinkering and innovation (Falk and Meier, 2017; Smithsonian Institution Office of Policy and Analysis, 2010; Smith, 2016). Participation in such programs has been tied to increased interest towards careers in scientific and technological fields, and changes in self-efficacy surrounding the pursuit of inventive and creative activities (Couch et al., 2019; Falk and Meier, 2017; Lemelson Foundation, 2020).

However, the goal of creating a workforce and citizenry that purposefully seek innovation in their professional and personal lives will require a nuanced and deliberately inclusive approach. In parallel with the well-documented gender and racial gaps in science, technology, engineering and mathematics (STEM) achievement and career persistence, data suggest substantial disparity in the number of females and minorities participating in the invention, patenting, and commercialization sectors of the economy (Bell et al., 2018; Hosler, 2018). Furthermore, researchers have found that it is uncommon for young people to strongly identify as inventors, even if they have participated in invention-oriented programs or competitions (Couch et al. 2019). To increase and sustain a diverse pipeline of youth who are both interested in and capable of innovation, invention education must address the challenges of fostering invention skills and invention-minded ways of seeing the world, while understanding the particular individual and contextual barriers and facilitating factors to participation for historically underrepresented groups (e.g. Hughes et al., 2020; Roberts and Hughes, 2019). To accomplish this, researchers and practitioners must have access to high-quality tools for measuring students' perceptions of their own proclivities towards invention, and information that can guide the design and evaluation of invention education programs.

In this study, we gathered data from participants in Camp Invention®, a national K-6 non-profit summer enrichment program that incorporates STEM and invention concepts with 21st century, hands-on learning. The data were used to develop an inventive mindset self-report tool as well as practice-oriented insights into contextual features of the program that can support children's exploration of their inventive mindset. The measure was designed for completion by upper elementary and middle school students, and we examined its psychometric properties in relation to identification with the in-school STEM content areas with which participating children would arguably be most familiar—science, mathematics and technology. Our analytical approach was sympathetic to the prospect of finding gender-related similarities and differences in inventive mindset and perceptions of various invention education program features.

Invention Education and STEM. Invention education refers to a transdisciplinary range of pedagogical strategies and formats for improving the processes and skills associated with problem finding and problem solving that mirror those used by accomplished inventors (Lemelson Foundation, 2019, 2020). Historically, invention education has been intertwined with STEM education and outreach, since inventions and patents often emerge from one or more of its constituent fields, and STEM outreach programs and competitions are often used as a vehicle for promoting students' awareness of marketing and entrepreneurship (e.g. Lemelson-MIT Program, 2019; National Inventors Hall of Fame, 2019; Moore et al., 2019). Common formats for invention education include afterschool programs, summer camps, and outreach through nonprofit organizations and universities. Programs often emphasize problem-based learning, guided or independent inquiry, engineering design, and tinkering, making, and fabrication. The particular approach varies depending on the participants' age group or grade level and the goals of particular programs, but in all cases the participants are encouraged to find and develop solutions to meaningful problems using iterative and creative design processes. In some programs, children are also introduced to entrepreneurship and marketing (Hosler, 2018; Zhang et al., 2019). Regardless of the particular strategy used—regular attendance at a school makerspace, participation in a regional or national design competition, or STEM infused innovation and entrepreneurship programming in an after-school club—invention education strives to achieve a goal of raising awareness and interest in invention and innovation among young students, in order to prepare the next generation to confront complex problems and thrive in a fast-paced and rapidly changing world.

Broadening Participation in the Invention and Innovation Pipeline. One reason why access to invention education programming is important is the tremendous need to increase participation from historically underrepresented groups in the many economic sectors in which research, development, innovation, and commercialization activities occur (Cook, 2019). Multiple lines of inquiry have highlighted the lack of gender, race, and socioeconomic diversity among North American inventors and patent holders. In their influential paper, Bell and colleagues examined United States patent holders' demographic information over a twenty-year period and found Caucasian race, male gender and high socioeconomic status to be positively influential in determining whether or not youth were exposed to invention opportunities (Bell et al. 2018). Other researchers have noted that nearly all (90%) of the current and historic patent holders in the United States are white or Asian males (Lemelson Foundation, 2019; Sarada et al., 2017). Regardless of the precise connection between such statistics and the relative absence of females in STEM and innovation (Hosler, 2018), or the fact that children of parents who hold patents are much more likely to be exposed to inventive opportunities themselves (Link and Ruhm, 2013), it remains the case that gendered, socioeconomic, and intergenerational factors act to limit access to invention opportunities. This has led to calls for expanded invention education efforts through in-school and out-of-school time (OST) programs, library and museum networks, and computing and technology enhanced makerspaces.

Impacts of Invention Education. Compared to STEM education, research on invention education is in its infancy. To our knowledge, no large-scale studies have examined participants' long-term innovation-related pathways or accomplishments after participation in invention education. However, a small number of research and evaluation studies and an influential white paper published by the Lemelson Foundation (2019) describe how invention education can promote inventive skills and habits of mind—ways of seeing the world through the eyes of an inventor—in ways that are responsive to (and galvanize students' interests in) particular community or societal needs. Thus, one important contribution of the invention education movement may be increased student empowerment and self-identification with those who make, create and innovate for the purpose of overcoming authentic, shared problems. One study by Couch et al. (2019) suggests that such programs can impact students' innovation-related self-perceptions. Couch and colleagues examined several hundred survey responses and analyzed interviews from a purposeful sample of six participants to gain insights into the invention-related monikers that high school students ascribed to themselves after participating in a year-long, university-run invention education program. The survey data revealed that students tended to identify with multiple labels such as leader, engineer, innovator, creator, technologist, maker, entrepreneur, and inventor. The interviews revealed that the students had constructed nuanced definitions of each self-descriptor through social interactions in the program, at school, and at home. Couch et al. concluded that the program had promoted students' movement towards an *inventive identity,* to include the acquisition of particular self-definitions pertaining to invention related skills that developed through social interactions and contexts.

The impact of invention education experiences on younger students has also been explored through the evaluation of programs designed to increase students' self-efficacy for creativity and inventing. In a technical report evaluating children's experiences at Camp Invention®, Falk and Meier (2017) describe several factors associated with positive outcomes. Using a pretest/posttest design, the researchers found statistically significant changes in participants' self-reported creative and science-related self-efficacy towards future, similar activities. The study also revealed variation in the impact of the camp on the students and highlighted the role of familial support in participation in out-of-school time STEM experiences. However, because the study did not attend to gender differences in student outcomes, or students' appraisals of the value of particular camp experiences, the extent to which gender and camp activities might impact students' developing sense of self as inventor, maker, or innovator remains an open question.

Identity Development and Invention Education. The previously noted findings of the impact of invention education on self-perceptions and self-definitions in the domains of invention, innovation, and STEM drew our attention towards the literature on identity development. Identity components such as self-perceptions and self-definitions, goals, beliefs, and intentions for future action have been linked with motivation for and persistence in STEM related coursework (Carlone and Johnson, 2007; Garner and Kaplan, 2018; Kim et al., 2018). In the professional realm, researchers have pointed to the centrality of invention-oriented self-perceptions among self-described inventors and innovators (Amabile, 1988; Lemelson Foundation, 2019). Most germane to this context is that identity development research has also highlighted the relevance of reciprocal processes between the individual and the environment, suggesting that change might arise from the immersion of the individual in particular educational contexts (Couch et al., 2019; Garner and Kaplan, 2018; Kim and Sinatra, 2018). An identity development lens therefore raises the question of the degree to which invention education programs can act as a context in which participants can explore particular features of their inventive identity. In order to understand how this might happen, however, participants' perceptions of those contexts must also be examined, and relevant self-definitional facets of inventive identity should be explored. To guide our conceptualization, we draw from research that has framed educational contexts as environments in which identity exploration can take place, and research that has examined the self-definitional components of inventiveness.

Identity Exploration in Educational Contexts. Identity development is a lifelong process involving cycles of exploration punctuated by the development and revision of commitments to values, self-definitions, beliefs, and possibilities for action (Grotevant, 1987). Identity exploration involves "seeking and processing information in relation to the self" (Flum and Kaplan, 2006, p.100) and can involve consideration of self-definitions and self-descriptions, beliefs about how the world and our society function, motivational purposes and personal goals, and perceptions about what might be possible or not in terms of immediate or future action in a particular context (Kaplan and Garner, 2017). A proposed connection between learning and identity formation is not new (Lave, 1991), but it is only recently that researchers have examined the features of learning environments that promote identity exploration specifically (Kaplan et al., 2014; Kaplan et al., 2020). In seminal work in this area, Sinai and colleagues (2012) worked with educators to present literature content so that it fostered students' meaning-making in relation to their own lives and identities. Students engaged in exercises and guided discussions in which the topic area was used as a tool for reflection about students' own past, present and future selves. Other research has employed a similar approach in science education. In their intervention study in high school biology, Hartwell and Kaplan (2018) describe how students learned content through the articulation of personal connections to the subject matter. Hartwell and Kaplan used writing prompts to gain insight into the students' construction of personal relevance to the content area of biological evolution. A rubric used to score the students' responses revealed a range of personal connections and connections with past, present and future self. Notably, the researchers' analysis revealed that references to the self in students' reflections were associated with increased scores on a subsequent measure of biological reasoning.

Across studies, these findings have been synthesized into features of learning environments that tend to support identity exploration (Heffernan et al., 2017; Kaplan et al., 2014). Specifically, such environments (1) promote self-relevance through activities that pique students' interest and that are perceived by the students to be novel and useful; (2) trigger identity exploration in relation to current and future self by providing activities that encourage students to look at the world differently as well as reflect on their ability to act to understand or investigate that difference; (3) instill a sense of psychological and emotional safety by incorporating adaptive approaches to challenge and failure and creating a social context that is non-judgmental, and; (4) scaffold exploratory actions using meaningful prompts, tasks, and exercises. The guided and supported problem finding, creative problem solving, and failure resilience features of invention education programming seem well aligned with these principles (Castillo et al., 2020), but little is known about whether they appear this way to students.

Inventive Identity and Inventive Mindset. The study of what makes a person "inventive" has a long history (Shavinina and Seeratan, 2003), and in social and behavioral sciences has been taken up in diverse fields such as intelligence and creativity in children (e.g. Cattell and Gruen, 1955) and individual and organizational change (Amabile, 1988). Inventiveness has been associated with qualities of creativity, persistence, openness to novelty, tolerance for and a willingness to learn from failure, and collaboration skills (Amabile, 1988; Crismond and Adams, 2013; Estabrooks and Couch, 2018) as well as technical skills in particular domains such as design, science, etc. (Amabile, 1988) and, some would argue, an enduring motivation to purposefully search for solutions and improvements (Drucker, 1985). Rather than measuring behaviors and inferring the presence of these qualities, in this study our goal was to measure elementary and middle school-aged children's perceptions of the degree to which they possess these qualities, in part because self-perceptions are related to self-efficacy for particular tasks such as inventing, and in part because no such measure has yet been developed.

A person's inventive identity connects with, but also draws beyond, specific contexts, domains, and experiences, and includes multiple psychological components (Kaplan and Garner, 2017). An inventive identity might encompass self-definitions and self-perceptions about qualities that pertain to invention, but in order to form an inventive identity such self-perceptions must become intertwined with beliefs about what invention is and how inventions become adopted or developed, general and specific purposes and goals for engaging in invention and its subtasks (e.g. creating, designing, problem finding, problem solving, prototyping, etc.), specific possibilities for action in a given context, and an awareness of social and cultural expectations about what others might consider to be inventive. This study focuses on inventive mindset, or the constituent self-definitions and self-perceptions that pertain to the tasks of inventing and contribute to the development of an inventive identity. That is to say, we did not seek to measure children's beliefs about invention in general, or their own specific motivations for invention, or their plans for invention after the camp was over. To capture children's inventive mindset, we sought the degree to which they thought of themselves as possessing the qualities listed above such as creativity, persistence, openness to ideas, and a willingness to share ideas and collaborate with others. We expected that an inventive mindset might reflect processes of invention such as problem finding, problem solving, and design. Finally, we expected that inventive mindset might correlate with children's self-perceptions in affiliated technical domains such as science, mathematics, and technology.

The Present Study. In this study we examined a virtual summer camp setting in which children experienced facilitated engagement in the core practices of invention within a supportive social environment. We used the principles of identity exploration in learning environments proposed by Kaplan et al. (2014) to guide a proof-of-concept appraisal of children's perceptions of the five-day program: since conditions for identity exploration should include the perception of novelty, utility, and a supportive social context that promotes confidence and happiness over anxiety, we anticipated that a successful invention education camp would promote a sense of emotional safety and an absence of fear of rejection, and would include opportunities to experience scaffolded interactions in the role of inventor. We expected children to rate their most preferred activities as involving tasks supportive of motivation and identity exploration such as problem solving, designing something new, and finding out something not previously known. In contrast, we anticipated that least preferred activities might be described as lacking in self-relevance, or lacking emotional or psychological safety.

More broadly, the present study addresses a gap in the invention education research literature concerning a measure that could contribute to research on inventive identity in school aged children. A related objective was to investigate the degree of overlap and separation between these self-perceptions and children's identification with STEM subject areas, as refining our ability to measure invention mindset and its relation to STEM identity will serve future design and evaluation efforts. These objectives are captured in the first research question: **What are the invention related self-perceptions of upper elementary and middle school aged children participating in an OST invention education program, and to what degree do these overlap with their identification with STEM subjects?**

Our second goal was to investigate the degree to which the invention education environment possessed potential as a context for identity exploration. We collected ratings of tasks commensurate with identity exploration such as perceived relevance, perceived novelty, and perceived opportunity to enact important invention skills. We did not assume that the environment would instigate changes in children's inventive identities, but we were curious to assess children's overall perceptions of the learning environment including the reasons why they liked or disliked particular activities. In this way, we hoped to reveal a new appreciation for children's perceptions of camp features that could serve as barriers or facilitating factors for identity exploration. These objectives are included in the second research question: **What features of an invention camp experience contribute to a context that is conducive for inventive identity exploration?**

Finally, since previous research points to gender-related differences in children's motivation and self-perceptions surrounding STEM and invention, we were interested in examining the responses to the first and second research questions with regard to gender. Potentially, this would allow invention education program designers to learn more about how to design effective activities and contexts for female and male participants. Our third research question was: **To what extent is gender associated with children's responses to an invention mindset questionnaire, their identification with STEM subjects, and in their perceptions of the invention camp experience?**

METHODS

Participants. The participants included upper elementary and middle school-aged children who were enrolled in a week-long invention education camp program offered throughout the summer of 2020 within the United States. Parents and guardians who had enrolled their children were sent an email containing information about the research study and a link to complete an informed consent form. In all, 390 children participated in the pre-camp data collection. This group was 57% male (n = 222), 43% female (n = 167), and <1% was neither male or female (n = 1). It was majority white (n = 267; 68.5%), and 10.5% two or more races (n = 41), 7.2% Hispanic or Latino/a (n = 28), 7.0% Asian (n = 27), 6.7% Black or African American (n = 26), and 0.3% Pacific Islander (n = 1). The demographic characteristics were similar to the entire enrollment of the camps, which was 58% male and 42% female, and 80% white, 5% Hispanic or Latino/a, 6% Asian, 4% Black or African American, and 0.2% Pacific Islander. The ages of the children who completed the surveys also varied; 30.5% were 8 years old (n = 118), 29.5% were 9 years old (n = 114), 28.7% were 10 years old (n = 111), 10.6% were 11 years old (n = 41), and 0.8% were 12 years old (n = 3), with an additional .8% (n = 3) not disclosing an age. Data from the pre-camp group was used to conduct the inventive mindset scale development analyses including the exploratory factor analysis.

The post-camp survey was completed by a subset of the larger group of individuals, and this resulted in a smaller matched sample (n = 108) that was representative of the larger group as it included 48 females and 60 males. The gender ratio for the matched pre- and post-camp sample was 55.6% male (n = 60) and 44.4% female (n = 48). The group was 64% white (n = 69), 15.7% two or more races (n = 17), 9.3% Black or African American (n = 10), 7.4% Hispanic or Latino/a (n = 8), and 3.7% Asian (n = 4). Age distribution in the pre- to post-camp data set was 38.9% 10 years old (n = 42), 27.8% 8 years old (n = 30), 25% 9 years old (n = 27), 6.5% 11 years old (n = 7) and 0.9% 12 years old (n = 1) with one child (0.9%) not disclosing their age. Data from the matched cases data set was used in the analyses that served the second and third research questions.

Measures. This study deployed a pre- and post-camp survey, a collaboratively developed scale designed to assess children's self-reported qualities associated with an invention mindset, and questions designed to reveal children's identification with particular STEM subjects. Basic demographic information was also collected from participants including age, gender, race/ethnicity, and most recently completed grade level.

Pre- and Post-camp Survey. Pre- and post-camp questionnaires were developed collaboratively by the authors. The pre-camp questionnaire asked children about their age, grade level, gender, career aspirations, and aspiration-related role models. It also included an inventive mindset scale (see below) and a brief, three item assessment of identification with particular STEM subject areas with which children would be familiar: "I am a math person," "I am a science person," and "I am a technology person." The post-camp questionnaire presented the inventive mindset scale once again, but also asked children to select choices for their most and least preferred camp activities and use a four-point Likert scale for each of these choices in order to provide their perceptions of the activities and reasons for their preferences. Children also used a four-point Likert scale to rate the activities according to whether they designed something new, solved a problem, and discovered something previously unknown to them. These items were designed to assess the degree to which the activities possessed features known to promote or inhibit identity exploration.

Inventive Mindset Scale. The invention mindset scale was developed using a multi-step inductive process (Boateng et al., 2018) involving collaboration among researchers, inventors, and invention education practitioners. Researchers at the organization that created and implemented the camp interviewed several hundred prolific inventors and used an analytical tool to find commonalities and themes in the interview transcripts. A small discussion group of 12 inventors was then convened. Themes were shared and revised before being shared with a group of public school administrators who provided feedback about themes' relation to K-12 education. Item writing efforts were guided by the following themes: design thinking to support problem identification and problem solving; self-confidence surrounding the translation of ideas into reality; creative problem solving for simple and complex problems; interest in STEM; persistence; the desire to innovate and improve; an appreciation for intellectual value in ideas; entrepreneurship and creative risk taking; and collaboration as a force for producing creative solutions.

During the item finalization process, the qualities of inventors that had been revealed by previous literature were considered in relation to the emergent themes and the resulting items by way of consensus-oriented discussions among the research team. The final scale included nine items assessed using a four point, Likert-type scale. Response options included strongly disagree, disagree, agree, and strongly agree. One of the nine items, "I give up easily," was designed to measure persistence and was reverse-coded at analysis. The scale registered as a 2.6 grade level equivalent on the Flesch-Kincaid readability measure (Ford et al., 2007), which was suitable for the participants who had completed grade 3 or above.

Procedure. Following IRB approval and parent/guardian and child consent, children completed the pre-camp questionnaire through an online survey platform. Children then participated in a five-day sequence of synchronous and asynchronous sessions led by a trained facilitator. Sessions focused on activities and challenges around the themes of flight, design thinking, real-world environmental challenges, and innovation in sports and sports equipment. Each session included coaching and facilitation from a licensed educator. Children were presented with real-world, open-ended challenges and given the opportunity to creative problem solve, collaborate, and brainstorm solutions. Further exploration included development and building of prototypes to represent their innovations. The program built in opportunities for children to share their ideas and progress with the group during their development process, and in final inventor showcase-style settings. At the conclusion of the camp, parents/guardians were sent a second email containing the link to the post-camp questionnaire. Data were collected in waves corresponding to the three camp sessions. During the first wave, n = 611 pre-camp and n = 255 post-camp responses were gathered. The second wave included n = 507 pre-camp and n = 321 post-camp responses. The final wave included n = 252 pre-camp and n = 173 post-camp responses. Parent/guardian consent and child responses were matched prior to anonymization of the entire data set.

Data Analysis. To address the first research question in which we sought to establish a coherent picture of invention-related self-perceptions and their relation to identification with STEM subjects, we conducted an exploratory factor analysis (EFA) using SPSS 26.0 on n = 390 pre-camp questionnaire responses, which provided a sufficient participant-to-item ratio (Nunnally, 1967). The EFA used principal axis factoring and direct oblimin rotation (Costello and Osborne, 2005) as the inventive mindset items and subsequent factors were expected to correlate (Amabile, 1998; Silvia et al., 2009; Tan et al., 2016). The delta for the direct oblimin procedure was left at zero and the number of factors were not forced for the first round of analysis. A factor correlation of .514 after the extraction and rotation reinforced the choice of oblique rotation as being appropriate. The Kaiser-Meier-Olkin (KMO) measures of sampling adequacy were all within acceptable ranges of .70 or greater (Field, 2009): the overall value was .78 and no individual item value was below .70. The final configuration of factors reflected two delineated subscales as well as the separation of both subscales from the three items measuring identification with STEM subjects.

For the second research question, we sought to identify the features of the camp experience that were potentially conducive or inhibitive of identity exploration. The matched pre- and post-camp subset (n =108) was used to reveal the most and least liked activities among options of making/creating/building, coaching, thinking up ideas, and sharing ideas. These were cross-tabulated according to ratings for each identity exploration dimension: from unsure to confident, anxious to happy, not useful to useful, and familiar to novel. We ran Chi-square analyses to examine the distribution of the four activity options across the most- and least-liked activities. The most and least liked activities were then examined with regard to the percentage of the participants who perceived that they were engaged in invention related activities of solving a problem, designing something new, and finding out something they did not already know.

To gain additional insight into the reasons why children liked or did not like particular activities, we conducted an inductive analysis of children's open-ended responses for their most and least liked activities, and a theory guided analysis of their responses to the question of whether they felt that they had learned anything about themselves during the camp experience. For the latter group of statements, responses were coded using the Dynamic Systems Model of Role Identity (Kaplan and Garner, 2017), which conceptualizes identity as including the dynamic and reciprocal components of self-perceptions and self-definitions, ontological and epistemological beliefs about how the world works and how knowledge is created and changed, purposes and goals, and possibilities for action. The resulting codes were tabulated to provide an overall picture of the identity component(s) that were most salient in children's descriptions of their self-learning.

To address the third research question, which focused on the degree to which gender played a role in children's perceptions and responses, we first examined the pre-camp responses from the matched cases dataset for evidence of gender effects on the inventive mindset scale, the three STEM identification items, and the correlations between these when aggregated as subscales. Finally, we looked at gender effects in children's ratings of the camp activities. These analyses were carried out using independent samples *t*-tests to uncover any gender differences and Pearson correlations to examine the relations between the scales for boys and girls.

RESULTS

An initial round of data analysis revealed that participant race-ethnicity and age did not play a statistically significant role in the results. We therefore present findings according to each research question using analyses in which data are collapsed across participant race-ethnicity and age.

Research Question 1. What are the Invention Related Self-perceptions of Upper Elementary and Middle School Aged Children Participating in an OST Invention Education Program, and to What Degree Do These Overlap with Their Identification with STEM Subjects? All items in the inventive mindset questionnaire loaded onto one of two factors in the pattern matrix at the recommended minimum factor loading of .32 (Costello and Osborne, 2005), with no cross-loading above .30. These two factors explained 47.4% of the cumulative variance and indicated the presence of two genuine constructs (Furr and Bacharach, 2014). We labeled the factors *Ingenuity* and *Solution-seeking*: the Ingenuity factor included five items reflecting creative thinking, imagination, and idea generation; the Solution-seeking factor consisted of four items corresponding to problem-solving, openness to novelty, and persistence. Factor loadings for each item are shown in Table 1. The inventive mindset measure demonstrated adequate internal consistency reliability. The Cronbach's alpha for the entire scale was $\alpha = .73$, and the Ingenuity and Solution-seeking factor subscales had slightly lower coefficients of $\alpha = .61$ and .69 respectively. This is likely due to the small number of items in each scale (Field, 2009).

Table 1. *Items and factor loadings in the inventive mindset measure.*

Item	Factor: Ingenuity	Factor: Solution Seeking
I am creative.	.76	
I am imaginative.	.67	
I have lots of good ideas.	.57	
I like to design things.	.47	
I like to share my ideas.	.32	
I am a problem solver.		.65
I like to make things better.		.53
I give up easily (reverse-coded).		.47
I am open to new ideas.		.41

The three items soliciting identification with science, technology, and mathematics demonstrated independence from the other inventive mindset items. The relations among these three items were also low, as revealed by the Cronbach's alpha when these three items were combined as a scale (see Table 2). The findings suggest that the STEM identification items should be considered separately from the inventive mindset measure. Notably, children did not necessarily respond in a consistent way to each of the STEM identification items.

Research Question 2. What Features of an Invention Camp Experience Contribute to a Context that is Conducive for Inventive Identity Exploration? This research question was addressed using the matched cases data set ($n = 108$). We examined children's responses to questions about their most and least liked activities and their descriptions of these activities according to four semantic differential scales derived from affective dimensions present in research literature on identity exploration in educational contexts. We anticipated that most liked activities would be rated more favorably along the four identity exploration dimensions than least liked activities, and that children would be more likely to agree with statements about these activities featuring invention-related tasks such as problem solving, creating things, and finding out something new. The quantitative analysis was supplemented by thematic coding of children's open-ended responses about why they liked or did not like particular activities, and their responses to a question about whether they learned anything about themselves during the camp experience.

Most and Least Liked Invention Activities. Statistically significant differences in activity preferences were revealed by

Table 2. *Internal consistency reliability for Inventive Mindset scales and subscales.*

Scale/Subscale	Cronbach's Alpha
Inventive mindset scale	.73
Ingenuity subscale	.69
Solution seeking subscale	.61
Identification with STEM subjects scale	.46

Table 3. *Ratings of most and least liked invention activities.*

Perception of task	Most liked activity		Least liked activity	
	Mean	SD	Mean	SD
Unsure-confident	2.61*	0.60	1.47	0.91
Anxious-happy	2.76*	0.52	1.70	0.88
Not useful-useful	2.62*	0.51	2.00	0.82
Familiar-novel	1.82*†	0.98	1.52	0.94

**p<0.05. †This difference was not statistically significant for girls.*

chi-square analyses for most liked activities, $X^2_{(2)} = 25.32$, p<0.000 and least liked activities, $X^2_{(3)} = 218.79$, p<0.000. The most frequently liked activity was making/creating/building, which was rated as the most liked activity by 85% of the children. While engaging in their most liked activity, nearly all (85%) of the respondents indicated that they were engaged in problem solving, 99% agreed that their most liked activity involved designing something new, and 82% agreed that it involved finding out something that was previously unknown. We interpret these findings as revealing a strong preference for hands-on activities, and corroboration that children found the activities to be engaging in several ways.

Two of the camp components (coaching and sharing ideas) were equally likely to be rated as the least liked activity. Nearly half of the children (44%) rated coaching as their least liked activity, and 46% rated sharing ideas as the least liked activity. A small percentage of children (10%) indicated that thinking up ideas was their least favorite activity. None of the participants indicated that making/creating/building was their least favorite activity. Regardless of the specific activity, however, 54% of children reported that it involved problem solving, 44% reported that it involved designing something new, 60% reported working on designing something new, and 73% reported finding out something previously unknown. These findings illustrate that even when reflecting on their least liked activity, many of the children reported being engaged in behaviors that fostered inventive and innovative skills and habits of mind.

Affective Dimensions of Invention Activities. Children rated their feelings during their most and least liked activities along dimensions known to affect motivation for identity exploration. Ratings varied depending on whether children were rating their most or least liked activity (Table 5). Children were more likely to rate feeling closer to confident than unsure, *paired* $t_{(97)} = 12.3$, $p<0.001$, and closer to happy than anxious, *paired* $t_{(97)} = 12.11$, $p<0.001$, for their most liked activities compared to their least liked activities. Similarly, they were more likely to rate most liked activities as useful than not useful, *paired* $t_{(93)} = 7.44$, p<0.001, and to a lesser extent, novel than familiar, *paired* $t_{(91)} = 2.42$, p<0.05.

Self-knowledge Associated with Invention Education Activities. Within the matched sample, forty-seven children (44%) chose to provide a response to the prompt about what they had learned about themselves and 34 (72%) responded yes, or yes with an elaboration. Of the affirmative responses, most statements ($n = 31$; 91%) referred to self-perceptions and self-definitions. The responses of thirteen of these children referred to creativity. One stated, "I learned that I like creating things very much" while others linked this with invention, saying "That I like to invent stuff and create stuff," "I LOVE inventing things!!" and "I learned that I like to invent my ideas for solving problems." Another common theme within self-perceptions was children's self-reported capacity or capability. Six children wrote about this, including one who stated "I learned that I could do more than I thought I could," and another who wrote "I learned that if I put my mind to it I can come up with something great." A small number of responses included self-perceptions of being perseverant ("I learned that I can persevere through challenges") and in possession of good ideas ("I learned that I have a lot of good ideas and that I can make the world a better place"). Three children wrote about having learned that they liked particular content knowledge such as aerodynamics or robotics. Only one child referenced their ontological (worldview) beliefs when writing about their self-learning, saying "That it is okay to try multiple ideas until you find the best one that works."

Research Question 3. To What Extent is Gender Associated with Children's Responses to an Invention Mindset Questionnaire, Their Identification with STEM Subjects, and in Their Perceptions of the Invention Camp Experience?

Gender and Inventive Mindset. We did not find gender differences in inventive mindset scores as measured ahead of camp participation; the pre-camp mean score was 29.57 (SD = 4.54) for boys and 30.58 (SD = 2.83) for girls. Inventive mindset scores were also stable over time for boys ($t_{(59)} = -1.27$, p>0.05) and girls ($t_{(47)} = -0.57$, p>0.05); the post-camp mean score was 30.38 (SD = 3.15) for boys and 30.81 (SD = 3.08) for girls.

The pre-camp data subset did reveal that gender was associated with the strength of the relationship between inventive mindset and STEM identity for both the overall scores and the subscale scores. For boys only, scores on the Solution-seeking factor were correlated with identification with science ($r = .29$, p<0.05) and technology ($r = .35$, p<0.01). For girls, scores on the Ingenuity factor were correlated with math ($r = .39$, p<0.01) and technology identity ($r = .33$, p<0.05). Girls' identification with STEM subjects was uncorrelated with scores on the solution-seeking factor. Total inventive mindset scores were positively correlated with girls' identification with math only ($r = .29$, p<0.05). This

Table 4. *Correlations among inventive mindset and identification with STEM subjects*.

	Ingenuity subscale		Solution seeking subscale		Inventive mindset total score	
	Girls	Boys	Girls	Boys	Girls	Boys
I am a math person	.39**	-.03	.10	-.16	.28*	-.88
I am a science person	.03	.05	-.01	.29*	.01	.28*
I am a technology person	.33*	.14	.12	.35**	.25	.29*

*p<0.05, **p<0.01

pattern was reversed for boys, with boys' total inventive mindset score being positively correlated with identification in science (r = .28, p<0.05) and technology (r = .29, p<0.05), but not math.

We also did not find pre- or post-camp gender differences in identification with STEM subjects. At the initial administration, girls' scores at pre and post camp respectively included means of 3.27 (SD = 0.86) and 3.35 (SD = 0.60) for science, means of 2.94 (SD = 0.81) and 2.91 (SD = 0.83) for math, and means of 3.29 (SD = 0.62) and 3.44 (SD = 0.50) for technology. For boys, scores at pre and post camp respectively included means of 3.27 (SD = 0.76) and 3.37 (SD = 0.69) for science, means of 2.97 (SD = 0.98) and 3.08 (SD = 0.85) for math, and means of 3.43 (SD = 0.7) and 3.48 (SD = 0.62) for technology.

Gender and Invention Activity Preferences. For the most part, gender did not influence whether particular activities were rated as most or least liked. Among the 88 responses from 45 boys and 43 girls on the topic of why making and building were their most favorite activities, just under half (41%) wrote that they "like" or "love" making, building, and creating, or that such activities were fun. Other themes that were apparent across genders included realizing ideas, working autonomously, and being creative. Responses of two girls and six boys were coded as realizing ideas, including one girl who wrote "Because it allows me to put my ideas into life somewhere" and a boy who wrote "Because you could make whatever you could think of." Two girls and three boys wrote about their appreciation for independent work and exploration. One girl wrote "I could do it by myself with no annoying people or someone telling me how" and a boy wrote "I could do what I wanted to with the things they gave me to work with." Six girls and eight boys included that they liked "building," and five girls and seven boys included that they liked "creating" or using their "creativity." Notably, only one participant included the word "inventing" to describe their making/creating/building activities; a boy wrote "I got to invent lots of cool things." Two girls and five boys made specific reference to a particular activity, such as working with a robot or clay.

Children's open-ended responses about their least favorite activities were also coded thematically. To a large extent, the reasons children gave for their least preferred activities of coaching and sharing ideas mapped onto the negative ends of the provided affective dimensions, and onto factors that inhibit identity exploration. For example, half of the 38 responses about not wanting to share ideas were coded as social anxiety. Of the fifteen girls who answered this open-ended question, eight wrote about disliking the sharing process because of feeling "nervous talking to new people" or feeling "shy with [the] virtual setup." Similarly, boys were also forthcoming with social anxiety as a reason for disliking sharing. One boy who wrote of his "fear of having to talk to a group" and another wrote "because sharing made me so anxious and I wanted to get off [the Zoom call]." Several children also wrote about having difficulty expressing or explaining their ideas without linking this difficulty to the social or virtual setting.

Response rates for why the coaching activity was least preferred were evenly distributed between twenty boys and twenty girls. Seven of the girls reported that the coaching sessions were too structured or that they preferred to work independently, reporting that "They told us what to do and I just want to do my own thing," "it took too long and I could just read the instructions by myself," or "I don't like being coached." Boys were more likely than girls to use the word "boring," and five boys reported that they "already knew" the material or that "I could have read the instructions. There was nothing extra."

DISCUSSION

Over the past decade, the United States has seen growth in the number of invention education programs aiming to inspire and prepare the next generation of innovators. The focus of this emerging field is on fostering motivation towards invention skills and habits of mind including problem finding, perseverance, creative risk-taking, and an interest in developing novel solutions. Invention education strategies are closely aligned with those found in other forms of STEM outreach, and include the use of design cycles, making and tinkering, open-ended exploration, and positive social support (Castillo et al., 2020). To date, although some scholars have linked invention education with students' self-efficacy and interest in pursuing innovation, particularly in STEM fields, little research has been conducted on how invention education experiences might serve as contexts for identity exploration. However, previous literature in education and psychology suggests that over time, within the context of a supportive community (Lave, 1991), and under particular conditions (Heffernan et al., 2018) such experiences may shape the way that children perceive themselves. This means that invention education might function as a platform for engaging students as they explore their current and future selves in the realms of invention, innovation, and commercialization (Lemelson Foundation, 2019). In this study, we sought to develop a measure of inventive mindset—the self-definitional component of inventive identity—for use in invention education contexts that serve upper elementary and middle school aged children, and we also sought to examine the relation between inventive mindset and self-identification with STEM subjects commonly encountered in school settings. We studied one invention education program in particular to assess the degree to which its contextual features aligned with those known to support (or inhibit) identity exploration and drew from literature on gender differences in STEM and innovation as a rationale for examining whether effective contextual features would differ for boys and girls (Hughes et al., 2020; Roberts and Hughes, 2019). In the following discussion we summarize our findings and consider the broader implications of framing invention education (with or without STEM) as a context for children's identity exploration, before presenting some limitations and opportunities for future research in this area.

Through this study we gained a more nuanced understanding of children's self-perceptions regarding their identification with STEM subject areas and characteristics often associated with success in STEM, invention, and innovation careers. Specifically, we learned that although children may perceive themselves as being creative, open to considering and sharing new ideas, imaginative, and capable of problem solving, these qualities were psychometrically (and, we suspect, phenomenologically) distinct from self-perceptions of being "a math person" or "a science person" or "a technology person." A second insight gained through the pre- and post-camp administration of the measure was that children's responses seemed relatively stable over time, or at least not sensitive to a one-week virtual and hands-on experience. The findings are worthy of replication and investigation in future research activities, as they suggest that whereas adults may tie these invention characteristics to STEM subject areas, children may not. This also points to the need for further research that explores invention education as an intervention that may be able to shift children's self-perceptions about both invention and STEM.

Although the enrichment program was not deliberately designed using principles of identity exploration, children's responses indicated that its activities elicited emotions and perceptions commensurate with conditions for learning about the self. This finding lends further support to the idea that invention education experiences might be appropriate contexts for children to not only learn about inventing, using tools, and gaining skills, but also for activities to be leveraged as possibilities for them to envision themselves in future roles and contexts. The two sources of data that point most directly to this include children's ratings of most liked activities as being associated with psychological safety (feeling happy and confident over anxious and unsure), and children's written reflections in which new understandings about qualities were shared, with most of the affirmative responses relaying information about invention related characteristics or adaptive beliefs. These insights could be used as a point from which interventions could be designed, such that children deliberately explore their beliefs about invention in relation to themselves and their social and lived experiences, purposes and goals for participating in making, inventing and commercializing their innovations, and possibilities for action in their current and future lives. In addition, incorporating identity-focused constructs in evaluations of STEM oriented invention programs would provide further insights for researchers and evaluators, who often examine related variables such as attitudes and interests (Cappelli et al., 2019).

Of equal interest was the idea that particular features of the invention education experience may act as a barrier for some children, and that existing factors might also provide some children with an advantage in terms of their preferences or readiness to engage with the camp content. Broadly, we found this not to be the case: gender, race-ethnicity and age were not influential factors in children's inventive mindset scores, identification with STEM subjects, or their ratings of most and least liked activities. Therefore, we conclude from the data that the camp context itself did not seem to appeal to, or cater to, one group of children over another. However, we did note gender differences in the relations between inventive mindset and STEM identification, with boys' scores more strongly correlated than girls' scores. This calls into question the relations between STEM and invention mindset as it is perceived by children, particularly for girls. Future research is needed to determine the robustness and generalizability of this finding to other samples, age groups, and contexts.

Implications for Theory. There has been a recent increase in researchers working together with industry leaders and educators to consider the mindsets needed to become an inventor and innovator. These include creativity, persistence, adaptability, initiative, ideation, tolerance for risk, and practical fluency in STEM and related fields (Lemelson Foundation, 2019). An inventive mindset—habitually seeing the world through lenses that purposefully apply the above qualities—is one component of an inventive identity. While it is difficult to measure an individual's mindset, and it will likely be manifest to a greater or lesser degree in different contexts, we propose that it is a valuable endeavor to use reliable and valid self-report measures to gain insight into individuals' inventive self-definitions and self-perceptions. The tools developed in this study originated in themes that emerged in interviews with inventors and syntheses of invention education programs (Lemelson Foundation, 2019; National Inventors Hall of Fame, 2019), but we gained a new understanding of the interrelations among the different self-definitions in young children from the use of an exploratory factor analysis. Our list of inventive mindset self-definitions fell into two groups that represent different facets of an inventive mindset: one reflected creativity, imagination, idea generation, idea sharing, and design; the second reflected problem seeking, problem solving, persistence, and openness to new ideas. Both of these were related to but also distinct from children's identification with the technical skills that have been identified by studies of inventors—specifically the science, mathematics and technology components of STEM, for which stronger correlations were found for boys compared to girls.

One interpretation of this finding is that children who identify with these subject areas may not necessarily perceive themselves to possess inventive mindset characteristics, and vice versa. Another conclusion is that girls' interpretations of the technical skills associated with invention are less connected to invention related self-definitions. Regardless, further research is needed to investigate the degree of separation and overlap between STEM identification and inventive identity in boys and girls, and we note that the addition of a question about identification with engineering may also provide meaningful gender-based insights. Intervention studies could examine the relative malleability or stability of ingenuity, solution seeking, and STEM identification scores that occur as a result of participating in particular types of invention education experiences including those that do not require technical knowledge in STEM.

In the present study we asked children about their persistence by asking if they perceived that they gave up easily. It is appropriate that this item loaded on the solution seeking factor, since prior literature has highlighted the importance of adaptive framing and interpretation of failure experiences in shaping high school students' persistence in invention activities (Estabrooks and Couch, 2018). It would be worthy to examine the relations between inventive mindset and attitudes towards failure in younger children and those who have little prior experience with making and inventing, to triangulate children's self-perceptions with observations of how these qualities are supported or inhibited in particular making and inventing contexts, and to study the role that children's ingenuity characteristics might play in moderating persistent solution seeking in these contexts. Finally, research on older children's self-definitions as an inventor has called attention to the role of being recognized by others as being inventive (Couch et al., 2019). Little is known about the development of the self-definitions included in the measure on inventive mindset in relation to children's perceptions of how others view them, and how invention education contexts might promote one, or both. If administered in its current and modified form, the tool developed in the present study could allow researchers to investigate the relations between individually constructed and socially derived aspects of inventive identity in diverse groups of children.

Implications for Practice. Children responded in definitive ways to specific invention related activities. The most liked activities of making and creating were consistently rated as being accompanied by positive emotions of happiness, confidence, utility, and novelty, and open-ended responses revealed preferences for autonomy, exploration, and high interest. Each of these descriptors aligns with known contextual features of educational environments that support identity exploration, such as supporting autonomy, providing some but not too much guidance, and striving to create personal meaning (Kaplan et al., 2014). Children's dislike of particular activities such as sharing ideas and being coached can also be interpreted using an identity exploration lens. One of the most common reasons why the recurring activity of sharing ideas was less liked is that children reported experiencing social anxiety in some form such as shyness or reluctance to speak in front of individuals they did not know well. Several children also voiced concerns about having their ideas stolen from them. These themes underscore the importance of children's sense of emotional safety and how a lack of perceived safety can influence the favorability of a particular activity. Children who did not enjoy the coaching sessions as much as other activities conveyed reasons of either boredom or low utility. This is also congruent with principles of designing for identity exploration, as previous research has linked the creation of personal meaning with activities that are considered to be useful, relatively novel, and of a moderate degree of challenge (Sinai et al., 2014).

Despite not being deliberately designed for identity exploration, our findings suggest that the enrichment program content and its delivery demonstrated the potential for this to happen. At the very least, students participated in some of the foundational skills of creating and making that may lead to an interest in innovation and entrepreneurship (Small, 2014). However, what we did not find in children's responses suggests that practitioners should make explicit connections between inventive activities and children's own sense of self as an inventor. Of the nearly one hundred responses to the open-ended questions about why children liked or did not like particular activities, only one child made a reference to their activities as inventing. Instead, most responses referred to subcomponents of inventing such as making and creating, rather than inventing itself. This finding echoes other research where invention education programs have been studied for their potential to shift participants' self-descriptions about inventiveness. In their study of high school students participating in an invention competition, Couch et al. (2019) found that although many saw themselves as leaders, creators, and engineers, very few labeled themselves as inventors. The qualitative portion of the study revealed that students held a particularly high bar for this descriptor and thought of it as describing someone who had invented a new solution or technology that others had found to be useful. Incorporating and evaluating an "authentic use" feature into invention education programs might increase identification as an inventor and increasing students' recognition that they are inventing as well as making, creating, and building. However, our data also suggest that this should be done with careful attention to participants' perceptions of psychological safety, because several children in our study alluded to social anxiety as a reason for their reluctance to share their ideas.

Finally, when asked to describe any learning that had taken place about themselves, most of the children responded by referring to the identity component of a self-perception or self-definition (e.g. I am creative; I am interested in making things). Only one of the children responded that they had learned in relation to their beliefs about the world (e.g. it is okay to try multiple ways to solve a problem). Because beliefs are known to influence motivation and persistence in many areas including STEM (Simpkins et al., 2006; Small, 2014), it may be beneficial for programs to include explicit references to principles associated with persistence in invention and innovation such as tolerance for risk and failure, and to build in opportunities for children to reflect on this in relation to their current and future selves in the STEM and invention domains but also other areas of their lives.

Limitations. A primary limitation of this study is the self-selected sample of respondents. The children who participated may not be representative of the broader population, as they had voluntarily enrolled in the invention education summer camp. In addition, due to the smaller number of matched pre- to post-camp responses, our in-depth analysis was conducted on a subset of responses. It is important that further research be conducted using a broader and more representative sample including children from more diverse ethnic and socioeconomic backgrounds, non-native English speakers, and those with disabilities, as well as children with varying amounts of prior exposure to STEM, making and tinkering, and invention education.

A second limitation is that due to the virtual nature of the camp setting it was not possible for the researchers to observe or participate in all sessions. Children's participation and responses therefore could not be verified or triangulated using observational data. Finally, a third limitation was the decision to limit our treatment of STEM disciplines on the pre- and post-camp questionnaire to science, technology, and mathematics and omit a question about identification with engineering. These were thought to represent in-school subject matter experiences that all participants would have been exposed to and would have an accurate understanding of the terms, but it should be noted that this does not mean that we consider engineering to be unimportant to the development of a STEM identity or unrelated to an inventive mindset. We hope that future research will reveal insights into the relations among inventive mindset and a broader range of STEM and other technical subjects including engineering and computer science.

CONCLUSION

Successful invention education initiatives seek to prepare and inspire children to become inventors and innovators, and many programs also feature an explicit commitment to broadening participation in the innovation and commercialization sectors of the economy for reasons of both social justice and societal benefit (Konig et al., 2019). Invention education is most frequently implemented through out-of-school time programming such as summer camps or innovation competitions. Because such settings have been found to impact students' self-perceptions including leadership skills, self-esteem, and social competencies (Cappelli et al., 2019; Garst et al., 2011; Thurber et al., 2007), we sought to investigate the potential for an OST invention education enrichment program to act as a context for exploration of self as well as exploration of content. We also took the opportunity to develop and study the underlying construct of inventive mindset in order to provide the fields of invention education and STEM outreach with a validated tool for capturing the impact of contexts that support identity exploration. Our findings revealed that both boys and girls exhibited self-perceptions congruent with an inventive mindset, with gender differences in the strength of the relationship between mindset and identification with invention-relevant subject areas of science, math, and technology. Children preferred activities with features that supported their autonomy and confidence and did not tend to like activities that lacked perceived emotional safety and utility. We conclude that invention education can offer a context for identity exploration, but that program designers should explicitly consider how this takes place in a program as it may not occur spontaneously during making, building and design activities.

AUTHOR INFORMATION

Corresponding Author

Dr. Joanna K. Garner. jkgarner@odu.edu

Author Contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

ACKNOWLEDGMENTS

We are grateful to the reviewers for their insightful comments.

FUNDING SOURCES

This work was underwritten by Overdeck Family Foundation and The Lemelson Foundation (award #19-01652).

ABBREVIATIONS

EFA: Exploratory Factor Analysis; KMO: Kaiser-Meier-Olkin; OST: Out-of-School; STEM: Science, Technology, Engineering and Mathematics

REFERENCES

Amabile, T.M. (1998). A model of creativity and innovation in organizations. Research in Organizational Behavior, 10, 123-167.

Bell, J., Chetty, R., Jaravel, X., Petkova, N., and Van Reenen, J. (2018). Who becomes an inventor in America? The importance of exposure to innovation. The Quarterly Journal of Economics, 134 (2), 647–713.

Boateng, G.O., Neilands, T.B., Frongillo, E.A., Melgar-Quinonez, H.R., and Young, S.L. (2018). Best practices for developing and validating scales for health, social, and behavioral research: A primer. Frontiers in Public Health, 6, 1-13.

Cappelli, C.J., Boice, K.L., and Alemdar, M. (2019). Evaluating university-based summer STEM programs: Challenges, successes, and lessons learned. Journal of STEM Outreach, 2 (1), 1-12. https://doi.org/10.15695/jstem/v2i1.13

Cattell, R.B., and Gruen, W. (1955). The primary personality factors in 11-year old children, by objective tests. Journal of Personality, 23, 460-478.

Carlone, H.B., and Johnson, A. (2007). Understanding the science experiences of women of color: Science identity as an analytic lens. Journal of Research in Science Teaching, 44 (8), 1187-1218.

Castillo, C., Yun, S., and Hartry. A. (2020). Supporting making-centered experiences in distance learning contexts. University of California: The Lawrence Hall of Science.

Cook, L.D. (2019). The innovation gap in black and pink. In M. Wisnioski, E.S. Hintz and M.S. Kleine, Does America Need More Innovators? MIT Press, pp.221-247.

Costello, A., and Osborne, J. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. Practical Assessment, Research, and Evaluation, 10 (7). Retrieved from https://dx.doi.org/10.4135/9781412995627.d8

Couch, S.R., Skukauskaite, A., and Estabrooks, L.B. (2019). Telling cases that inform an understanding of factors impacting the development of inventors from diverse backgrounds. Technology and Innovation, 21 (2), 133-142.

Crismond, D.P., and Adams, R.S. (2013). The informed design teaching and learning matrix. The Journal of Engineering Education, 101 (4), 738-797.

Drucker, P.F. (1985). Innovation and Entrepreneurship: Practice and Principles. London, UK: Heinemann Press.

Estabrooks, L.B., and Couch, S.R. (2018). Failure as an active agent in the development of creative and inventive mindsets. Thinking Skills and Creativity, 30, 103-115.

Falk, J., and Meier, D. (2017). Camp Invention® 2017 Pilot Study Report. Institute for Learning Innovation: unpublished technical report.

Field, A. (2009). Discovering statistics using SPSS. Thousand Oaks, CA: SAGE publications.

Flum, H., and Kaplan, A. (2006). Exploratory orientation as an educational goal. Educational Psychologist, 41, 99-110.

Ford, K., Sankey, J., and Crisp, J. (2007). Development of children's assent documents using a child-centered approach. Journal of Child Health Care, 11(1). Retrieved from https://doi.org/10.1177/1367493507073058

Furr, R., and Bacharach, V. (2014). Psychometrics: An introduction. Thousand Oaks, CA: SAGE publications.

Garner, J.K., Haas, C., Alley, M., and Kaplan, A. (2018). The emergence of outreach ambassador role identities in undergraduate engineering students. Journal of STEM Outreach, 1, 1-18.

Garst, B.A., Browne, L.P., and Bialeschki, M.D. (2011). Youth development and the camp experience. New Directions for Youth Development, 130. https://doi.org/10.1002/yd.398

Grotevant, H.D. (1987). Toward a process model of identity formation. Journal of Adolescent Research, 2 (3), 203-222.

Grotevant, H.D. (1987). Toward a process model of identity formation. Journal of Adolescent Research 2 (3), 203-222.

Hartwell, M., and Kaplan, A. (2018). Students' personal connection with science: Investigating the multidimensional phenomenological structure of self-relevance. Journal of Experimental Education, 86 (1), 86-104.

Heffernan, K., Kaplan, A., Peterson, S., and Newton Jones, K. (2017). Integrating identity formation and subject matter learning: Math concepts as tools for identity exploration. In E. Lyle (Ed.), At the intersection of selves and subject: Exploring the curricular landscape of identity, pp. 53-62. Rotterdam, The Netherlands: Sense Publishers.

Hosler, L. (2018). From the USPTO: Mind the gap - the USPTO's efforts to narrow the gender gap in patenting and innovation. Technology and Innovation, 19 (4), 759-762.

Hughes, R., Schellinger, J., Billington, B., Britsch, B., and Santiago, A. (2020). A summary of effective gender equitable teaching practices in informal STEM education spaces. Journal of STEM Outreach, 3 (1), 1-9. https://doi.org/10.15695/jstem/v3i1.16

Kaplan, A., and Garner, J. K. (2017). A complex dynamic systems perspective on identity and its development: The dynamic systems model of role identity. Developmental Psychology, 53 (11), 2036–2051.

Kaplan, A., Sinai, M., and Flum, H. (2014). Design-based interventions for promoting students' identity exploration within the school curriculum. In S. Karabenick and T.C. Urdan, Advances in Motivation and Achievement: Motivational Interventions, pp.243-291.

Kaplan, A., Bridgelal, I., and Garner, J.K. (2020). Sociocultural processes in identity-based motivational interventions: A dynamic systems perspective. In G.A.D. Liem and D.M. McInerney (Eds.), Promoting learning and motivation in contexts: Sociocultural perspectives on educational interventions. Research on Sociocultural Influences on Motivation and Learning. Charlotte, NC: Information Age Publishing, (pp.83-114).

Kim, A., Sinatra, G., and Seyranian, V. (2018). Developing a STEM identity among young women: a social identity perspective. Review of Educational Research, 88 (4), 589-625.

Konig, R., Samila, S., and Ferguson, J-P. (2019). Female inventors and inventions. SSRN. Retrieved from SSRN: https://ssrn.com/abstract=3401889

Lave, J. (1991). Situating learning in communities of practice. In L. B. Resnick, J. M. Levine, and S. D. Teasley (Eds.), Perspectives on socially shared cognition (p. 63–82). Washington, DC: American Psychological Association.

Lemelson Foundation, (2019). Researching Invention Education: A White Paper. Retrieved from https://lemelson.mit.edu/node/2511

Lemelson Foundation, (2020). A Framework for Invention Education. Retrieved from https://www.lemelson.org/our-work/education/

Lemelson-MIT Program. (2019). Overview. Retrieved from https://lemelson.mit.edu/overview

Link, A.N., and Ruhm, S.J. (2013). Fathers' patenting behavior and propensity of offspring to patent: An intergenerational analysis. Journal of Technology Transfer, 38 (3), 332-340.

Moore, R. A., Newton, S. H., and Alemdar, M. (2019). K–12 InVenture prize: Teacher reflections on educating K–12 inventors. Technology and Innovation, 20 (3), 221–233.

National Inventors Hall of Fame (2019). Annual Report. Retrieved from 2019 Annual Report (invent.org)

Nunnally, J. (1967). Psychometric theory. New York, NY: McGraw-Hill publications.

Roberts, K., and Hughes, R. (2019). Girls' STEM identity growth in co-educational and single-sex STEM summer camps. Journal of STEM Outreach, 2 (1), 1-9. doi

Sarada, Andrews, M., and Ziebarth, N. (2017). Historical changes in the demographics of inventors in the United States. SSRN. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2908160

Shavinina L.V., and Seeratan, K.L. (2003). On the nature of individual innovation. In L.V. Shavinina (Ed.), The International Handbook of Innovation, pp.31-43. New York, NY: Elsevier Science.

Silvia, P.J., Nusbaum, E.C., Berg, C., Martin, C., and O'Connor, A. (2009). Openness to experience, plasticity, and creativity: Exploring lower-order, higher-order, and interactive effects. Journal of Research in Personality, 43, 1087-1090.

Simpkins, S. D., Davis-Kean, P. E., and Eccles, J. S. (2006). Math and science motivation: A longitudinal examination of the links between choices and beliefs. Developmental Psychology, 42, 70–83.

Sinai, M., Kaplan, A., and Flum, H. (2012). Promoting identity exploration within the school curriculum: A design-based study in a Junior High literature lesson in Israel. Contemporary Educational Psychology, 37, 195-205.

Small, R. V. (2014). The motivational and information needs of young innovators: Stimulating student creativity and inventive thinking. School Library Research, 17, 1–36.

Smithsonian Institution Office of Policy and Analysis, 2010. Spark!Lab Visitor Survey Study. Retrieved from: https://soar.si.edu/sites/default/files/reports/10.09.sparklabvisitor.final.pdf

Smith, M.M. (2016). Playful invention, inventive play. International Journal of Play, 5 (3), 244-261.

Tan, C.-S., Lau, X-S., Kung, Y-T., and Kailsan, R. (2019). Openness to experience enhances creativity: The mediating role of intrinsic motivation and the creative process engagement. The Journal of Creative Behavior, 53 (1), 109-119.

Thurber, C.A., Scanlin, M.M., Scheuler, L., and Henderson, K.A. (2007). Youth development outcomes of the camp experience: Evidence for multidimensional growth. Journal of Youth and Adolescence, 36 (3), 241-254.

Zhang, H., Estabrooks, L., and Perry, A. (2019). Bringing invention education into middle school science classrooms: A case study. Technology and Innovation, 20 (3), 235-250.