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A Measure of Inventive Mindset for Use in K-12 Engineering and Invention Education

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Abstract

To develop a workforce that finds innovative solutions to society's problems, researchers and practitioners have combined pre-college STEM/STEAM curricula with strategies that explicitly teach the invention process. In this study, we replicated and extended work on the development of an *Inventive Mindset* measure designed for use in evaluating children's self-perceptions of their inventive capacities and the effectiveness of invention education programs. We also examined the relations between children's *Inventive Mindset* scores and identification with science, technology, engineering, arts, and mathematics. The study included responses from *N*=462 elementary and middle school aged students immediately prior to participation in a national-scale invention education program. Confirmatory factor analysis supported the construct validity and potential utility of the measure, which was found to include two subscales: *Ingenuity* and *Solution Seeking.* The scale also demonstrated adequate internal consistency reliability. Correlations between children's perceptions of their inventive habits of mind and their identification with STEAM subjects were moderate and highest for science. The findings suggest that STEAM subject identification and an inventive mindset can, but do not always, overlap.

Keywords: invention education, inventive mindset, STEM identity, STEAM, K-12 education.

Introduction

To develop a robust engineering pipeline and future workforce, researchers and practitioners are seeking to understand how children's psychological characteristics influence engagement and persistence in STEM related activities (Lockhart, et al. 2022; Wang, 2013). The past several decades has yielded a plethora of survey measures to assess children's self-perceptions of science, technology, engineering, and mathematics capabilities, with some also focusing on children's appraisal of their own problem-solving skills and entrepreneurial capacities (e.g., Garner, et al., 2021; Friday Institute, 2012b; Jones, et al., 2021; see also Newman, et al., 2019). Less attention has been paid to measuring children's self-perceptions of their *inventiveness*, which includes problem-solving, but also problem-finding, sharing ideas with others, maintaining persistence, and seeking novel solutions for the common good (Lemelson Foundation, 2020; Small, 2014). In this paper, we present a concluding step in the construct validation of the *Inventive Mindset (IM)* measure which can be used in pre-college invention education, STEM/STEAM education, and engineering education outreach settings. The measure is intended to capture self-perceptions that, theoretically, can change in response to supportive programming. Since few validated measures of inventive mindset exist and little is known about how inventive mindset as a cluster of self-perceptions and preferences might overlap with, or be distinct from, STEAM identity, our goal was to provide the field with a measure that can be used with upper elementary, middle, and high school aged students, and can serve as a research and program evaluation tool.

Background

The successful pursuit of an innovation and commercialization related career requires technical skills in science, technology, engineering, and mathematics, but also habits of mind including problem finding, problem solving, creativity, and the desire to share ideas with others (Garner, et al., 2021; Estabrooks & Couch, 2018; Lemelson Foundation, 2020). These proclivities have been revealed in several studies with successful inventors, entrepreneurs, and scientists (Garner, et al., 2021; Drucker, 1985; Shavavina & Seeratan, 2003). Self-report measures offer a useful way to gauge children's perceptions of their own capacities; self-perceptions of STEM and engineering related strengths are predictive of persistence in coursework, participation in relevant co-curricular activities, and career exploration (Cabell, 2021; Simon et al, 2015).

Invention education includes a transdisciplinary range of pedagogical strategies that are designed to improve children's inventive habits of mind as well as their awareness of commercialization related topics such as intellectual property and business model development (National Inventors Hall of Fame, 2019). Programs often teach invention processes such as identifying problems, ideating, designing and testing prototype solutions, and sharing the idea with others[1]. Common formats for invention education include after-school programming, summer camps, and competitions, with the curriculum used in these settings focusing on technical and creative challenges. Invention education programs often require students to consider and develop prototype solutions that draw on their STEM or STEAM skills. It therefore provides a context for strengthening students' identification as "a person who" has an affinity for STEM subjects, which in turn may also increase the likelihood that they will persist in technical, innovation-oriented coursework (Conradty, Sotiriou, & Bogner, 2020). As such, the development of a strong identification with STEM/STEAM is a secondary but important goal of invention education (Garner, et al., 2021; Couch, Skukauskaite & Estabrooks, 2019).

A review of the literature revealed a need for a single, self-report measure of inventive habits of mind. For example, we found that existing self-report measures of problem solving tend to focus on subject domains such as mathematics (Gok, 2014), generic problem-solving steps (Ekici, 2016), problem solving in particular contexts (e.g. Wolf, 1997), or tested specific problem-solving strategies such as divergent thinking (Puente-Diaz & Arroyo, 2017). Similarly, self-report measures of creativity tend to focus on creativity in specific contexts such as game-based learning (Yeh, Ting & Chiang, 2023) or include items that are specific to instances of creativity such as making connections between a current problem and a possible solution, (Conradty, Sotiriou & Bogner, 2020). Self-report measures of design self-efficacy also tend to reflect subject domains such as science (self-efficacy for designing experiments; Hushman & Marley, 2015) and the arts (designing in a visual arts environment; Catterall & Peppler, 2007). Notably, we did not find a self-report measure for problem-finding, ingenuity, or inventiveness that could be used in elementary and middle school settings.

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[1] Models of the invention process are analogous to the pedagogical guidance provided in models of the engineering design process or the scientific method.

Rationale for the Study

Using Inventive Mindset measure data from 252 elementary and middle school aged children, Garner, et al. (2021) demonstrated satisfactory exploratory factor analysis (EFA) structure, adequate internal consistency reliability, and moderate correlations with science, engineering, and mathematics identification. The 9-item, two-scale IM measure was initially found to have two factors labeled *Ingenuity* (creativity, imagination, idea generation and sharing) and *Solution-Seeking* (problem-solving, openness to ideas, making improvements, tenacity). The purpose of the present study was to replicate and extend the prior one. We sought to use confirmatory factor analysis (CFA) techniques and new data collected in summer 2022 to provide additional evidence for the measure's internal consistency reliability and construct validity. We also sought to examine relations between IM scores and additional curriculum-related subject areas including engineering and art. Our guiding research questions were:

(1) To what extent does the Inventive Mindset measure demonstrate adequate internal consistency reliability and construct validity?

(2) To what extent are children's self-perceptions of inventiveness correlated with their identification with STEAM subjects?

Methods

Context and sample. Camp Invention is a summer day-camp run by the National Inventors Hall of Fame, in which children entering grades K-6 engage in a weeklong, hands-on program that promotes STEM interest and participation and builds 21st century learning skills (e.g., creativity and problem solving); all through the lenses of invention, innovation, and entrepreneurship. National Inventors Hall of Fame Educational programs served 286,000 participants in PreK-Grade 12 spanning all 50 states in 2022. Of these, 197,000 students were underserved, about 47% of students were female, and 51% were male. Camp Invention delivered programming through partnerships with 23,000 teachers in 2022. The survey sample mimics the geographical similarities, socio- and demographics of our national reach, including sites in several urban areas of the Midwest and West Coast.

In this study, data were gathered from N=462 elementary and middle school aged students at the beginning of their five-day Camp Invention program. Respondents were 56% male, 43% female, and 1% did not wish to disclose. The sample was 66% White, 16% Black, 12% two or more races, 5% Hispanic/Latinx, 2% Asian, and fewer than 1% American Indian or Alaskan Native and Did not Disclose, respectively. Any participants with a missing response value were removed to ensure the stability of the analysis procedure. Parents and guardians provided consent for the children to participate.

Measures and procedure. The measure development process is described elsewhere (Garner, et al., 2021) and followed a multi-step inductive process (Boateng, et al. 2018). Steps included an analysis of interviews with noted inventors, a focus group, and item review. Single subject identification items were added to the inventive mindset items. Subject areas of science, technology, engineering, art and mathematics were discussed by the research team and items were written for each of these due to their relevance to the invention education program in which the children were participating. Since the goal of the study was to establish the internal construct validity of the measure rather than its concurrent, divergent, or criterion related validity, the study did not include the administration of other measures.

Ahead of participating in invention education programming, participants used an online form to complete both the IM scale and a set of 5 subject-specific STEAM identification items. The 9-item scale used a 4-point, Likert-type agreement scale (0 = strongly disagree, 1 = disagree, 2 = agree, 3 = strongly agree). The STEAM items were not included in the factor analysis. Survey items, sample means, and standard deviations are shown in Table 1.

Data analysis. IBM SPSS was used to calculate descriptive statistics and correlations. IBM SPSS AMOS was used to examine model fit. Findings are presented for the entire sample because gender differences in composite scores were not found.

Findings

Item-level and whole-scale statistics. We did not find evidence of floor or ceiling effects for the subscales or the full scale (Ingenuity mean = 12.03, SD = 2.29, maximum possible score = 15; Solution Seeking mean = 8.88, SD = 1.64, maximum possible score = 9; Total mean = 23.25, SD = 3.83, maximum possible score = 27). Table 1 presents the item-level means and standard deviations.

Internal consistency reliability. No items posed concerns for error covariance via high modification indices, and the measure presented with acceptable internal consistency reliability (Factor 1 $\alpha = .78$, Factor 2 $\omega = .78$).

Table 1. Inventive Mindset and STEAM identification item-level descriptive statistics

Inventive Mindset		
	Mean	SD
I am open to new ideas	2.26	0.649
I give up easily*	2.08	0.696
I am a problem-solver	2.21	0.616
I like to design things	2.50	0.641
I have lots of good ideas	2.40	0.616
I am imaginative	2.48	0.599
I like to share my ideas with others	2.19	0.708
I am creative	2.47	0.595
I like to make things better	2.34	0.580
I am inventive	2.33	0.632
STEAM Identification		
	Mean	SD
I am a math person	2.00	0.841
I am a science person	2.17	0.674
I am an engineering person	2.04	0.736
I am an arts person	2.32	0.706
I am a technology person	2.23	0.687

* Reverse-coded

Construct validity. Standardized regression weights for all nine items ranged from β = .34 - .74, with only two items below .45. The factors were permitted to correlate, and did so significantly ($r = .79$, $p < .001$). The analysis allowed confirmation of the two factors identified in the exploratory study. The factors are *Ingenuity*, which includes children's perceptions of their creativity, imagination, idea generation and sharing, and *Solution-seeking*, which includes children's perceptions of their problem-solving skills, openness to ideas, desire for making improvements, and tenacity. The Inventive Mindset measure was examined using maximum likelihood, with the chi square to degrees of freedom ratio satisfying the benchmark for a CFA conducted with a larger sample size ($\chi^2 = 91.27$, $df = 26$, $\chi^2/df = 3.51$). The chi square score itself was significant, meaning the test was failed; however, chi square tests with a structural equation model like a CFA procedure are less reliable as a measure of model fit with sample sizes larger than 200 participants (Alavi, et al, 2020; Bayback & Green, 2010).

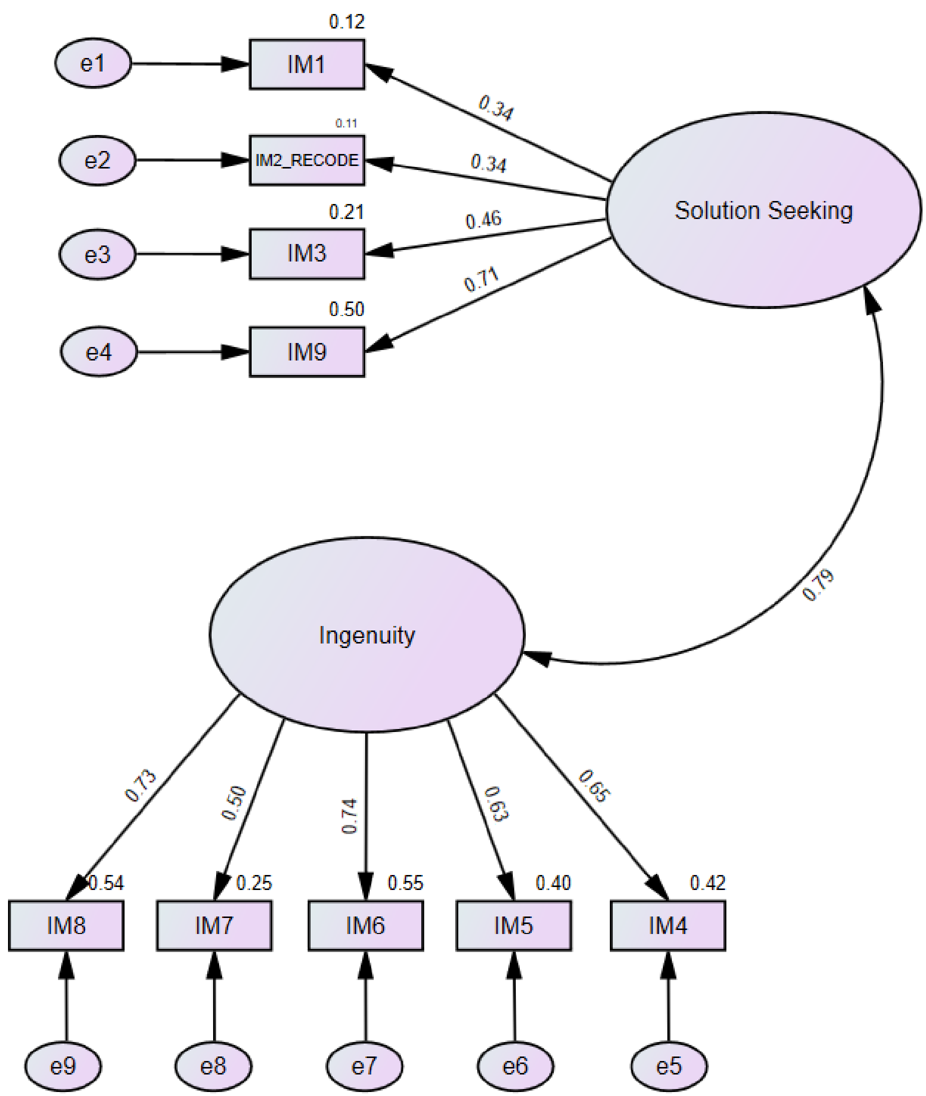
Table 2. Standardized regression weights and square multiple correlations (SMC) for the Inventive Mindset measure

Item	Ingenuity	Solution-Seeking	SMC
IM1: I am open to new ideas		.344	.118
IM2: I give up easily*		.336	.113
IM3: I am a problem solver		.460	.212
IM4: I like to design things	.650		.422
IM5: I have lots of good ideas	.633		.401
IM6: I am imaginative	.740		.547
IM7: I like to share my ideas with others	.505		.255
IM8: I am creative	.734		.539
IM9: I like to make things better		.710	.504

* Reverse-coded

Standardized regression weights for all nine items of the Inventive Mindset Measure ranged from $\beta = .34 - .74$, with only two items below a loading of .45. The correlation between the constructs of solution-seeking and ingenuity was also significant ($r = .79$, $p < .001$). No items posed concerns for error covariance via high modification indices, indicating the model required no additional modifications. The standardized regression weights and square multiple correlations for the scale are found in table 2: the structural equation model diagram for the Inventive Mindset measure can be found in Figure 1.

Figure 1. Structural equation diagram for the Inventive Mindset measure.



Fit indices determine the quality of a structural equation model such as a CFA in lieu of the fallibility of the chi square test with larger sample sizes. Standard benchmarks for each commonly used fit index and the score of the IM on this index is provided in Table 3.

Table 3. Fit index scores for the Inventive Mindset measure

Index	Standard for Model Fit	Inventive Mindset fit score
Normed Fit Index (NFI)	≥ .90	.91
Relative Fit Index (RFI)	close to 1	.87
Incremental Fit Index (IFI)	≥ .90	.93
Tucker-Lewis (TLI)	≥ .90	.90
Comparative Fit Index (CFI)	≥ .90	.93
Root Mean Square Error of Approximation (RMSEA)	< .08	.07

Relations among Inventive Mindset and STEAM identification. Identification with STEAM subject areas was found to be moderately correlated with Inventive Mindset total score (Pearson's r^2=.54, $p<0.001$) as well as the Ingenuity sub-scale total score (Pearson's r^2=.47, $p<0.01$) and the Solution Seeking sub-scale total score (Pearson's r^2=.422, $p<0.01$). The single item "I am inventive" showed the strongest correlation with "I am an engineering person" (Pearson's r^2=0.43, $p<0.01$) followed by "I am a science person" (Pearson's r^2=0.33, $p<0.01$), "I am an arts person" (Pearson's r^2=0.27, $p<0.01$) and "I am a math person" (Pearson's r^2=0.16, $p<0.01$). Bivariate correlations between Inventive Mindset total score and the two sub-scale scores with individual STEAM subject items are shown in Table 4.

Table 4. Correlations among Inventive Mindset items and identification with STEAM subjects.

	Identification with STEAM subjects				
	Science	Tech.	Eng.	Arts	Math
Ingenuity sub-scale score	.34**	.20**	.32**	.40**	.21**
Solution-seeking subscale score	.33**	.20**	.29**	.20**	.28**
IM Total score	.40**	.25**	.39**	.37**	.27**

* $p<0.05$; ** $p<0.01$.

Discussion and Limitations

The study replicates and extends prior work by Garner, et al. (2021) which included an exploratory factor analysis of the Inventive Mindset measure and, as such, it provides additional evidence of the measure's construct validity. Further, the findings suggest that the Inventive Mindset measure has adequate internal consistency reliability and acceptable model fit. The study also calls attention to considering children's identification with STEAM subjects as being relevant to but separate from children's perceptions of, and preferences for, inventive behaviors. Bivariate correlations between identification with STEAM subject areas and an inventive mindset were moderate at best, and favored science and art over engineering, technology, and mathematics. However, children's responses to the item "I am inventive" correlated most strongly with identification with engineering.

At present, access to validated measures of children's perceptions of their own inventiveness has lagged growing professional interest in invention education. Until recently, researchers, program evaluators, and practitioners had few instruments at their disposal when seeking to evaluate solution-seeking and ingenuity tendencies in children who are participating in STEAM-oriented invention education programming. The Invention Mindset measure and its ancillary STEAM identification items can be useful in this regard. The measure may be useful in evaluating the impact of engineering and invention education programming, and researchers may wish to explore the relations between children's self-perceptions and their persistence in coursework and co-curricular activities pertaining to invention, commercialization, and entrepreneurship.

It is important to note several limitations to this study and the use of the measure. First, the study does not assess the potential for invention education programming to change or further develop children's inventive mindset. Although Garner, et al. (2021) found that programming can be effective in changing students' self-perceptions and promoting identity exploration in relation to STEAM subject areas, further research is needed to investigate the degree to which inventive mindset is stable or malleable, and the types of programming that are most effective for diverse and intersectional groups including females, individuals of color, and individuals from economically disadvantaged and historically marginalized backgrounds. This is an important area of future research that should be pursued. A second limitation is that our sample was mostly self-selecting into the program through parental enrollment of children in the camp. It was also two-thirds majority White and did not include substantial representation from many other racial-ethnic groups. As a result, we urge caution in generalizing the findings to in-school settings and diverse populations of students. Finally, a third limitation is that the study was conducted with upper elementary and middle school aged students. It will be important to replicate this research with older students including high school and college aged students, as well as adults engaged in alternative STEM/STEAM and career and technical education, and entrepreneurship education settings.

Conclusion

This study marks a contribution to the field of STEM/STEAM and invention education as it provides psychometric evidence for a self-report measure of inventive mindset that can be administered to upper elementary and middle school aged students. Such students are frequently included in programming designed to address the shortage of individuals who are interested in postsecondary education and careers in the innovation and entrepreneurship sectors of our economy. The Inventive Mindset measure demonstrated adequate internal consistency reliability and construct validity as well as the capacity to contribute in distinct but overlapping ways to our understanding of the development of a strong STEAM identity, which is one predictor of persistent engagement in engineering and innovation related programming.

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