Identifying Engineering Interest and Potential in Middle School Students: Developing an Instrument

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Abstract

Due to the projected U.S. market demand in 2014 for 1.64 million engineering educated and trained individuals[45], it is vital that we help children understand engineering concepts, explore career choices in the field of engineering, and determine if pursuing engineering would be a good fit for them.

Today's curriculum is very focused on mathematics and writing due to the demands of standardized testing, however with a national interest in Science, Technology, Engineering, Mathematics (STEM) education, there is a movement to incorporate engineering into the curriculum. Since children make career choices by 7th grade[57], integrating engineering concepts and engineering college education and career options into the K-6 curriculum are a necessary change.

One way to determine if engineering is a good fit is for a student to use a self-assessment instrument. A self-assessment tool helps an individual discover more about him/her self[55]. In making career choices, an assessment of one's skills, interests, personality, and values influences career decisions[9]. Exploration of the literature reveals that an instrument for self-assessment of young engineering talent, interest, and fit does not exist.

The purpose of this research is to create an instrument to help fifth and sixth grade students identify themselves as having engineering interest and potential. The purpose of this instrument is to raise awareness of student interest and potential in engineering and is not intended to serve as a screening instrument. This work describes the instrument development, the input from the engineering and education communities in the context of content validity, the pilot and revision of the draft instrument, and the content validation of the final instrument.

Introduction

Since Sputnik's launch in 1957, our nation has focused on STEM education improvement. Key legislation, policies, and campaigns have been introduced during every presidential term, with the hopes that measurable gains will be made in our leadership position in the STEM fields.

The education focus in the STEM content areas, specifically engineering, is closely associated with the current focus on the engineering job market. The U.S. Department of Labor forecasts that by the year 2014, the United States will need approximately 1.64 million individuals who are engineering educated and trained to fill the engineering employment demand[45]. Based on the current pipeline, this country is facing a period of an inadequate supply of American engineers.

This shortage is due to several factors: a substantial number of baby boomer engineers are retiring[12], there are not enough U.S. college students studying engineering today[54], engineering is not a commonly understood profession[26], the number of 16-24 year old U.S. workers is projected to decrease 6.9% from 2006 to 2016[50], the trend for graduates with advanced engineering degrees to return to their home countries is increasing[46], international students are less dependent on the U.S. for their engineering education[43], and engineering graduates who are not U.S. citizens can not fill vital military positions due to security clearance requirements[49].

To meet this future market demand and address the concern of an engineering shortage, it is imperative that a more comprehensive guidance program[17] be implemented into middle schools, along with integrating the E of STEM into the curriculum, educating the key influencers of children on engineering concepts and careers, and developing an engineering interest self assessment instrument. Support of these key components may increase the likelihood that students with STEM-based talent will choose to pursue engineering.

This paper describes the construction and validation of an instrument that was designed for middle school students to self assess their interest and potential in engineering in response to the research questions: *1) What constructs should be included in a self-assessment tool that may be used to identify middle school students' interest and potential in engineering, and 2) What is the validity of the instrument created?* Pertinent literature on career theory as it pertains to children and on self-assessment instruments will be reviewed. Gaps in the literature will be identified and addressed.

Literature Review

STEM Legislation, Programs, Reports Focus on Shortage

In the midst of the world's recognition bestowed on the scientific, technological, engineering, and mathematical minds of Russia for their launch of Sputnik in 1957, it seems that this outstanding accomplishment would immediately bring to light the need to address the deficiencies in the educational system in the United States. More than 25 years later, the National Commission on Excellence in Education published *A Nation at Risk: the Imperative for Educational Reform*, which primarily assessed the quality of teaching and learning in the public schools[41]. Educational researcher Paul Hurd stated that "We are raising a new generation of Americans that is scientifically and technologically illiterate" [41].

More than 10 years later, in an effort to reform education, the Improving America's Schools Act of 1994 was signed. The purpose of Title III Part E--Elementary Mathematics and Science Equipment Program was to improve the quality of mathematics and science instruction in the elementary schools by supplying equipment and materials needed for hands-on activities[18].

The *No Child Left Behind Act of 2001* made education and educational excellence top priorities and suggested that every child would be provided appropriate educational interventions to achieve success in school and in turn, life[47]. Two primary concerns with NCLB was that Read First was not as successful as anticipated with America's lowest-performing students, and that school districts had reduced class time in science and social studies because of the time Read First required[24].

Three education-based policy introductions followed in 2006 and 2007 in an effort to improve STEM education. The American Competitiveness Initiative designated substantial funding for world-class STEM-focused education[3]. The Carl D. Perkins Career and Technical Education Improvement Act of 2006 targeted to improve the quality of technical education programs[10]. The America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act of 2007 provided additional funding for STEM education and teacher preparedness[2].

In the first week of 2010, President Obama announced that he will expand his Educate to Innovate campaign for excellence in science, technology, engineering, and mathematics education in grades K-12; however it appears that the program's focus is to improve only the science and mathematics of STEM education.

Problem Starts in STEM Education

Education-based legislative policies that are intended to improve K-12 STEM education and raise subsequent test scores, integrate all STEM fields into the national education standards, and increase student pursuit of engineering study and careers are not successful.

This focus on STEM education over the last 15 years suggested that the complete integration of the STEM disciplines into the K-12 school curriculum was vital to the future of this nation's children[26]. Yet, although technology dominates the global marketplace, very few K-12 school districts regularly or formally include technology and engineering in their K-12 core curriculum[20, 26, 40]. STEM-talented high school students are pushed toward college prep in math and science, but get few opportunities to explore engineering design and problem solving before heading to college, as evidenced by a review of the state educational standards that shows that engineering is not integrated into the core K-12 curriculum[40].

STEM-based legislative efforts and programs have not improved U.S. students' scores on international math and science tests. The results of the Third International Math and Science Study (TIMSS) in 2007 indicated that American students consistently performed worse in math and science than students from several other countries, including Singapore, Chinese Taipei, Republic of Korea, Japan, Hong Kong, England, Hungary, and Russian Federation[38,39]. U.S. students also ranked below most of these countries in the 2003, 1999, and 1995 TIMSS tests[31, 32, 33, 34].

The Program for International Student Assessment (PISA) measures literacy in both mathematics and science in 15-year-olds[35]. In mathematics, the U.S. ranked 14th in 2000[22], 2fifth in 2003[29], and 25 in 2006[37]. In science, the U.S. ranked 14th in 2000[22], 20th in 2003[30], and 21st in 2006[36]. The U.S. regularly ranks below the member country average in both mathematics and science.

With STEM-focused legislation, it seems that the U.S. would by now have a plethora of bright graduating college students preparing to be employed in the STEM fields. However, this does not seem to be the case as “other countries are demonstrating a greater commitment to building their brainpower” [7], evidenced by these facts and projections:

- In 2010, 15% of the people in the world who will hold science and engineering doctorate degrees will be Americans; in 1970, that figure was 50%[59].
- In 2004, 350,000 engineers graduated from India's colleges; 70,000 from U.S. colleges[19].
- South Korea, with one-sixth of the U.S. population, graduated more engineers than the United States in 2001 and in 2002[44].
- From 1985 to 2002, the number of first university engineering degrees awarded in China was up 245%, Japan was up 43%, South Korea was up 176%, and the U.S. was down 22 % [44].

Much would be gained by adding engineering to the K-12 curriculum. The Committee on K-12 Engineering Education presented 5 potential benefits to students that will result from adding engineering education into the K-12 curriculum: improve learning in science and mathematics, increase literacy in technology, increase awareness of engineers’ work, engage in engineering design, and gain interest in an engineering career[26]. Based on these projected benefits, a commitment to provide complete STEM education for K-12 students in the U.S. is paramount[42]. Further, educators, government agencies, and employers recognize the need to engage the next generation of potential engineers at earlier ages[62]. Engineering education needs to begin in elementary school while student interest in mathematics and science is still high. About eighty percent of fourth graders report positive attitudes toward mathematics and science compared to an estimated thirty-three percent of eighth graders who report positive attitudes toward mathematics and science[28].

Based on the projected U.S. market demand in 2014 for 1.64 million engineering educated and trained individuals[45], it is vital that we help children understand engineering concepts, explore career choices in the field of engineering, and determine if pursuing engineering would be a good fit for them. Having a career goal may help students focus on their educational objectives.

Career Development as it Applies to Children and Engineering

Career counseling typically occurs in high school with the help and support of guidance counselors and teachers; however career interests and attitudes are formed as early as in middle school[61, 63]. Engineering school administrators act on this information through their outreach programs[57]. While Hughes and Karp studied career counseling outcomes, specifically the work of Oliver and Spokane[51], they noted that the largest effect size between the variables career counseling outcomes and ages groups belonged to junior high students[17, 51]. Whiston, Sexton, and Lasoff replicated Oliver and Spokane’s study and drew a similar conclusion that career guidance was most effective with middle school and junior high students, although caution was given due to the small number of studies in both analyses[65].

The primary role of many middle school and junior high counselors is not career counseling, which may require school counselors to get familiar with career counseling and invite other school staff, teachers, and parents to get trained to assist students with career development[17].

School personnel and family members spend many hours each day with their students and children, influencing and guiding them academically, socially, emotionally, and developmentally, and oftentimes are instrumental in students' university study and career choices. If engineering is going to be integrated into the K-12 curriculum, then teachers and counselors will need to learn new skills, methods, and strategies to be more effective in teaching engineering concepts. To offer engineering education and career assistance to their students, teachers and counselors will need to learn about the field of engineering, engineering studies, and engineering careers[64].

This level of knowledge about engineering also applies to parents. The role of parents in facilitating education and career decisions with their children is important, and by many, considered the most important[4, 16, 23, 53]. Otto[52] states that parents should be directly involved in advising their children during the engineering education and career development process.

All individuals who are instrumental in advising and guiding children with study and career exploration and decisions should be knowledgeable about as many fields and careers as possible, and this includes engineering. Teachers, counselors, and parents need to be able to advise and guide children with engineering career exploration and decisions, and assist them in determining if their skills and interests fit with an education and career in engineering.

Making career decisions is a developmental process that lasts a lifetime. Super's Life-Span / Life-Space Career Development Theory is based on a life-long process where individuals reflect on their changing self concepts as they pass through stages of growth, exploration, establishment, maintenance, and disengagement with each career decision and transition[6, 60]. Super's growth stage, where role models, interests, and abilities are recognized, and early exploration stage, where career choices begin to narrow, align with student as they navigate their K-12 education.

Super applied his growth and exploration stages to develop a child-specific model of nine concepts that he believed supports children in their career decisions[56, 61]. Super's childhood years career development model consists of curiosity, exploration, information, key figures, interests, locus of control, time perspective, self concept, and planfulness[56].

Others have explored models on children making career choices. Gottfredson's theory of Circumscription and Compromise suggests that self-concept, one's abilities, interests, personality, is key in vocational decisions[14]. Children initially view familiar occupations positively, but as the child ages and self-concepts develop and change, these concepts serve as criterion to eliminate or compromise on vocational choices and "job-self compatibility" [14].

Gottfredson's vocational theory suggests that a matching process occurs when an individual chooses a vocation that corresponds to his/her interests and skills[15]. This process begins when a child is young; however, before this process can begin, the child needs to learn about different jobs and identify his/her self-concept. Only then can a child determine which job matches his/her interests and skills[15]. Gottfredson states assessment tools that help youth identify their interests are valuable, especially when administered by the age of thirteen when children circumscribe their interests based on sextype boundaries and prestige levels[14].

Addressing career development in middle school grades requires an understanding of the skills and attributes of engineers.

Practicing Engineers' Attributes

Applying these concepts of childhood career development theory, learning about engineering careers, and assessing one's interests and abilities seem central in the process of making career decisions and determining if engineering is a good match with one's interests[14, 15, 61, 63].

Learning about engineering careers implies understanding the attributes of engineers. Stakeholders interested in identifying these attributes may include engineering-affiliated organizations, representing an independent agency, a national manufacturer, and an accreditation bureau. The National Academy of Engineering (NAE), founded in 1964, "provides engineering leadership in service to the nation" and will "investigate, examine, experiment, and report upon any subject of science or art" when requested by any governmental agency[27]. NAE developed a list of specific attributes of engineers that are key to the success of the engineering profession. The Boeing Company, manufacturer of commercial jetliners and military aircraft, is a long-standing supporter of K-12, college, and university programs. Because of its business, Boeing devised a specific set of attributes that they require of the engineers who they will consider for employment.

The Accreditation Board for Engineering and Technology (ABET), originally established in 1932 as an accreditation agency, expanded its role to evaluate engineering and engineering technology degree programs. ABET is composed of twenty-eight professional and technical societies with practicing professionals who hail from academia, government, and industry[1]. ABET, a primary stakeholder, issued engineering program outcomes that describe the skills, knowledge, and behaviors that are expected of students who have graduated[1].

A gap in the literature is a comparison of these three organizations' lists of attributes. To better see how they compare, the listings of attributes of engineers that these three organizations developed are organized by similarities in Figure 1.

Figure 1

Comparison of Preferred Attributes of Engineers

National Academy of Engineering[25]	Boeing Company[5]	Accreditation Board for Engineering and Technology[1]
strong sense of professionalism possess high ethical standards	high ethical standards	demonstrate professional and ethical responsibility
good communication	good communication skills	communicate effectively
lifelong learners	curiosity and a desire to learn for life	engage in life-long learning
strong analytical skills	a solid understanding of the context in which engineering	identify, formulate, and solve engineering problems

National Academy of Engineering[25]	Boeing Company[5]	Accreditation Board for Engineering and Technology[1]
	is practiced	
	a solid understanding of engineering science fundamentals	apply knowledge of mathematics, science, and engineering
	a solid understanding of design and manufacturing processes	design and conduct experiments, and analyze and interpret data
	a solid understanding of a multi-disciplinary, systems perspective	design a system, component, or process to meet desired needs within realistic constraints
practical ingenuity (skill in planning, combining and adapting)	the ability and self-confidence to adapt to rapid or major change	
	a profound understanding of the importance of teamwork	function on multidisciplinary teams
flexibility & agility	flexibility	
creativity	an ability to think both critically and creatively, independently and cooperatively	
leadership master of business and management		understand the impact of engineering solutions in a global, economic, environmental, and societal context
dynamism		
resilience		
		have a knowledge of contemporary issues
		use the techniques, skills, and modern engineering tools necessary for engineering practice

These attributes are similar to those in the engineer profile that Davis, Beyerlein, and Davis[11] developed, as they used similar sources. For children to determine how well their skills and interests compare with the attributes of engineers, Gottfredson supports the use of an assessment tool that would help youth identify their interests. A review of the literature reveals prior work in the development of engineering assessments for children.

Prior Work in Engineering Interest Instruments for Children

In order to help students determine if engineering matches their skills and interests, the administration of a self-assessment instrument is valuable. A self-assessment tool helps children discover more about themselves[55]. In making career choices, an assessment of skills, interests, personality, and values influences career decisions[9]. A review of the literature shows that there are only a few tools available for children regarding engineering.

Dr. Christine Cunningham, from the Boston Museum of Science, developed the Draw an Engineer Test (DAET) questionnaire, which primarily asks students to 'Draw a picture of an engineer at work' and write an answer to the question, 'What does an engineer do?' This questionnaire contains 3 other questions: 'In your own words, what is engineering?', 'Do you know any engineers?', and 'If yes, then who are they?' [21], but, Dr. Cunningham states that the focus of her analysis is the first two questions listed. She describes that the purpose of the DAET tool is "to investigate students' stereotypes about engineering" [21].

Another tool was a Student Interview used for a Pilot Study at Miller Elementary in Centerline, Michigan. Its purpose is to determine what students "think engineering is and what kind of work engineers do" [8]. The interview contains 19 questions which focus on students' perceptions of engineering and engineers and students' involvement in engineering activities. The only question relating an engineering career to the student is #18, which asks 'Would you like to be engineer when you grow up? Why or why not?' [21].

A third tool, the Middle School Students' Attitude to Mathematics, Science, and Engineering Survey, was developed to gauge "middle school students' attitudes to mathematics, science, engineers and jobs in engineering, as well as their knowledge about engineering careers" [13]. This survey was adapted from the version that measured the attitudes and knowledge of high school students[13].

Missing from these 3 tools is the opportunity for young students to self-assess their interests to help determine if they would be a good fit for engineering. This is a significant gap based on this nation's future engineering employment need and STEM focus.

<u>Integrating Multiple Theoretical Perspectives to Measure Engineering Interests in Children</u>

Based on key theorists, Piaget, Erikson, Kohlberg, Gilligan, Werner, Rousseau, Vygotsky, Montessori, and Malaguzzi, an investigation of the developmental, cognitive, social, emotional, and physical aspects of middle school students directed the selection of the factors that were measured in this instrument. As a result of the work of these theorists, we can create an instrument that measures a more complete set of relevant variables.

Figure 2

Engineering Attributes in Children that Theorists Measured

Erik Erikson	Learning Ethical and professional responsibility

	Ambiguity
Carol Gilligan	Ethical and professional responsibility
Lawrence Kohlberg	Ethical and professional responsibility
Loris Malaguzzi	Problem solving Creative
Maria Montessori	Learning Creative Ethical and professional responsibility
Jean Piaget	Problem solving Reason analytically How things work Learning Creative Ethical and professional responsibility Flexible Ambiguity
Jean-Jacques Rousseau	Problem solving Learning
Lev Vygotsky	Learning Creative
Heinz Werner	How things work Flexible

With the confidence that these attributes can be measured, a new instrument was developed.

Methods

Development of Engineering Interest Instrument

The basis for developing this instrument originated from the projected state of the engineering job market, youth's general lack of knowledge about engineering careers, and an interest to help children determine engineering job-self compatibility. The items for this construct was based on the attitudes and behaviors of successful engineers identified by ABET, Boeing, and NAE in conjunction with several theoretical perspectives.

The purpose of this instrument was for middle school students to self-assess their interest and potential in engineering using Behaviorally Anchored Rating Scales (BARS). BARS was developed by Smith and Kendall to construct rating scales anchored to examples of expected behavior[58]. For this instrument, in order to have consensus on understanding the meaning of the items and the rating that measures each item, the items were written as middle school recognizable behaviors representing the attributes of successful engineers. This method should improve face-validity by the middle school students.

Development of this instrument was an iterative process with several revisions made after each review by experts and peers.

The preliminary draft of the self assessment instrument included forty-eight items written for fifth and sixth grade students that measured twelve factors. Thirteen people completed a content validation of this preliminary instrument draft. The eleven graduate engineering students acted as content knowledge experts, the one postdoctoral research assistant served as an instrument development expert, and the one middle school science teacher provided expertise with age-appropriate language and readability. Each expert filled out a Content-Validity Rating Form, which provided Item-Factor Matching, ratings for Confidence of Item-Factor Matching and for Item-Construct Appropriateness, and written feedback and comments. Feedback from these reviewers prompted two revisions of the instrument draft, reducing the factors to ten and modifying some of the wording on the remaining items. These iterations resulted in a pilot version of the instrument.

Pilot Study of Draft Instrument

A teacher at a local middle school agreed to sponsor the pilot study. The pilot instrument was administered to eighteen sixth grade students made up of ten female students and eight male students. No ethnic or racial information about the students was collected. All participants completed the survey within 12-15 minutes.

Data was tabulated and using SPSS software, a Split-Half Cronbach's Alpha, Guttmann Split-Half Coefficient, and Spearman-Brown Coefficient were computed. Alpha of 0.6 was not consistently met due to small pilot study sample size, n=18. For purposes of acquiring an adequate number of participants in the study, at least ten participants will be needed for each of the items on the final version of the instrument[48]. Based on a preliminary confirmatory factor analysis, several of the items loaded somewhat equally on more than one factor, which was primarily due to the limited number of participants.

Observations of the eighteen students who took the pilot survey gave evidence that some students were confused with the word 'innovation' and also misread the items that included the word 'not'. This information was consolidated in the final revisions of the instrument.

Instrument Modification and Content Validity

Evaluation of the pilot instrument indicated that the items needed further modification to be written more as behavior-based statements with which middle school students could identify. Based on additional research, the number of items and factors were reduced. The instrument was distributed for another content validation to a new group of experts, which included five education and engineering education professors, one engineering education staff, two postdoctoral research assistants, and three graduate students. Of the 32 items, twenty-one items were approved and seven items had minor changes recommended by the experts. Of these twenty-eight items, fourteen scored 100%, seven scored 91%, five scored 82%, and two scored 64%. The last four items required rewording based on their unclear focus. A mini-validation of those four items was conducted and their Item-Factor Matching improved to 82%.

The final version of the instrument included 32 items. The items were evaluated on a 5-point Likert scale ranging from strongly disagree to strongly agree.

The survey is currently being sent to 8-10 Public, Catholic, Charter, and International Baccalaureate middle schools in Idaho, Florida, and Indiana, representing approximately 19 classrooms of fifth and sixth grade students. Teachers from these middle schools will invite approximately 600 students to take the survey, which will be administered anonymously. Once the surveys are returned, an analysis of the data will determine construct validity.

Discussion

Based on the projected employment need for engineers, this nation needs to continue to increase engineering curriculum integration in elementary and middle schools. Many educators are already teaching engineering concepts but seldom are recognized as engineering. Students would be better served if they understood when they were engaging in engineering so that they may be able to relate their skills and interests to those of a practicing engineer. Administering this instrument would help middle school students self assess their interest and potential and determine if they match the attributes of practicing engineers. This new awareness may result in more students pursuing engineering.

This instrument appears to be valid based on the results of the final content validation. Several groups of experts – faculty, graduate students, post-doctoral students, and faculty and students who had practical engineering experience – examined the various versions of items and factors, and with each examination, items and factors were modified until there was at least an 80% consensus on the factors. The instrument still needs to be administered to students in order to determine construct validity.

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