

Gender Differences in Conceptualizations of STEM Career Interest: Complementary Perspectives from Data Mining, Multivariate Data Analysis and Multidimensional Scaling

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Abstract

Data gathered from 325 middle school students in four U.S. states indicate that both male ($p < .0005$, $RSQ = .33$) and female ($p < .0005$, $RSQ = .36$) career aspirations for *being a scientist* are predictable based on knowledge of dispositions toward mathematics, science and engineering, plus self-reported creative tendencies. For males, strong predictors are creative tendencies ($\beta = .348$) and dispositions toward science ($\beta = .326$), while dispositions toward mathematics is a weaker ($\beta = .137$) but still a significant ($p < .05$) predictor. For females, significant ($p < .05$) predictors ordered by strength of contribution are dispositions toward science ($\beta = .360$), creative tendencies ($\beta = .253$) and dispositions toward mathematics ($\beta = .200$). Additional analyses indicate that engineering appears to be more closely aligned with STEM career aspirations for females than for males. These findings contribute to the growing body of knowledge indicating that at the middle school level major contributors to choosing a path toward a STEM career differ for boys versus girls.

Keywords: middle school, gender differences, STEM career interest

Introduction

This paper presents research conducted as part of a five-year Innovative Technology Experiences for Students and Teachers (ITEST) project, funded by the U.S. National Science Foundation (NSF). The project's goal is to focus pre-teen interest in activities that foster learning about energy consumption in students' homes and communities, and to incubate interests and knowledge about STEM majors and careers. Data mining techniques (Witten, Eibe, & Hall, 2011; Gibson & Clarke-Midura, 2013) were employed to help select a parsimonious list of predictors to be used in multiple linear regression analysis for each gender, and then multidimensional scaling techniques (Dunn-Rankin, Knezek, Wallace, & Zhang, 2004) were applied to produce visualizations of major results (Knezek & Christensen, 2014). The targeted outcome of this process was isolation of variables worthy of more detailed study

during the four-year scale-up phase of the project begun in 2013.

The Middle Schoolers Out to Save the World (MSOSW) Project

The MSOSW project was designed to develop middle school students' interest in Science, Technology, Engineering, and Mathematics (STEM) content areas and to increase students' perceptions and attitudes toward a career in STEM. The ongoing project aims to direct middle school students' enthusiasm for hands-on activities, and to guide students to solve real-world problems. Students in this study are trained by their teachers to use energy monitoring equipment to audit standby power consumed by the electronic devices in the students' homes and communities.

Standby power (also called vampire power) is the electricity consumed by many appliances when they are plugged in but "turned off" (U.S. Department of Energy, 2011). Many appliances consume some electricity while not performing any useful function. The U.S. Department of Energy has estimated that over the lifetime of a typical home appliance, 70% of the power consumed will be when the appliance is turned off (U.S. Department of Energy, 2011). Televisions, game consoles, home computers and microwaves are a few of the appliances that commonly consume standby power. During MSOSW project activities, with the guidance of their teachers, sixth and seventh grade students learn to measure the vampire power consumption of various appliances in the students' homes. After measuring standby power, students gather their data together with their classmates in spreadsheet projections to explore energy conservation plans that can lower a family's monthly electric bill and reduce the greenhouse gas emissions that contribute to global warming. Students share their results with other middle school students from across the U.S.

Ultimate Goal: STEM Career Interest

A primary goal of the NSF ITEST program is to develop a better understanding of the primary constituents of precollege experiences that encourage increased selection of STEM majors in college and eventual advancement to

STEM careers (Learning Resource Center, 2012). According to George, Stevenson, Thomason, and Beane (1992), STEM career intervention and enrichment plans should be initiated well before the high school years. As education and popular perception of technology and engineering standards evolve, there is an increased awareness of the need for STEM literacy within society. STEM literacy fosters intelligent participation in public socio-scientific and ethical decisions, which direct the future of engineering and technology (Gorham, 2002; Stiller, De Miranda, & Whaley, 2007). Many studies focus on factors affecting students' attitudes towards science such as the influence of teachers, parents and peers on students' science attitudes (George, 2006; Rodrigues, Jindal-Snape, & Snape, 2011; Sevinc, Ozmen, & Yigit, 2011; Christensen, Knezek, & Tyler-Wood, 2015). However, there is a need for more studies evaluating the effectiveness of authentic hands-on projects in STEM content areas.

In a study by Tai, Liu, Maltese and Fan (2006), early career expectations of middle school students influenced what careers they selected in the future. Eighth graders in the 2006 study who had early expectations about a career in STEM were more likely to work in a science-related career, especially in physics and engineering careers. Similarly, high school students in Packard and Nguyen's (2003) study reported that their career aspirations were highly influenced by their interests in subject areas in school.

Attitudes formed during middle school had a large influence on students' academic performance (Liu, Horton, Olmanson, & Toprac, 2011), which in turn affected students' career aspirations (Choi & Chang, 2011). Therefore, understanding middle school students' perceptions regarding STEM content areas is crucial to preparing our future STEM workforce. This paper is one contribution to that ongoing process, with a special focus on extracting new information about differences in male versus female conceptual frameworks of STEM career interest. Higher-order quantitative analysis techniques such as data mining and multidimensional scaling, are applied to data originally gathered to assess simple pre-post changes, in order to produce the reported findings.

Instrumentation: Indicators of STEM Career Interest

Career Interest Questionnaire

The Career Interest Questionnaire (Tyler-Wood, Knezek, & Christensen, 2010) is a Likert-type (1 = strongly disagree to 5 = strongly agree) instrument composed of 12 items on three scales. The three scales measure the following constructs: interest in pursuing a career in science, intent to pursue educational opportunities that would lead to a career in science, and perceived importance of a career in science. The instrument was adapted from a longer instrument developed for a Native Hawaiian Studies project promoting STEM interest (focusing on science) in Hawaii. Adaptations of the instrument were based on a comprehensive analysis completed by Bowdich (2009).

The Career Interest Questionnaire (CIQ) was selected to fulfill a particular MSOSW research team goal of including a brief, reliable, and construct-valid instrument in an education-friendly, Likert-type format – one that could be used to cross-validate and further enrich some portion(s) of the STEM Semantics Survey analyses. Although the CIQ was created for career interest in science and the items selected were used as written, the research team envisioned that the instrument's original form, once confirmed to be useful for science, could be easily modified to address any STEM discipline.

STEM Semantic Survey

The STEM Semantics Survey (Tyler-Wood, Knezek, & Christensen, 2010) was used to measure interest in each STEM subject as well as interest in STEM careers more generally. The STEM Semantics Survey was adapted from Knezek and Christensen's (1998) Teacher's Attitudes Toward Information Technology Questionnaire (TAT) derived from earlier Semantic Differential research by Zaichkowsky (1985). The five most consistent adjective pairs of the ten used on the TAT were incorporated as descriptors for target statements reflecting perceptions of science, mathematics, engineering and technology. A fifth scale representing interest in a career in science, technology, engineering, or mathematics was also created. The internal consistency ratings for the five subscales ranged from 0.88 to 0.93, which can be considered very good (DeVellis, 1991). The five scales had five items each and each item was presented as semantic adjective pairs (fascinating: mundane; exciting: unexciting; and so forth) to describe STEM dispositions and career attitudes.

Computer Attitude Questionnaire

Several subscales from the Computer Attitude questionnaire (CAQ) (Knezek, Christensen, Miyashita, & Ropp, 2000) were used for this middle school project. Among these were Computer Enjoyment, Computer Importance, Computer Learning, Computer Comfort, Motivation/Persistence, Study Habits, Empathy, Self-Concept, Cre-

ative Tendencies (a.k.a. Creativity), and Attitudes Toward School. The subscales contained Likert-type items with ratings ranging from strongly disagree (1) to strongly agree (5). Reliabilities for the computer attitude and learning disposition scales of the CAQ have been consistent for middle and secondary schools students for several years. The reliability estimates for the subscales were most recently analyzed and found to be in the range 0.73 to 0.85 in the MSOSW project (Mills, Wakefield, Najmi, Surface, Christensen, & Knezek, 2011). These fall in the range of respectable to very good according to the guidelines provided by DeVellis (1991).

Subjects and Variables

The participants for the study were 325 middle school students from six schools in Louisiana, Texas, Maine and Vermont. The participants were from the 6th and 7th grades in school. Male (n=157) and female students (n=168) were almost equally represented in the sample. Data for this study were gathered as part of a larger study during 2010–2011 and includes only the post test data which was gathered in the spring of 2011 after the students had completed the project activities. While pretest data were gathered, the post test data were more complete and therefore used for the analyses. While a battery of instruments was used to measure knowledge of standby power, attitudes toward STEM content and careers, learning dispositions such as creative tendencies, motivation, study habits, and interest in various careers – only the variables used in the current research are discussed here.

Analysis Methods

Data mining techniques (Witten et al., 2011; Knezek & Christensen, 2014) complemented by more traditional multivariate analysis approaches such as linear regression, were the primary analysis methods employed in this research. Multidimensional scaling techniques (Dunn-Rankin et al., 2004) were also used, with choice of technique dictated primarily by prospects for visualization of findings. There were two guiding objectives for the analyses: (1) to explore new structural relationships that had not yet been found or reported, and (2) to compare findings from symbolic regression to linear regression and hierarchical clustering analysis.

Symbolic Regression

In symbolic regression (Koza, 1992), a label y is provided for every $\sim x$ and an explicit symbolic relationship of the form $y = f(\sim x)$ is sought. Unlike traditional statistical regressions that fit parameters to an equation of a given form, symbolic regression searches both the parameters and the form of equations simultaneously (Schmidt & Lipson, 2009). Scientists have attempted to identify and document analytical laws that underlie physical phenomena in nature. Despite the prevalence of computing power,

the process of finding natural laws and their corresponding equations has resisted automation. A key challenge to finding analytic relations automatically is defining algorithmically what makes a correlation in observed data important and insightful. We propose a principle for the identification of nontriviality. We demonstrated this approach by automatically searching motion-tracking data captured from various physical systems, ranging from simple harmonic oscillators to chaotic double-pendula. Without any prior knowledge about physics, kinematics, or geometry, the algorithm discovered Hamiltonians, Lagrangians, and other laws of geometric and momentum conservation. The discovery rate accelerated as laws found for simpler systems were used to bootstrap explanations for more complex systems, gradually uncovering the "alphabet" used to describe those systems. "author": [{"family": "Schmidt", "given": "Michael"}, {"family": "Lipson", "given": "Hod"}], "container-title": "Science (New York, N.Y.). Beginning with randomly combined mathematical expressions, a search algorithm probabilistically alters, tests recombined forms, and discards subexpressions until a set of equations is found that best models the data. After expressions reach a desired level of accuracy using some criteria of fit, the algorithm terminates, leaving those that are most likely to explain the intrinsic mechanisms of the observed real-world system.

Some underlying assumptions about this approach for educational data include: (1) educational phenomena are explainable by natural laws (e.g. psychological laws, learning theory, emotions, socio-cultural constructivist theories and such are naturally occurring phenomena amenable to scientific discovery) and (2) because of assumption (1), the discoverable relationships are inherently a search for conserved quantities and invariant equations in the system of data.

Eureqa Data Mining

The research team used the data mining application "Eureqa", also known as "Formulize" (creativemachines.cornell.edu/eureqa), to conduct a symbolic regression analysis of the MSOSW data. A compact data set was created with no missing data, and no manipulated or replacement data, with 157 records of males and 168 records of females, for a total of $n = 325$. After a dependent variable and the predictors were selected, a series of one-minute searches were conducted using a fitness metric of maximizing the correlation of the models. The searches resulted in sets of equations that can be represented as a network of production relationships among the variables in the data set. Here we are concentrating on just the production relationships that explain the CIQ Total score. To verify the primary result, we then conducted a traditional linear regression for the dependent variable, CIQ Total (Career Interest Questionnaire Total Scale Score).

Choice of Predictors

The research team agreed on three conditions in the selection of the predictors:

1. The 12-item Likert CIQ (Career Interest Questionnaire = CIQ Total) is the best outcome measure, especially for the CAQ (Computer Attitude Questionnaire) with 13 Creative Tendency items plus a combined total of 22 Computer Comfort and Computer Learning, Likert-style items.
2. Predicting one scale of an instrument (STEM Career Interest) from other scales of the same instrument will likely introduce artificial alignments, and was avoided.
3. Having three instruments involved, one as dependent and two as predictors, is the most conservative and balanced approach.

Thus the research team conducted exploratory searches for explanatory equations using this model:

Dependent Variable: CIQ Total Scale Score

Predictors: STEM Semantic Survey Scales (i.e. SciTot, MathTot, EngTot, TechTot) Computer Attitude Questionnaire Scales (i.e. Creativity, Computer Comfort, Computer Learning)

Preparing the Data

The research team divided the data into males (gender=1) and females (gender=2) for comparisons and sorted the data by CIQ Total scale score. The team then performed two data preparation steps: (1) researchers smoothed the data by row with no weight, and (2) researchers normalized the scales with no offset. Figure 1 shows an interactive data exploration screen for three of the four variables reported on in this article: Mathematics and Creative Tendency predictor variables and CIQ Total, the outcome variable representing total attitude toward a STEM-related career. The sort of data by the outcome variable allows visual inspection of the relationship to predictor variables.

One of the simplest approximations for gender=1 (males) under the data manipulations outlined above (smoothed and normalized, with no offset) involves Math and Creativity. The equation produced with goodness of fit indices for males (n = 157) is:

$$CIQ_{ScienceTotal} = 4.214 * MathTot + MathTot * CAQ_Creativity$$

R ² Goodness of Fit	0.98983735
Correlation Coefficient	0.9960369
Maximum Error	0.33925499
Coefficients	1

As shown in Figure 1, for males, mathematics is both shaped like the outcome variable and is above the outcome variable on the normalized scale. Creativity is mostly above the outcome variable and has a similar curve form to CIQ Total as well.

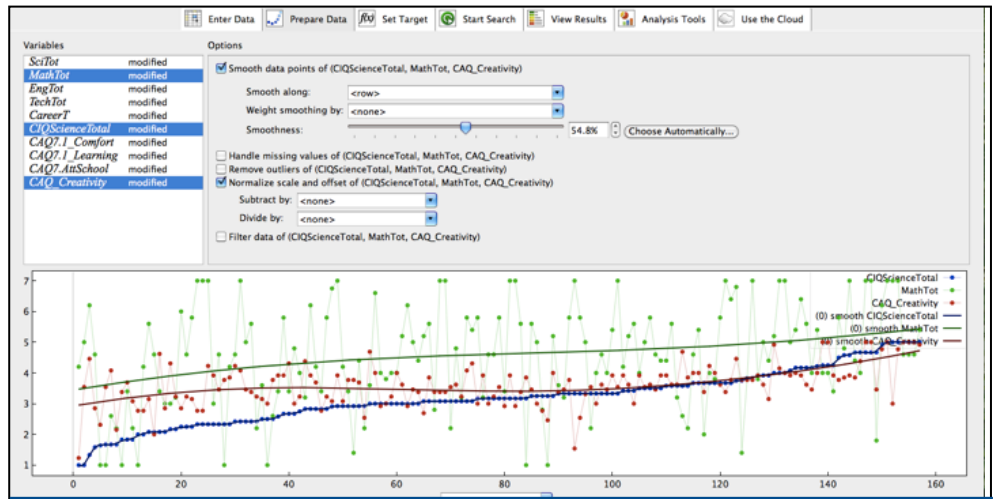


Figure 1. Visual inspection of male data shows mathematics and creative tendencies are potential drivers of STEM career interest.

With females, as shown in Figure 2, Creative Tendency tracks below the outcome variable CIQ Total but with a similar curve form on the normalized scale. Mathematics does not exert upward pressure on STEM career interest (CIQ Total). We give specific numerical meaning to these observations in equations below.

Females are different from males in the drivers of STEM career interest. Creative Tendency remains important, but Science and Engineering replace Mathematics for females. A solution with low error, low complexity, high correlation found for females (n = 168) is listed here:

$$CIQ_{Total} = 3.278 + 3.147 * SciTot + -1.606 * EngTot + 0.5615 * CAQ_Creativity$$

R ² Goodness of Fit	0.99337144
Correlation Coefficient	0.99575189
Maximum Error	0.22608999
Coefficients	4

Note that other solutions could result in equal or greater predictive power. The solution using these three predictors was chosen because the result is a parsimonious equation

with variables relevant to the goals of the research project.

Regression Analysis

As previously concluded by Perathiruvadi, Knezek, Christensen and Tyler-Wood (unpublished manuscript), using the same MSOSW data and many of the same predictors with SPSS linear regression, the Likert-based computer attitude scales (Computer Comfort and Computer Learning) did not make major contributions to the research team's ability to predict STEM career interest. However, Eureka data mining identified a unique combination of predictors for females that was similar to that found by Mills (2013) from a separate data set gathered from middle school students not participating in the MSOSW project. Therefore SPSS-based linear regression was applied to the MSOSW data set used for the Eureka analyses in order to better understand the relationships from a linear regression perspective.

Regression analysis for males. In order to provide a basis of comparison for the effect of adding Engineering to the previously-used predictors of Mathematics, Science

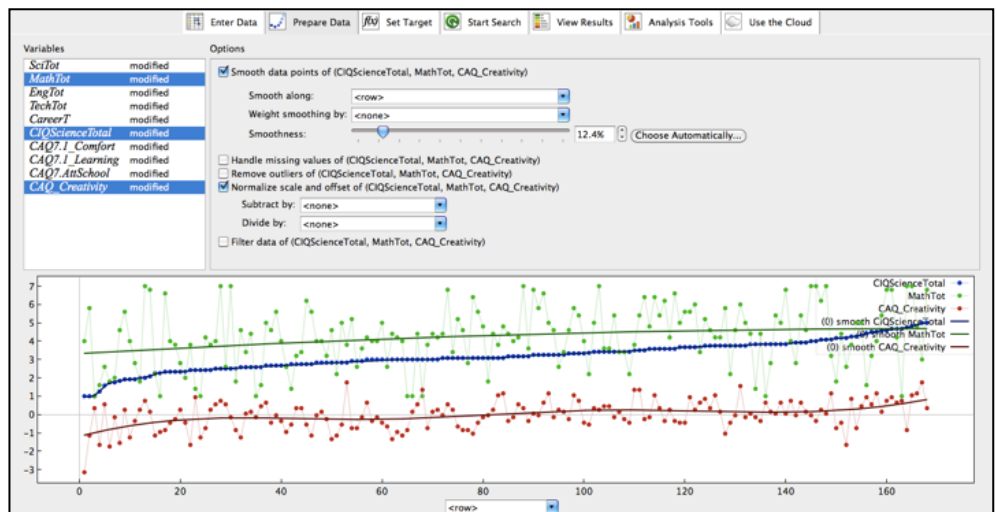


Figure 2. Visual inspection of female data shows mathematics is less of a driver for STEM career interest while creative tendency remains correlated with career interest, as with males.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F	Sig.
1	.575 ^b	.330	.315	.69895	21.705	.0005

Regression Coefficients for Males for Career Interest Total

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.371	.321		1.157	.249
	Creativity (CAQ 7.0 subscale)	.430	.085	.348	5.075	.0005
	Science disposition total	.173	.035	.326	5.012	.0005
	Mathematics disposition total	.069	.032	.137	2.168	.031
	Engineering disposition total	.008	.037	.014	.207	.837

Table 1. Analysis for Career Interest (CIQ Total) as a Function of Science, Mathematics, Engineering, and Creativity (Males only)

and Creativity, a regression analysis (not shown) was first run without Engineering in the equation. This model accounted for approximately 34% of the variance in Career Interest (CIQ Total) (RSQ = .337). As shown in Table 1, for males, including Engineering added very little to the ability to predict career interest, with a standardized beta (regression coefficient) very near to zero (.014) and the total RSQ (R Square) declining slightly to .330.

Regression analysis for females. Regression analysis for females using CIQ Total as the dependent variable and Science, Mathematics, and Creativity as predictors (not shown) resulted in an RSQ of .338. As shown in Table 2, when Engineering was added, the RSQ rose to .357 and the standardized regression coefficient (beta) was .080, compared to .014 for males. This is not a large additional contribution to the prediction equation in itself

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F	Sig.
1	.597 ^b	.357	.342	.64086	24.255	.0005

Regression Coefficients for Females for Career Interest Total

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.333	.323		1.030	.304
	Creativity (CAQ 7.0 subscale)	.341	.092	.253	3.700	.0005
	Science disposition total	.205	.036	.360	5.613	.0005
	Mathematics disposition total	.096	.029	.200	3.253	.001
	Engineering disposition total	.041	.033	.080	1.220	.224

a. Gender = 2

b. Dependent Variable: Career Interest Questionnaire Total Scale Score

Table 2. Regression Analysis for Career Interest (CIQ Total) as a Function of Science, Mathematics, Engineering, and Creativity (Females only).

for females, but it is much larger than the contribution for males. The special connection between perception of engineering and STEM career interest for females will be further elucidated in the hierarchical cluster analysis of the following section.

Hierarchical Cluster Analysis

Hierarchical cluster analysis (Dunn-Rankin et al., 2004) was the scaling technique selected by the research team to assist in visualizing the different conceptualizations of male versus female middle school students regarding STEM career interest. The SPSS procedure *Hierarchical Clustering* was run separately for males and females, using the same data employed in the regression analyses previously reported. Interval level data assumptions were used with squared Euclidean distance computations and within-groups linkages as the optimization goal. Horizontal dendrograms of the clusters were produced. As shown in Figure 3, for males, Creativity is very closely coupled with STEM career interest (CIQ Total), and these two are also somewhat connected with perception of Mathematics.

As shown in Figure 4, for females the connections between learning dispositions and STEM career interests are different from those shown in Figure 3 for males. Specifically, for females perception of Engineering (rather than Mathematics) is the first to join the Creativity + Career Interest cluster.

Discussion

Results from the current study are consistent with major findings published from the traditional multivariate analysis of pre-post gains for the project (Knezek, Christensen, Tyler-Wood, & Periathiruvadi, 2013), that the impact of the energy monitoring activities was especially strong in girls. Findings also correspond with outcomes from the longitudinal follow-up of students from one of the MSOSW schools (Christensen, Knezek, Tyler-Wood, & Gibson, 2013; Christensen, Knezek, Tyler-Wood, & Gibson, 2014), that for girls, Science became more closely aligned with STEM Career Interest during the course of participating in the project and tended to still be aligned in that manner two years later.

New information from the current study includes confirmation of the prominent role of Creative Tendencies in STEM Career Interest for both males and females. This was identified as a probable trend by Mills (2013) in her examination of pretest versus post test predictors of STEM Career Interest for MSOSW. (One of her four sets of data, from 2 years of pre versus post test analysis, was the same as the data set employed for the current study.) This trend

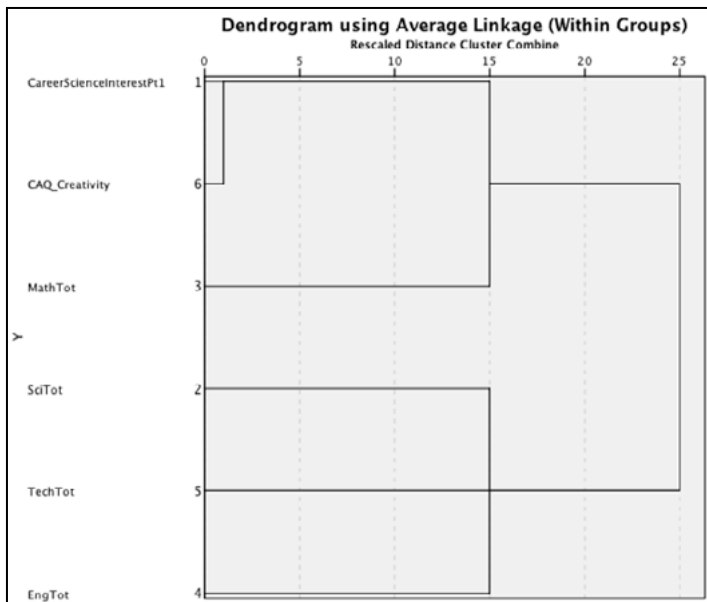


Figure 3. Dendrogram of relationships between learning dispositions and STEM career interest for male middle school students in the MSOSW project.

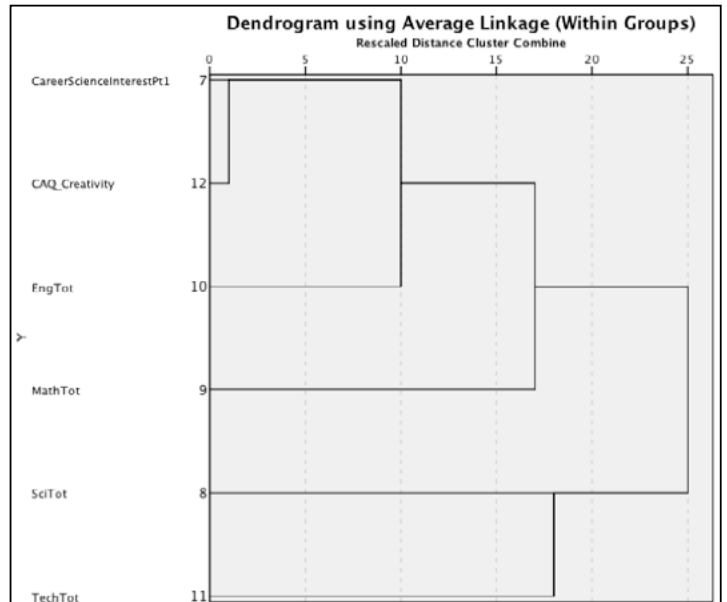


Figure 4. Dendrogram of relationships between learning dispositions and STEM career interest for female middle school students in the MSOSW project.

for alignment of Creativity with STEM Career Interest (CIQ Total) has strongly emerged through the techniques utilized in the current study.

Gender differences in STEM interest and achievement have been the subject of numerous discussions in scholarly literature (Choi & Chang, 2009). Although earlier studies have shown that male students perform better in STEM areas than female students, Choi and Chang (2009) observed that recent studies have shown mixed results. As Knezek, Christensen & Tyler-Wood (2011) argued, the gender gap is less of an ability gap than a gap in perceptions of science careers (Knezek, Christensen, & Tyler-Wood, 2011). Dubetz and Wilson (2013) found that middle school girls mentored by female role models during university-based summer outreach activities developed greater interest in science, mathematics and higher education while being introduced to potential STEM career opportunities. Liu (2008) observed that girls had better mathematics grades on classroom tests while boys had better mathematics scores on standardized tests. This difference was attributed to the social aspect of the classroom compared to the impersonal standardized test environment. Including social aspects in science and mathematics activities may be more effective for girls. In their study of science attitudes of high school students, Quinn and Lyons (2011) found that although there were no gender differences in how students enjoyed science, boys reported enjoying science more in comparison with other content areas. Gafoor and Narayan (2012) found that for upper primary school students in India "... experimental acts are more influential on interest in science for girls than boys" (p. 191). The finding by Gafoor and Narayan (2012) is consistent with one of the results of the current study indicating that both dispositions toward science and dispositions toward engineering are stronger predictors of

aspirations toward being a scientist for girls than they are for boys.

Fewer than 10% of engineers in the United States are female (Hirsch, Carpinelli, Kimmel, Rockland, & Bloom, 2007). Many women have historically been relatively uninformed about STEM fields and many are thought to have a higher attraction to career fields perceived as being of service to society (Hirsch et al., 2007). Part of the explanation for why the MSOSW project's measured positive impacts on female STEM dispositions were generally greater than for males (Knezek, Christensen, Tyler-Wood, & Perithiruvadi, 2013) may lie in the fact that saving the world is also being of service to society. The current study's findings that for middle school females, Engineering is in some sense closer to the *Creativity-STEM Career Interest* core cluster than is Mathematics (nearest to the core cluster for males), may hint that a potential STEM career path would capitalize on female interest in "making things" (Modi, Schoenberg, & Salmond, 2012) as a route to a larger number of females in STEM careers. Much more research is needed in this area.

Summary and Conclusions

Three quantitative data analysis techniques were used to identify indicators of STEM career interest for middle school boys and girls. Findings indicate that while STEM career interest can be predicted reasonably well ($RSQ > .3$) for both males and females, the strongest indicators are not necessarily the same for the two genders. In particular, for boys, creative tendencies and dispositions toward science accounted for 33% of the variance in STEM career interest, while for girls a linear combination of dispositions toward science, creative tendencies, and mathematics was able to explain 36% of the variance in interest in *becoming a scientist*. Hierarchical clustering analysis

showed that dispositions toward engineering were more closely aligned with interest in a career in STEM for girls than for boys.

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