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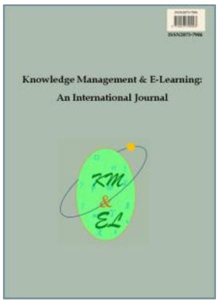

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Longitudinal analysis of cognitive constructs fostered by STEM activities for middle school students

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Abstract: The purpose of this study was to determine whether the changes found to occur pre- to post intervention in students' cognitive structures continued to persist two years later. Major findings were: 1) higher-order STEM-related constructs established during the treatment year tended to persist two years later, even as component dispositions varied, and 2) gender differences in level of persistence emerged in only one of the four higher-order constructs identified. For the participants taken as a whole, perceptions of science and STEM as a career became more aligned with interest in being a scientist, from pretest to posttest time during the treatment year and continued to be aligned two years later. Perception of engineering moved from alignment with science and STEM as a career at time 1, to alignment with perception of technology and creative tendencies after the treatment year, at time 2, and remained aligned with technology two years later, at time 3. Perception of mathematics was separated from the other constructs during the pre-post treatment year and remained largely separated two years later. One subscale of the career interest survey focusing on working with others to make the world a better place through science, separated from other career interest subscales and became its own higher-order construct at time 2, and still remained on its own at time 3. Data mining techniques as well as higher-order factor analysis were used to identify changes in relationships among these and other constructs over time.

Keywords: Cognitive constructs; Data mining; Middle school students; STEM education

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1. Introduction

A key question regarding the effectiveness of educational interventions is whether or not the desirable changes brought about through curricular activities remain embedded in the minds of learners over time. Teachers have long observed the loss of knowledge and skills students display over extended summer vacations (Cooper, 2003). Little is known about whether and which types of cognitive constructs manifesting themselves as interests in types of knowledge-skill-profession clusters need on-going experiences (exposure) for reinforcement or whether they persist, once established, over time. This study focuses on the question of whether higher order constructs related to science, technology, engineering, and mathematics (STEM) dispositions – found to emerge during hands-on science activities – remained as constructs two years later, even in the absence of continued exposure to the specific activities created to foster the constructs. These higher-order trends are important to address because they may persist in spite of aberrations in component measures. The most important indicators regarding STEM education research could be those that emerge and persist at the higher order level.

Middle school students were the target of the hands-on energy monitoring project providing the intervention for this study. The Middle Schoolers Out to Save the World (MSOSW) project is funded from the Innovative Technology Experiences for Students and Teachers (ITEST) program of the U.S. National Science Foundation (NSF). Students in the project monitor home energy consumption under the supervision of their teachers and then use the data gathered to develop optimum scenarios for conserving energy and reducing the production of greenhouse gases in local communities, with a particular focus on standby power. The main goal of the MSOSW project, entering its sixth year at the time of completion of this manuscript, is to foster STEM content and career interest in order to prepare middle school students to participate in the science, technology, engineering and mathematics (STEM) workforce of the future.

2. Conceptual rationale/Theoretical framework

2.1. Importance of STEM to society

In the United States as in many nations, efforts are being made to improve science, technology, engineering and mathematics (STEM) education and make it a national priority to strengthen the nation's position in discovery and innovation globally (The White House, 2009). The skills in STEM areas that students acquire in middle school lay the foundation for a successful career in STEM (Woolley, Strutchens, Gilbert, & Martin, 2010). Most STEM occupations require competencies in science, mathematics and logical thinking to support effective problem solving. Middle school is a crucial stage in student development as students prepare for a fast changing future (George, Stevenson, Thomason, & Beane, 1992). Therefore, it is vital to prepare and develop interest in middle school students to participate in the future STEM workforce.

In Europe as well as the U.S., an alarming decline in student interest in STEM has been noted (Rocard et al., 2007). A European Commission panel of experts has indicated that interest in STEM is directly related to how STEM is taught in schools. According to many sources, STEM career intervention and enrichment plans should be initiated well before the high school years (George, Stevenson, Thomason, & Beane, 1992). Middle school is an appropriate age to develop an interest in science that will persist through secondary school, into college and beyond into a career. Providing authentic, active learning experiences contributes to the internalization of learning about science. Researchers conducted a retrospective study measuring changes in STEM career interest during the high school years. A regression model analysis for the national sample of more than 6,000 students indicated that students who begin high school with high STEM career interest are nine times more likely to report this same interest at the end of high school (Sadler, Sonnert, Hazari, & Tai, 2012). As education and popular perception of technology and engineering standards evolve, there is an increased awareness of the need for STEM literacy within society.

2.2. Engaging students in science

There are several approaches to consider for increasing students' interest in a STEM career, most of which perhaps require a change in pedagogy and/or philosophy from traditional classroom instruction. Hands-on science as such is not new for science education. It has been advocated since the 1960s by science curriculum specialists (Voogt, 1996). However, the implementation in the everyday science class appeared to be problematic (Roth, 1989). Hands-on science requires learning environments in which the student assumes an active role, in contrast to more traditional approaches to science teaching that stress the learning of facts, concepts and theories. The foundation of problem-based learning (PBL) has been in existence for decades and is rooted in Dewey's *learning by doing and experiencing principle* (Dewey, 1938). Dewey argued that a child's schoolwork should have meaning and be engaging as well as have connections to other disciplines and life experiences. Science educators are increasingly using this approach to help connect learning to the real world (Akinoglu & Tandogan, 2007).

According to Boud and Felatti (1997), "PBL was developed not only as a specific instructional method but also as central to [a] philosophy for structuring an entire curriculum promoting student-centered, multidisciplinary education, and lifelong learning" (p. 2). PBL is a learner-centered approach that involves self-directed learning. The logic behind this approach is that by solving problems students learn to generate procedures that can be used again when they encounter other similar situations (Bonwell & Eison, 1991). Characteristics that are included in problem-based active learning include:

- relevance to real world applications
- authentic solving of real world problems
- application of prior knowledge and/or experiences to solve new problems
- collaboration with others
- integration of subject matter (interdisciplinary) and
- self-directed learning.

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). However, there is a need for more studies evaluating the effectiveness of authentic hands-on projects in STEM content areas. As students participate in hands-on activities, students learn what it means to be a scientist and in the process reshape their cognitive structures toward being scientists. There is a need for new methods to assess these changes in cognitive constructs and attitudes.

2.3. Longitudinal persistence of learning

Middle school students who had taken part in the MSOSW project featured in this paper participated in many components of active learning, such as hands-on experiences as well as real world applications. These students exhibited changes in content knowledge as well as dispositions toward, and interest in, STEM. For indicators of STEM career interest, pre-post test items were adapted from the National Center for Education Statistics Longitudinal Study (NELS) and the American Women in Engineering item banks (Nolte & Harris, 2010). These were used to measure career aspirations and demographics on identical pre- and post-tests. Among the primary findings, a 15.8% increase was found for project students who say they will obtain a Ph.D., M.D., or other advanced degree (Nolte & Harris, 2010). This finding is important because project researchers have recently confirmed through an eight-year longitudinal follow-up study that similar projects can indeed have an impact on STEM dispositions as students advance from elementary school to college. Specifically, Tyler-Wood, Ellison, Lim, and Periathiruvadi (2011) used Facebook to follow up with fourth grade girls (and their contrast group participants) who took part in a project designed to promote girls' interest in science during 2001-2002. In the project, girls participated in hands-on, environmental science activities solving real world problems. During the follow-up study, first year participants were freshmen in college. Former participants retained positive STEM dispositions as they advanced to college age. These dispositions were roughly equivalent to those of a comparison group of junior and senior college women who were enrolled in STEM majors. These dispositions were significantly higher than those of the contrast group, who were matched at the fourth grade level to participants using science achievement scores obtained on the standardized Iowa Test of Basic Skills (ITBS). These two projects provide credible evidence that STEM-related active learning projects for students in grades 4-8 can make an impact on their interest in STEM-related aspirations.

A new methodological approach is also important because student attitudes are influenced by a large number of factors in their educational environment (Klausmeier & Goodwin, 1975). Research has shown that student attitudes toward learning dispositions and attitudes toward school in particular decline as students advance throughout each school year as well as throughout their school career. For example Christensen and Knezek (2001) have shown that attitudes toward school as well as many learning dispositions decline as students advance through years in school. This trend is graphically illustrated in Fig. 1. This trend is consistent with findings from research conducted three decades earlier (Dunn-Rankin et al., 1971) showing a similar decline in attitudes toward school from grades one through eleven (see Fig. 2). Note that both studies also show a small increase in attitudes toward school at the end of the 12th grade.

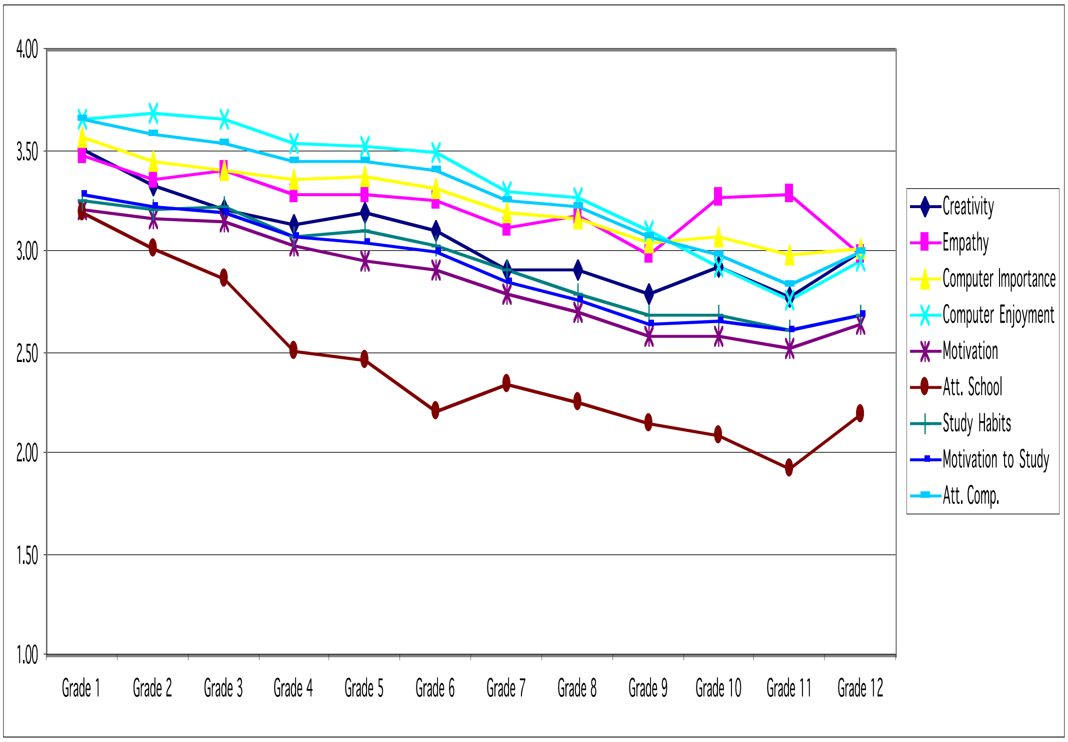

Fig. 1. Trends for student learning disposition ratings in Texas in 2001

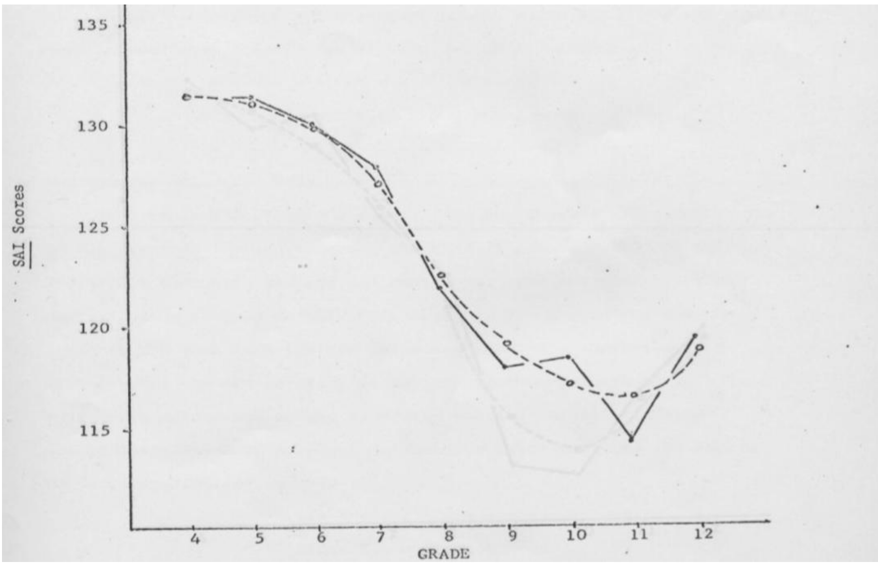

Fig. 2. Trends in school attitude inventory ratings for students in Hawaii in 1969-1970

This general trend toward decline in attitudes over time can make it appear that interventions promoting positive dispositions in middle school students are ineffective. Other techniques are needed to determine whether desirable attitudes persist in a longitudinal study design. Methods that identify persistence of targeted cognitive schema are utilized in this study to examine the development and persistence of cognitive constructs, rather than attempting to assess measurable gains in one specific index or skill.

The Cognitive Reconstruction of Knowledge Model (CRKM) developed by Dole and Sinatra (1998) incorporates cognitive psychological perspectives, science education concepts and social psychology theory to explain how cognitive constructs change with learning. According to Dole and Sinatra (1998) it is important to assess students' conceptions over time through a delayed as well as immediate posttest. This is directly relevant to the engaged learning activities featured in the MSOSW project and studied in a time-delayed fashion in this paper. An overarching goal of MSOSW is to create future citizens who are cognizant of the broader issues relevant to the roles of various STEM careers impacting the future. In the words of Dole and Sinatra (1998), "Regardless of students' existing views, educators hope that students will gain more insight into critical issues facing society and be able to view them from multiple perspectives" (p. 125). For this paper, these perspectives involve how individual dispositions evolve into long lasting cognitive structures that represent positive STEM trajectories.

3. Methodology

3.1. Subjects

Follow up data were collected from one set of students (n=60) two years after they participated in the MSOSW project activities as sixth graders. These students completed pretest surveys in fall of 2010 (time 1), posttest surveys in spring of 2011 (time 2) and follow up surveys in spring 2013 (time 3). The students had previously participated in a classroom-based energy monitoring science unit as part of a larger project involving 600 sixth and seventh grade students from Louisiana, Maine, Texas and Vermont. Classroom science teachers received hands-on training and program support from the research university at a summer institute prior to implementation. The teachers then guided students in the implementation of this authentic learning energy-monitoring science unit designed to connect classroom activity to real-world science. This authentic learning experience was designed to encourage meaningful learning (Jonassen, Howland, Moore, & Marra, 2003) and student use of technology (Herrington & Kervin, 2007) to enhance learning (Bransford, Brown, & Cocking, 2000) by using power monitoring devices. Students conducted monitoring activities and data collection in their homes by learning to identify and reduce unnecessary standby (*vampire*) energy consumption from devices that are using energy while they are not serving a useful function.

3.2. Instrumentation

Three different survey instruments were used to gather data for this study. All data were gathered online via a project website. The STEM Semantics Survey (Tyler-Wood, Knezek, & Christensen, 2010) was used to measure perceptions of science, mathematics, engineering, technology, and STEM careers, while the Computer Attitude Questionnaire (CAQ) (Knezek & Christensen, 1998) was used to measure self-perceived motivation, creative tendencies, and attitudes toward school. The Career Interest Questionnaire (CIQ) (Bowdich, 2009) was used to examine student attitudes toward a career as a scientist.

The STEM Semantic Survey is a semantic differential instrument designed to assess perceptions of STEM disciplines. This instrument consists of 25 items, divided into five sub-scales: Science, Mathematics, Engineering, Technology and STEM as a Career. The items for each of the five scales are semantic adjective pairs such as boring/interesting or exciting/unexciting. Previous studies using this instrument ($n = 174$) revealed internal consistency reliabilities on perceptions of science, mathematics, engineering, technology, and STEM as a career ranged from $\alpha = .84$ to $\alpha = .93$ (Tyler-Wood, Knezek, & Christensen, 2010).

Learner disposition measurement scales from the Computer Attitude Questionnaire (Self concept, Creative Tendencies, and Attitudes toward School) were also utilized in this study (Knezek, Christensen, Miyashita, & Ropp, 2000). These scales are comprised of Likert-type question items with response ratings ranging from strongly disagree (1) to strongly agree (5). The reliabilities of these scales ranged from $\alpha = .72$ to $\alpha = .88$ in a prior study (Knezek & Christensen, 2000).

The Career Interest Questionnaire is a Likert-type (1 = strongly disagree to 5 = strongly agree) instrument composed of 12 items in three sections that can each form a measurement scale. Both the three parts as well as the 12-item total CIQ scale were used in this study. The CIQ is adapted from an instrument developed in a project promoting STEM interest (Bowdich, 2009). Reliabilities for the CIQ total scale score based on 12 items have typically fallen in the range of $\alpha = .94$, while part a, b, and c reliabilities have typically ranged from .78 to .94 (Tyler-Wood, Knezek, & Christensen, 2010).

DeVellis (1991) has established guidelines for assessing internal consistency reliabilities of Likert-type scales that specify below .60 as unacceptable; between .60 and .65 as undesirable; between .65 and .70 as minimally acceptable; between .70 and .80 as respectable; between .80 and .90 as very good; and much above .90 as sufficiently high (excellent) to consider shortening the scale. Based on these criteria, internal consistency reliability estimates for attitudinal indices gathered in this study lie in the range of respectable to excellent.

3.3. Research design

The research design for this study is an empirical, longitudinal design involving administration of the same survey instruments at three time periods. The design involves a convenience sample of one school site. However, the design can also be considered a post hoc analysis of one of many sites that were involved in the original MSOSW schools as a treatment group. The reason this group was selected was they were still intact as a group two years later whereas for many of the other schools, the students would have matriculated into another school. The authors completed a longitudinal analysis of a structural model using scaling methods (Dunn-Rankin, Knezek, Wallace, & Zhang, 2004) to analyze persistence of constructs over time. From a mathematical perspective, this research design focuses on the relationships among the columns (psychological objects) in a data matrix, rather than focusing on subjects represented by the rows. Thus the research design is more closely related to the types of analyses completed in structural equation modeling than it is to traditional experimental designs such as those described in Campbell and Stanley (1963).

3.4. Research questions

This research was guided by the following questions:

1. What changes in cognitive constructs occur in students' attitudes toward STEM during hands-on energy monitoring activities?
2. Do these constructs persist over time?
3. Are there gender differences in the constructs and component attitudes before activities, or in the form of their changes over time?

4. Findings

4.1. Descriptive findings

Descriptive data for dispositions with significant changes are supplied in Table 1 for all three administrations of the surveys. As shown in Table 1, this group of students generally followed the trend noted in previous studies, of steady declines in learning dispositions as students progress through grade levels (and age) in school (Knezek & Christensen, 2000; Christensen & Knezek, 2001). One noteworthy exception is in Attitude Toward School that exhibited a significant increase from pretest to posttest time during the MSOSW activities of their sixth grade year, before reverting to the general trend towards decline by the eighth grade year (see Fig. 3). As shown in Table 1, dispositions for Self Concept, STEM Science, STEM Technology and Career Interest all became less positive from time 1 to time 2 while attitude toward school became more positive. Effect sizes were: Attitude Toward School, ES = .21, Self Concept, ES = -1.00, STEM Science, ES = -.85, STEM Technology, ES = -.33 and Career Interest Part1, ES = -.41. This trend for Attitude Toward School apparently overcame the tendency toward downward general decline. This is graphically displayed in Fig. 3.

Table 1
Analysis of variance for three administrations of survey instruments

		N	Mean	Std. Dev.	Sig.	ES for T1 to T2
CAQ Attitude Toward School	Time 1	63	3.06	.64		
	Time 2	53	3.18	.51		.21
	Time 3	60	2.90	.60		
	Total	176	3.04	.60	.039	
CAQ Self Concept	Time 1	63	4.83	1.05		
	Time 2	53	3.96	.63		-1.00
	Time 3	60	3.85	.66		
	Total	176	4.23	.92	.000	
STEM Science	Time 1	63	5.98	1.11		
	Time 2	53	4.92	1.37		-.85
	Time 3	59	4.98	1.52		
	Total	175	5.32	1.42	.000	
STEM Technology	Time 1	63	6.27	1.10		
	Time 2	53	5.89	1.20		-.33
	Time 3	59	5.73	1.41		
	Total	175	5.97	1.26	.048	
CIQ Part1	Time 1	63	3.21	.79		
	Time 2	53	2.85	.97		-.41
	Time 3	59	3.12	.94		
	Total	175	3.07	.90	.087	

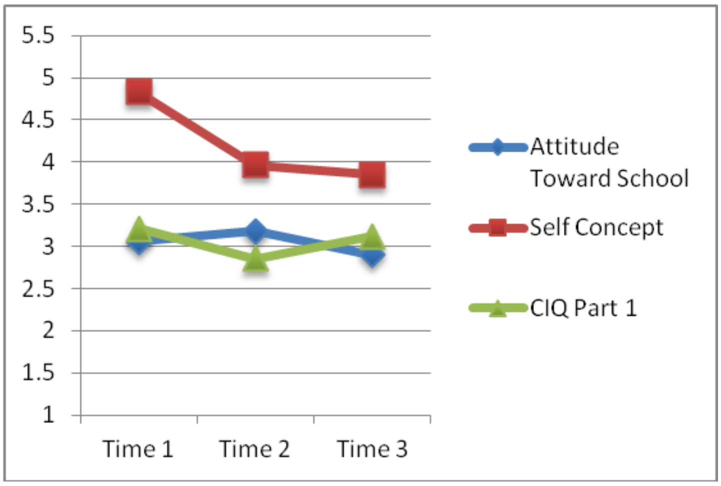

Fig. 3. Student attitude toward school, self-concept and career interest over time

4.2. Correlational relationships for time 1, 2 and 3

Trends in correlations that changed from time 1, to time 2 and time 3 were a primary impetus for examining these data from a construct-based perspective. A detailed explanation of all significant corrections can be found in Christensen, Knezek, Tyler-Wood, and Gibson (2013). Major trends are reiterated in the higher-order factor analysis section that immediately follows, so the current narrative will address only relationships between attitude toward school and science.

Morrell and Lederman (1998), in a study of student attitudes toward school and school science, reported finding a statistically significant relationship between students' dispositions toward school and science. In the current study, significant ($p < .05$) correlations were found between attitudes toward school and all five measures of science or being a scientist at time 1, while no significant ($p < .05$) correlations were found between attitudes toward school and any of the five measures of science or being a scientist at time 2. By time 3, which was two years later, all five measures of science or being a scientist were again significantly ($p < .05$) correlated with attitudes toward school. This implies that the MSOSW activities were disruptive (in a good way) compared to the normal schooling environment. Perceptions of science became connected to something broader than school, as will be explained in more detail in the following section.

4.3. Higher order factor analysis

Higher order factor analysis is a type of exploratory factor analysis in which the variables to be factor analyzed are scale scores rather than individual item responses (Cattell, 1973; Dunn-Rankin, Knezek, Wallace, & Zhang, 2004). Each scale score typically represents a defined construct (such as creative tendencies or perception of mathematics) and therefore the rationale for the process is that the researcher is searching for higher-order constructs that may explain an individual's attributes on several dispositions related at a higher level.

As shown in Table 2, at the time of the pretest when the students were beginning the sixth grade, the three parts of the CIQ were aligned in higher-order factor 1 together while semantic perception of engineering, semantic perception of STEM as a career and semantic perception of science were together in higher-order factor 2. Higher-order factor 3 contained creative tendencies and semantic perception of technology, while in Factor 4 mathematics emerged as a higher-order construct on its own. The four higher-order factors extracted explained 77.0% of the common variance in the data. Note that semantic perceptions of science and STEM as a career were not strongly aligned with the CIQ scales relevant to having a career as a scientist or doing science, and creative tendencies clustered with semantic perceptions of technology at time 1, prior to MSOSW activities.

Table 2
STEM-related constructs existing among 6th grade students as of pretest time, treatment year

	Component			
	1	2	3	4
CIQ Part 3	.847			.264
CIQ Part 1	.816	.411		.135
CIQ Part 2	.800	.406		-.142
STEM Engineering	.306	.781		
STEM Career	.437	.648		.354
STEM Science	.381	.421	.287	.382
CAQ Creative Tendencies	.115	-.363	.804	
STEM Technology		.387	.789	
STEM Mathematics				.942

Notes: Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization, Rotation converged in 4 iterations, Factor loadings < .1 suppressed

At the end of the sixth grade year, the four factors extracted explained 75.1% of the common variance in the data. These relationships are shown in Table 3. The relationships among the STEM dispositions are shown in Table 3. Perception of STEM as a career had joined perception of science and *being a scientist* (CIQ Parts 1 and 2) in higher-order factor 1, while *working with others to make the world a better place through science* (CIQ Part 3) had evolved to be on its own in higher-order factor 3. Perception of mathematics remained on its own.

Table 3
STEM-related constructs emerging among 6th graders by the end of treatment year (time 2)

	Component			
	1	2	3	4
CIQ Part 2	.852		.189	-.138
CIQ Part 1	.800	-.101	.434	-.143
STEM Career	.595	.568	-.182	
STEM Science	.564	.219	.512	.361
STEM Engineering	.227	.774		
STEM Technology	-.323	.766	.230	
CAQ Creative Tendencies	.219	.543		-.537
CIQ Part 3	.239	.133	.868	-.165
STEM Mathematics				.852

Notes: Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization, Rotation converged in 7 iterations, Factor loadings < .1 suppressed

As shown in Table 4, at the time of the follow up survey two years later, CIQ Part 1 (family and environmental support for career as scientist) and Part 2 (interest in college courses in science) remained clustered together in higher-order factor 1 with semantic perception of STEM as a career and semantic perception of science, while semantic perception of engineering and semantic perception of technology remained clustered in Factor 2. CIQ Part 3 (making the world a better place through science) also remained as its own higher-order construct in higher-order factor 3, while creative tendencies separated from its time 2 clustering with semantic perception of engineering and semantic perception of technology in higher-order factor 2 and became the opposite pole of semantic perception of mathematics in higher-order factor 4. The four higher-order factors explained 78.1% of the common variance in the data. These relationships are shown in Table 4.

Table 4
STEM-related constructs existing among 6th graders at the end of their 8th grade year

	Component			
	1	2	3	4
CIQ Part 2	.932			
CIQ Part 1	.870	.117	.301	.103
STEM Career	.674	.528	-.169	
STEM Science	.571	.488	.321	.304
STEM Technology		.849	.313	
STEM Engineering	.366	.756		
CIQ Part 3	.157	.152	.928	
CAQ Creative Tendencies		.230		.824
STEM Mathematics		.439	-.145	-.607

Note: Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization, Rotation converged in 7 iterations, Factor loadings < .1 suppressed

4.4. Evolution of constructs over time based on higher order factor analysis

Several changes in the conceptual frameworks of the students involved in this project can be identified as still persisting at the time of the two-year follow-up study. These were identified through higher-order factor analysis even as the results of ANOVAs comparing increases or decreases at time 1 versus time 2 and time 3 are inconclusive at best. The major trends can be summarized as:

1. Desire to be a scientist (CIQ Parts 1, 2, 3) formed its own higher order factor prior to initiation of MSOSW activities at the beginning of the sixth grade school year. Desire to be a scientist and the semantic perception of a career in STEM became attached to semantic perception of science by the end of the sixth grade treatment year. This alignment of desire to be a scientist with semantic perception of science continued to persist two years later, when the students were at the end of their eighth grade year in school.

2. Semantic perception of science was clustered together with semantic perception of engineering (in higher order factor 2) at the beginning of the sixth grade year for these students. By the end of the sixth grade treatment year semantic perception of science had moved to be clustered with desire to be a scientist (CIQ Parts 1 and 2), while semantic perception of engineering, technology, and creative tendencies clustered together to form higher-order factor 3. Two years later, at the end of the eighth grade year, semantic perception of STEM as a career remained aligned with semantic perception of science and desire to be a scientist.

3. Semantic perception of mathematics, at the time of the pretest and posttest of the sixth grade year, was its own higher-order factor 4. By the end of the eighth grade year, semantic perception of mathematics was joined by creative tendencies but as a polar opposite, meaning those who had higher perceptions of their creative tendencies had lower semantic perceptions of mathematics.

4.5. Analysis based on data mining techniques

The Eureqa data mining package was used to reconfirm the major trends uncovered through higher order factor analysis. Eureqa is a software tool for detecting equations and hidden mathematical relationships in data. This technique uses Symbolic Regression to unravel the intrinsic relationships in data and explain them as simple math. Eureqa can create accurate predictions that are explainable to non-mathematicians (Nutonian, 2014). Using the Eureqa data mining software the three measures were compared: Time 1, 2 and 3. Searches of 1 minute 30 seconds were performed on each data set, during which time approximately 2.2 * 10^9 evaluations were performed comparing potential symbolic expressions against a metric of minimizing the absolute error (Fig. 4). A progress over time graph for each search represented the drop in absolute error over time and helped verify that a reasonable level of stability (e.g. a horizontal line) had been reached at the time of the conclusion of the search.

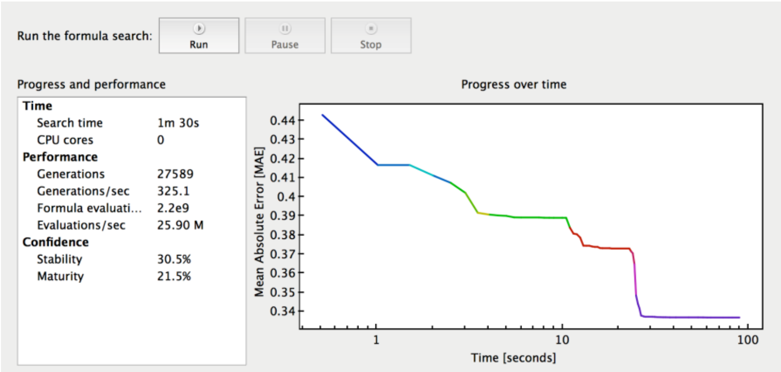

Fig. 4. Graphic representation of a search for equations given a data set documents the time of the search, the performance of the computational method, and confidence metrics

Details of the analysis have been published elsewhere (Christensen, Knezek, Tyler-Wood, & Gibson, 2013). However, major contributions of the Eureqa data mining analyses were: a) to reconfirm that semantic perception of science plays an important role in predicting reported interest in *Being a Scientist*; b) to reconfirm the important association of creative tendencies at time 1 and time 2 with interest in *Being a Scientist*, as well as to highlight questions about why creative tendencies became disconnected (not a major predictor) by the end of the eighth grade year, at time 3; and c) to note that attitudes toward school was a major predictor of interest in *Being a Scientist* at time 1, was not a major predictor at time 2, and then returned to be a major predictor at time 3. Eureqa findings collectively imply that the hands-on science activities introduced during the sixth grade may have ameliorated the well-known trends toward decline in attitudes toward school as students advance through higher grade levels.

These collective findings from data mining and higher order factor analysis were viewed by the authors as providing sufficient evidence to answer research questions 1 and 2. Regarding research question 1, the changes in cognitive constructs from pretest to posttest appear to be both: a) *constructive* with respect to project goals in that perception of STEM as a career comes to be aligned with perception of science and desire to "become a scientist"; while the changes are b) *disruptive* with respect to established norms and findings previously reported in the literature (Knezek & Christensen, 2000; Morrell & Lederman, 1998). With regard to research question 2, a major desired project outcome, which was development of a robust conception of STEM as a career, appears to persist over time, but some desirable dispositions appear to regress over a two-year time period, in the absence of continued exposure to "project" activities.

4.6. Gender differences

Gender differences for the key measures exhibiting significant ($p < .05$) differences at time 1 are shown in Table 5. At the beginning of the sixth grade year, before taking part in MSOSW activities, girls reported significantly ($p < .05$) lower semantic perceptions of science, engineering, and STEM as a career than boys. Effect sizes for boys versus girls ranged from .46 for STEM as a career to 1.06 for perception of engineering. These lie in the range of moderate to large according to guidelines by Cohen (1988). They surpass the ES = .3 criteria at which the magnitude of a difference is normally considered educationally meaningful (Bialo & Sivin-Kachala, 1996).

After completion of MSOSW activities, at the end of the sixth grade year in school, a very different picture regarding gender differences emerged. Specifically, there were no significant ($p < .05$) differences between boys and girls on any of the three measures of science, engineering, and STEM as a career. In addition, effect sizes had been reduced to the point at which none of the three identified measures indicated educationally meaningful (ES > .3) differences between the semantic perceptions of science, engineering, and STEM as a career for boys and girls. As shown in Fig. 5, generally the boys became less positive in their perceptions from pretest to post test, while girls declined little or (in the case of engineering) became more positive in their perceptions from pretest time to post. This implies that MSOSW activities had an especially positive impact on girls, as was reported for the overall findings across schools by Knezek, Christensen, Tyler-Wood, and Periathiruvadi (2013).

At the time of the follow-up assessment two years later, at the end of the eighth grade year (time 3), girls had generally retained their end-of-sixth grade perceptions of science, engineering, and STEM as career (Fig. 5), but the boys had rebounded to the point where their dispositions toward science, technology and engineering were once again significantly ($p < .05$) more positive than girls in all three areas of semantic perception of science, engineering, and STEM as a career.

Table 5
Significant differences between males and females on STEM measurement indices

	Gender	n	Mean	SD	Sig	ES
STEM Science Time 1	Male	31	6.30	.95		
	Female	32	5.67	1.19		
	Total	63	5.98	1.11	.024	.59
STEM Engineering Time 1	Male	31	5.91	1.49		
	Female	32	4.30	1.56		
	Total	63	5.09	1.72	.000	1.06
STEM Career Time 1	Male	31	5.62	1.22		
	Female	32	4.94	1.68		
	Total	63	5.27	1.50	.069	.46
STEM Science Time 2	Male	25	5.00	1.54		
	Female	28	4.86	1.24		
	Total	53	4.92	1.37	.709	.10
STEM Engineering Time 2	Male	25	5.18	1.93		
	Female	28	4.71	1.37		
	Total	53	4.93	1.66	.303	.28
STEM Career Time 2	Male	25	4.64	1.69		
	Female	28	4.39	1.42		
	Total	53	4.51	1.54	.548	.16
STEM Science Time 3	Male	33	5.32	1.58		
	Female	26	4.54	1.33		
	Total	59	4.98	1.52	.048	.54
STEM Engineering Time 3	Male	32	5.01	.81		
	Female	26	4.10	.97		
	Total	58	4.60	.99	.000	1.02
STEMCareer5 time 3	Male	33	5.40	1.58		
	Female	27	4.55	1.16		
	Total	60	5.02	1.46	.023	.61

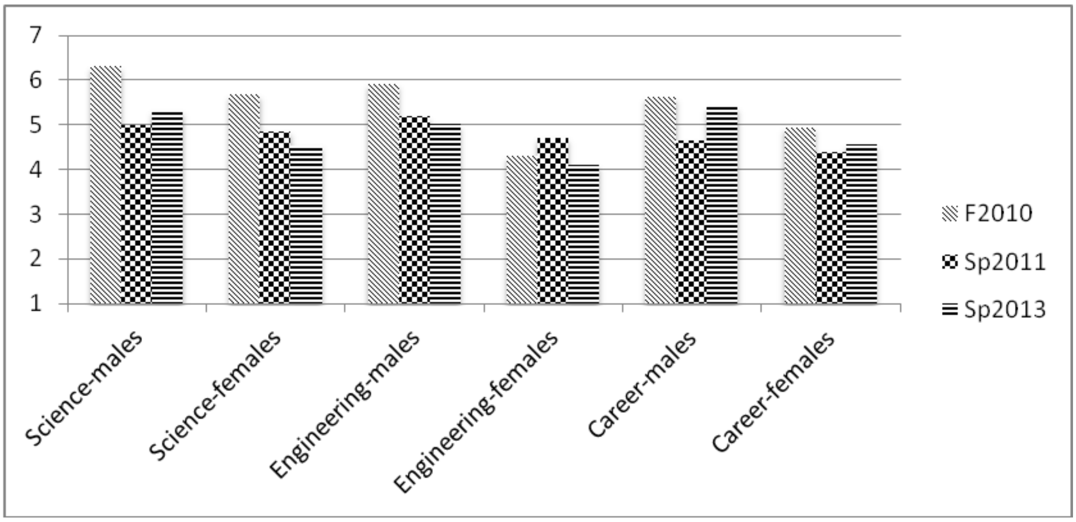

Fig. 5. Changes pre-post for these three across time 1, 2, 3

Higher-order factor scores were produced in order to assess whether gender differences existed in the higher-order constructs identified in Tables 2-4. This is a theoretical score produced for each student, reflecting the value each student would have reported if we could ask all students to respond with their ratings on the higher-order construct without any error. After the factor scores were produced for each of the four higher order factors, an independent samples *t*-test was run for males versus females on each of the higher-order factors. Findings were that at time 1 (pretest) males were significantly ($p < .05$) higher on higher-order factor 2 which included STEM engineering, STEM career and STEM science. Males and females were not significantly different on the other higher-order factors at time 1. At time 2, there were no significant ($p < .05$) differences on any of the higher-order factors. This is consistent with findings that there were no significant differences for gender at posttest time on individual disposition measures. At time 3, males were again significantly higher than females on the higher-order factor 2, which included only STEM Technology and STEM Engineering. Semantic perception of STEM as a career moved from higher-order factor 2 at time 1, to higher-order factor 1 at time 2, and persisted in alignment with the CIQ Parts 1 and 2 in higher-order factor 1 at time 3. This indicates that perception of STEM as a career did not revert to a male preference disposition at the time of the two-year follow up.

Other interesting trends emerged as a result of analysis of gender differences among the higher-order constructs. At time 3 (8^{th} grade follow up), CIQ Part 3 (having a career that makes a difference in the world) emerged as a higher-order construct independent of the other STEM dispositions. Although there were no significant ($p < .05$) male versus female differences, females tended to report more positive dispositions on this construct. The effect size (Cohen's *d*) for females versus males was .35, which would be considered educationally meaningful according to guidelines provided by Bialo and Sivin-Kachala (1996). This finding corresponds to studies in the literature indicating that that females tend to rate "making a difference in the world" high on their list priorities for a career (Modi, Schoenberg, & Salmond, 2012).

Changes in gender differences for higher-order factor 2 were found over time, from pretest to post test and in the follow up two years later. At time 1, higher-order factor 2 (which included STEM Engineering, STEM Career and STEM science) was significantly higher for males (p <.0005) than females. Cohen's d for males versus females was .99, which would be considered large according to guidelines provided by Cohen (1988) of small = .2, moderate = .5 and large = .8. At time 2, higher order factor 2 (which included STEM Engineering, STEM Technology and Creative Tendencies) was not significantly different between males and females. The effect size was .28. However, at time 3 higher-order factor 2 (which included STEM Technology and STEM Engineering) returned to a higher-order factor strongly preferred by males. Cohen's d for males versus females was ES = .86, which would be considered large according to guidelines provided by Cohen (1988). This implies that the MSOSW STEM learning experience ameliorated gender differences in higher-order cognitive constructs, but one of the four reverted to having a strong preference among males by the end of the eighth grade year. There may be a need for ongoing STEM engagement activities, especially for girls.

After considering these collective findings regarding gender, the authors concluded that the answer to research question 3 is yes, there are some gender differences in the higher order constructs identified in this paper, and there are several gender differences in the component dispositions before MSOSW activities began as well as how they change over time.

5. Discussion

In this study, a combination of techniques including analysis of correlation coefficients, higher-order factor analysis and data mining were used to confirm the persistence of desirable cognitive constructs over time. This is somewhat of a paradigm shift in assessment, from measuring traditional pre-post changes in individual indices, to identifying whether underlying constructs have persisted over time. This more holistic assessment of cognitive structures is assumed to be important for sustaining pursuit of STEM careers.

This research paradigm has obvious limitations in that that all data analyses are completed on the single treatment group, with no opportunity to examine comparison group data. Also all subjects are from a single school environment, so generalizability to all middle school students is not claimed. Nevertheless, this approach to research is closely akin to the model building and model testing paradigm commonly employed in the physical sciences and also used frequently in the form of structural equation modeling in the assessment of multiple simultaneous influences on learning.

In this study, other areas beyond traditional STEM disposition measures were identified as important indicators of interest in STEM careers. Creative Tendencies is one construct that emerged as an important indicator across multiple analysis techniques. Attitude toward school is assumed to be a driver of many other learning dispositions in the absence of overriding interventions. Findings from this study are consistent with this conjecture, as data mining confirmed the importance of attitudes toward school as a predictor of interest in being a scientist at time 1 (prior to intervention), then appears to have been less influential at time 2 (post intervention) when the strongest impact of the intervention was identified. At time 3 (two years later), attitudes toward school was once again an important predictor, implying that the impact of the intervention two years earlier had waned.

Strobel and van Barneveld (2009) completed a meta-synthesis of meta-analyses regarding problem-based learning to create a generalizable statement about Problem-Based Learning (PBL). The results of their synthesis favored traditional instruction for short-term knowledge retention. However, findings regarding longer-term retention and skill development favored PBL and also PBL was received more favorably by students as well as teachers. The findings of the current study are consistent with the Strobel and van Barneveld findings, that PBL results in long-term development and retention.

Active learning has been shown to improve long-term knowledge retention and deep understanding (Croxton & Berger, 1996; Balleck, 2006; Montero, Rising, & Perez-Sabater, 2008). As the ancient Chinese proverb says: " I hear and forget, I see and remember, I do and I understand". Bransford, Brown, and Cocking (2000) have incorporated active learning components under the characteristics of deep learning. Salient features of deep learning have been specified by Rhem (1995) and McKay and Kember (1997) as: (1) structured knowledge base focusing on concepts and the integration of knowledge in cumulative experiences, (2) an emphasis on intrinsic motivation with a sense of ownership of learning, (3) learning in an active format rather than passive and (4) interaction with others, including other students as well as teachers (Rhem, 1995, p. 4; McKay & Kember, 1997, p. 65). Based on these definitions, the MSOSW project activities serving as the intervention of the current study appear to match the criteria for fostering active, deep learning.

Two longitudinal studies conducted by Aschbacher, Ing, and Tsai (2013) surveyed 7^{th} through 12^{th} grade students and found one characteristic that set apart the high school students who persisted in Science, Engineering or Medical aspirations, compared to those who dropped out of the pipeline, was the opportunity to experience compelling, authentic STEM experiences *outside* of school. They concluded that more students might be interested in learning science if learning opportunities were more personally relevant and provided more space to explore and develop who they might want to be (Aschbacher, Ing, & Tsai, 2013). Findings by Aschbacher, Ing, and Tsai (2013) closely align with those reported in this paper and others, for MSOSW.

In a study surveying 852 girls ages 14-17 (Modi, Schoenberg, & Salmond, 2012), analyses were based on dividing girls who said they were highly interested in STEM and those who were not interested in STEM. One of the many differences reported was that STEM girls more strongly preferred learning via hands-on activities (83% of STEM interested girls versus 56% of non-STEM interested girls). The girls who were interested in STEM also reported preferring learning how things work over the girls who were not interested in STEM (87% vs. 65% for non-STEM girls). Apparently there are large differences in levels of preference for STEM within as well as between genders. Different preferences also appear to align with alternative curricular approaches. Future research using MSOSW data is planned for this area.

6. Conclusion

Many researchers have assumed that STEM dispositions represent a psychological trait (permanent belief) rather than a state that results from environmental conditions immediately at hand. One implication of the results of this study is that STEM dispositions are somewhere in between a permanent trait and a temporary state. Dispositions can be changed through meaningful activities but also tend to persist beyond the timeframe in which the intervention caused the change. Tyler-Wood, Ellison, Lim, and Periathiruvadi (2011) have demonstrated that positive dispositions fostered through hands-on science activities can still persist nine years beyond the intervention, spanning the critical timeframe in maintaining STEM career interest from fourth grade to freshman year in college. This type of learning would appear to fall in the realm of what scholars such as Rillero and Padgett (2012) have characterized as deep learning. According to Bransford, Brown, and Cocking (2000), "Deep learning leads to a genuine understanding that promotes long-term retention of the learned material."

The longitudinal persistence of higher order constructs identified in this paper is consistent with the Cognitive Reconstruction of Knowledge Model (CRKM) developed by Dole and Sinatra (1998), that incorporates cognitive psychological perspectives, science education research and social psychology in explaining how cognitive constructs change with learning. The model explains why students often return to previously held conceptions over time with the reason being focused on the level of cognition used for learning the concept. Dole and Sinatra (1998) postulated that the more engaging, deeper learning level for which a student learns, the more likely the cognitive construct will remain over time. This implies that success in the quest for determinants of STEM career interest may lie in identifying, establishing and maintaining higher order constructs that serve as long term attractors toward STEM careers.

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