PERSISTENCE OF COGNITIVE CONSTRUCTS FOSTERED BY HANDS-ON SCIENCE ACTIVITIES IN MIDDLE SCHOOL STUDENTS

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ABSTRACT

The purpose of this paper is to determine whether the changes that were found to occur pre- to post intervention in students' cognitive structures (Mills, 2013; Knezek, Christensen, Tyler-Wood, & Periathiruvadi, 2013) continued to persist two years later. Major findings were: a) semantic perception of science and STEM as a career became more aligned with interest in being a scientist, from pretest to post test time during the treatment year and continued to be aligned two years later; b) semantic perception of engineering moved from alignment with science and STEM as a career at time 1, to alignment with semantic perception of technology and creative tendencies after the treatment year, at time 2, and remained aligned with technology two years later, at time 3; and c) semantic perception of mathematics was separated from the other constructs during the pre-post treatment year and remained largely separated two years later. Data mining techniques were also used to explore changes in relationships among these and other constructs over time.

KEYWORDS

Cognitive constructs, data mining, middle school students, STEM education

1. INTRODUCTION

Middle school students were the target of this hands-on energy monitoring project. The Middle Schoolers Out to Save the World (MSOSW) project was funded from the Innovative Technology Experiences for Students and Teachers (ITEST) program of the National Science Foundation (NSF). The main goal of the MSOSW project has been to interest and prepare middle school students to participate in the science, technology, engineering and mathematics (STEM) workforce of the future.

While there were 15 classrooms in eight schools participating in the MSOSW project, the researchers were able to gather longitudinal data two years after the treatment for one school (with three classrooms). These students were surveyed three times, once prior to the treatment (pretest) in the fall of their sixth grade year, once following the treatment (post test) in the spring of their sixth grade year and again two years later in the spring of their 8th grade year.

2. RESEARCH STUDY

2.1 Instrumentation

Three different survey instruments were used to gather project data. The data were gathered online via the project website. The STEM Semantics Survey (Tyler-Wood, Knezek, & Christensen, 2000) 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 in science.

The STEM Semantic Survey is a semantic differential instrument designed to assess elementary through secondary students' as well as pre-service and in-service teachers' perceptions of STEM disciplines.

This instrument consists of 25 items, divided into 5 sub-scales: Science, Mathematics, Engineering 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, math, engineering, technology, and STEM as a career ranged from α = .84 to α = .93 (Tyler-Wood, Knezek, & Christensen, 2010).

Learner disposition measurement scales from the Computer Attitude Questionnaire (Self concept, Creative Tendencies, and Attitudes toward School are 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 α = .72 to α = .88 in a prior study (Knezek & Christensen, 2000).

The CIQ 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 3 parts as well as the 12-item total CIQ scale was used in this study. The CIQ is adapted from an instrument developed 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).

2.2 Methods

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).

2.3 Findings

2.3.1 Descriptive Findings

Descriptive data of the significant changes in dispositions 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 in 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 post test time during the MSOSW activities of their sixth grade year, before reverting to the general trend towards decline by the eighth grade year.

Table 1. Analysis of Variance for Three Administrations of Survey Instruments

		N	Mean	Std. Dev.	Sig.
CAQ Attitude Toward School	Time 1	63	3.06	.64	
	Time 2	53	3.18	.51	
	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	
	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	
	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	
	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	
	Time 3	59	3.12	.94	
	Total	175	3.07	.90	.087

2.3.2 Gender Differences

Gender differences for the key measures exhibiting significant ($p < .05$) differences at time 1 are shown in Table 2. As shown in Table 2, 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 ($p < .05$) significant 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 Figure 1, generally the boys declined a large amount from pretest to posttest, while girls declined little or (in the case of engineering) became more positive in their perceptions from pretest time to post. This implies that the 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 (Figure 1), 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 2. 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

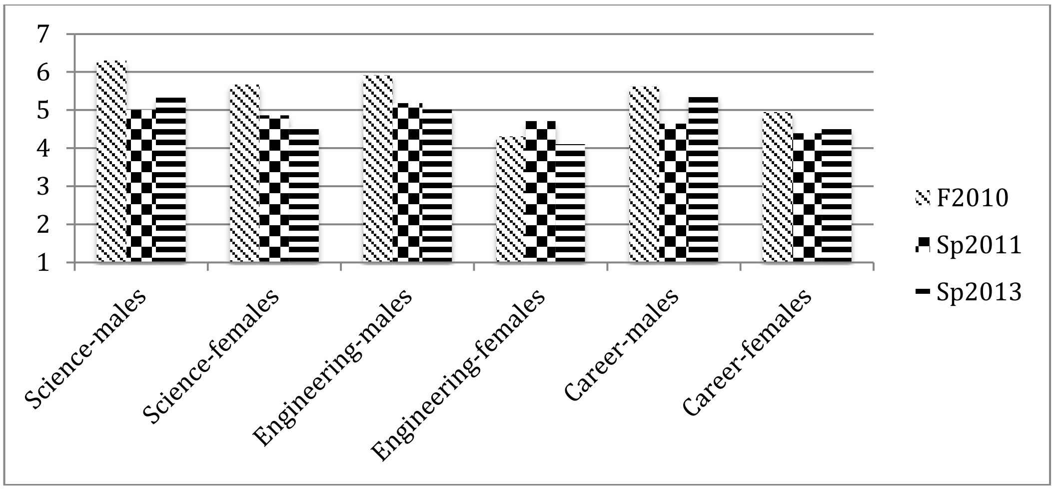

Figure 1. Changes Pre-Post for these Three Across Time 1, 2, 3.

2.3.3 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. As shown in Table 3, semantic perception of technology was the only STEM measure strongly associated with other gathered indicators at the time of the pretest, time 1. Especially notable is the positive association between STEM technology measures and creative tendencies ($r = .303$, $p < .016$). By the end of the sixth grade treatment year, significant positive correlations existed between creative tendencies and semantic perception of engineering ($r = .377$, $p < .005$) semantic perception of technology ($r = .275$, $p < .047$), CIQ Part 1 ($r = .275$, $p < .047$), CIQ Part 2 ($r = .327$, .017), CIQ Part 3 ($r = .285$, $p = .040$), and the CIQ total scale score ($r = .346$, $p < .011$). Associations had developed over the course of the year of MSOSW activities between creative tendencies and numerous measures of interest in "doing science" or "being a scientist" as a career.

Two years later, at time 3, creative tendencies had retained its significant ($p < .05$) associations with CIQ Part 1 (family and environmental influence on STEM career) ($r = .263$, $p < .044$) and on science in the form of semantic perception of science ($r = .310$, $p < .017$). In addition, computer enjoyment had become aligned with semantic perception of STEM as a career ($r = .331$, $p < .01$). These patterns indicate that the cognitive perceptions of the MSOSW participants underwent an extensive change from the beginning to the end of the MSOSW treatment activities school year. In addition, evidence shows that some of these were still retained two years later.

Systematic examination of changes in these inter-correlations led to exploration of the emergence and retention of these constructs through higher-order factor analysis and data mining techniques.

2.3.4 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 (Dunn-Rankin, Knezek, Wallace, & Zhang, 2004).

Each scale score typically itself represents a defined construct (such as creative tendencies or perception of mathematics) and therefore the rationale for the process is searching for higher-order constructs that may explain an individual's attributes on several constructs related at a higher level.

As shown in Table 3, at the time of the pretest when the students were beginning the sixth grade, the three parts of the CIQ were aligned in Factor 1 together while semantic perception of engineering and semantic perception of STEM as a career and semantic perception of science were together in Factor 2. 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 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.

Table 3. STEM-related Constructs Existing Among 6th Grade Students as of Pretest Time of the 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

By the end of the sixth grade year, CIQ Part 1 (family and environmental support for career as scientist) and Part 2 (interest in college courses in science) clustered together in Factor 1 with semantic perception of STEM as a career and semantic perception of science. Semantic perception of engineering joined creative tendencies and semantic perception of technology in Factor 2. CIQ Part 3 (making the world a better place through science) separated out to be on its own higher order construct, and semantic perception of mathematics continued as its own higher order construct, in Factors 3 and 4. The four factors extracted explained 75.1% of the common variance in the data. These relationships are shown in Table 4.

Table 4. 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 conv in 7 iterations, Factor loadings < .1 suppressed

As shown in Table 6, at the time of the follow up survey two years later, CIQ parts 1 (family and environmental support for career as scientist) and Part 2 (interest in college courses in science) remained clustered together in 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 Factor 3, while creative tendencies separated from its time 2 clustering with semantic perception of engineering and semantic perception of technology in Factor 2 and became the opposite pole of semantic perception of mathematics in Factors 4. The four factors extracted explained 78.1% of the common variance in the data. These relationships are shown in Table 5.

Table 5. 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

2.3.5 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 can be 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 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 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 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 semantic perception of STEM career.

3. Semantic perception of mathematics, at the time of the pretest and posttest of the sixth grade year, was its own 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 creative tendencies had lower semantic perceptions of mathematics.

2.3.6 Analysis Based on Data Mining Techniques

Using the Eureqa data mining software developed at Cornell University, three measures were compared: Time 1, 2 and 3 which represent a pre-assessment, a one year post and a two-year post. Searches of 1 min 30 sec 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 (Figure 2). 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.

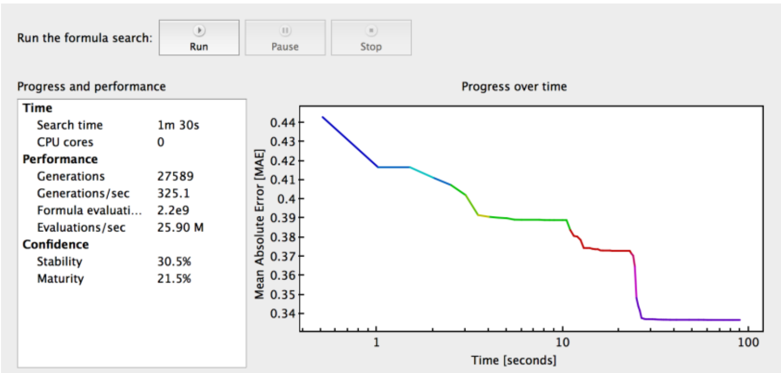

Figure 2. Graphic representation of a search for equations given a data set documents the time of the search, the performance of the computational method, and confidence metrics.

At the conclusion of each search, a decision is made concerning which equation to select to represent the best trade-off of complexity versus error with an acceptable correlation coefficient. A number of comparisons aid in the decision, for example, the gain in correlation coefficient per unit of complexity, the change in number of coefficients, and the use of variables within the candidate expressions. In general, a solution is selected that minimizes both error and complexity and which has an interpretable mathematical structure. The analysis then proceeds to find and interpret changes among the selected equations that may have statistical support from regression analysis, that may have external support from previous research, that may help further explain or validate previous results, and that may suggest additional analyses.

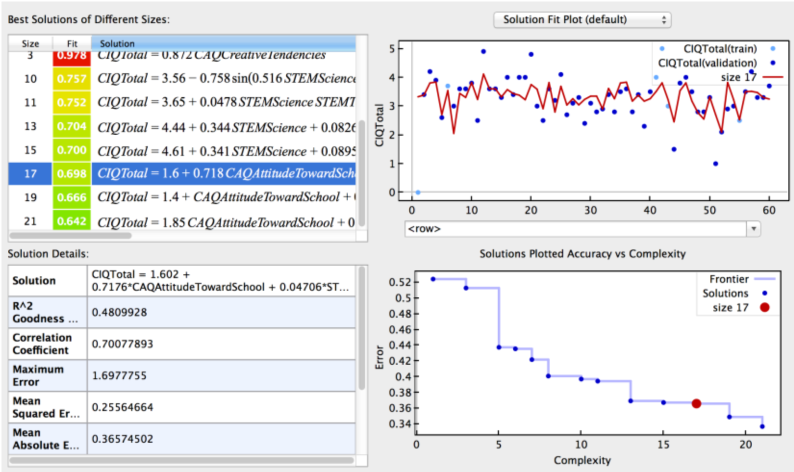

Figure 3. Equation options at the conclusion of a search showing the position (red dot in the lower right panel of the graphic) of the selection along the Pareto curve of complexity versus accuracy. Full solution details are reported in the narrative.

Table 6. Results of Search for Best Predictors of Science Career Interest Using Eureqa Data Mining Software

CIQTotal = f(CAQCreativeTendencies, CAQAttitudeTowardSchool, CAQSelfConcept, STEMScience, STEMMathematics, STEMEngineering, STEMTechnology)			
	Time 1	Time 2	Time 3
R^2 Goodness of Fit	0.52122356	0.52367202	0.58247764
Correlation Coefficient	0.72217347	0.72538579	0.76433976
Complexity	19	21	21
Time 1 Solution	CIQTotal = CAQAttitudeTowardSchool + 0.08586*CAQCreativeTendencies * STEMMathematics + 0.02497*STEMScience*STEMEngineering – 0.1384*CAQAttitudeTowardSchool * STEMMathematics		
Time 2 Solution	CIQTotal = 3.836*CreativeTendencies + 0.1653*CAQCreativeTendencies*STEMScience – 4.253 – 0.3318*STEMScience – 0.5892*CAQCreativeTendencies^2		
Times 3 Solution	CIQTotal = 1.789*CAQAttitudeTowardSchool + 0.3188*STEMScience + 0.06987*STEMTechnology^2 – 1.364 - 0.277*CAQAttitudeTowardSchool*STEMTechnology		

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*, 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 attitude 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 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. Further research is needed in this area.

3. CONCLUSION

Semantic perception of Science and of STEM as a Career became more closely aligned with *Doing Science* and *Being a Scientist* over the course of the MSOSW grant activity year. This alignment remained in place two years later. Two major outcomes of the MSOSW project were related to the current study.

First, students emerge from project activities with increased aspirations for STEM-related careers with gains in students' understanding of what scientists do, and with gains in belief that scientists can work on things that help the world. Second, female students gained more than males in their perceptions of science, engineering, mathematics and technology (Knezek, Christensen, Tyler-Wood & Periathiruvadi, 2013). The current findings provide further evidence that the positive impact of MSOSW persists in student participants for several years beyond the time frame of the project. This finding is consistent with a nine-year follow-up study of BUGS girls (Tyler-Wood et al, 2011) that used the same instruments employed in the current study to demonstrate that participants' higher STEM dispositions (vs. childhood comparison group) persisted from elementary school into university studies.

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