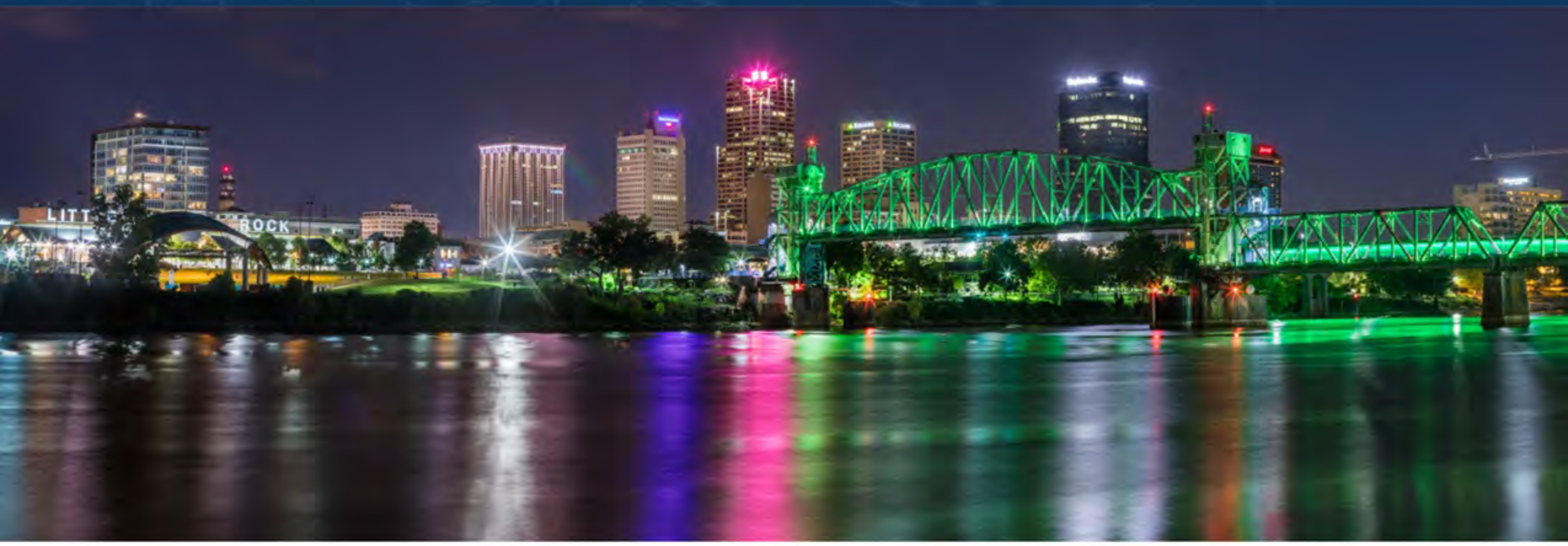
School Science and
Mathematics Association
Founded in 1901



SSMA 2018

Proceedings - Volume 5

117th Annual Convention

October 18 - 20, 2018

Jonathan Thomas
Margaret J. Mohr-Schroeder
Editors

PROCEEDINGS OF THE 117TH ANNUAL CONVENTION OF THE SCHOOL SCIENCE AND MATHEMATICS ASSOCIATION

October 18 – 20, 2018
Little Rock, Arkansas USA

Editors: Jonathan N. Thomas & Margaret J. Mohr-Schroeder

Cite Proceedings Volume as:

Thomas, J. N., & Mohr-Schroeder, M. J. (Eds.). (2018). *Proceedings of the 117th annual convention of the School Science and Mathematics Association* (Vol. 4). Little Rock, AR: SSMA.

Cite Proceedings Chapter as:

Author. (2018). Title of chapter. In J. N. Thomas & M. J. Mohr-Schroeder (Eds.), *Proceedings of the 117th annual convention of the School Science and Mathematics Association* (Vol. 4). Little Rock, AR: SSMA.

Website: www.ssma.org

The proceedings are also available via http://www.ssma.org/convention-proceedings

ISBN: 978-1-5323-8632-9

SSMA 2018 ANNUAL CONVENTION: LITTLE ROCK, ARKANSAS

2018 Program Chairs and Local Arrangements
Texas A&M University Commerce Department of Curriculum & Instruction
Gil Naizer, Becky Sinclair, Amy Corp

Convention Chairs
Melanie Shores, University of Alabama Birmingham
Tommy Smith, University of Alabama Birmingham

SSMA Leadership

President, 2016-2018
Stacy Reeder, University of Oklahoma

President-Elect, 2017-2018
Suzanne Nesmith, Baylor University

Directors-at-Large, 2015-2018
Ken Miller, Montana State University Billings
Margaret Mohr-Schroeder, University of Kentucky

Directors-at-Large, 2016-2019
Toni Ivey, Oklahoma State University
Christa Jackson, Iowa State University

Directors-at-Large, 2017-2020
Megan Che, Clemson University
Andrea Milner, Adrian College

Co-Executive Directors, 2014-2019
Melanie Shores, University of Alabama Birmingham
Tommy Smith, University of Alabama Birmingham

Journal Editor and Office, 2011-2021
Carla Johnson, Purdue University
Shelly Harkness, University of Cincinnati

Newsletter Editor, 2013-2016
Georgia Cobbs, University of Montana

Proceedings Editors
Jonathan Thomas, University of Kentucky
Margaret Mohr-Schroeder, University of Kentucky

Special thanks to
The 2017-18 Publications Committee for reviewing and providing valuable feedback on the submitted manuscripts.

School Science and Mathematics Association Founded in 1901

The School Science and Mathematics Association [SSMA] is an inclusive professional community of researchers and teachers who promote research, scholarship, and practice that improves school science and mathematics and advances the integration of science and mathematics.

SSMA began in 1901 but has undergone several name changes over the years. The Association, which began in Chicago, was first named the Central Association of Physics Teachers with C. H. Smith named as President. In 1902, the Association became the Central Association of Science and Mathematics Teachers (CASMT) and C. H. Smith continued as President. July 18, 1928 marked the formal incorporation of CASMT in the State of Illinois. On December 8, 1970, the Association changed its name to School Science and Mathematics Association. Now the organizational name aligned with the title of the journal and embraced the national and international status the organization had managed for many years. Throughout its entire history, the Association has served as a sounding board and enabler for numerous related organizations (e.g., Pennsylvania Science Teachers Association and the National Council of Teachers of Mathematics).

SSMA focuses on promoting research-based innovations related to K-16 teacher preparation and continued professional enhancement in science and mathematics. Target audiences include higher education faculty members, K-16 school leaders and K-16 classroom teachers.

Four goals define the activities and products of the School Science and Mathematics Association:

- Building and sustaining a community of teachers, researchers, scientists, and mathematicians
- Advancing knowledge through research in science and mathematics education and their integration
- Informing practice through the dissemination of scholarly works in and across science and mathematics

  Influencing policy in science and mathematics education at local, state, and national level

PREFACE

These proceedings are a written record of some of the research and instructional innovations presented at the 117th Annual Meeting of the School Science and Mathematics Association held in Little Rock, Arkansas, October 18 – 20, 2018. The blinded, peer reviewed proceedings includes 7 papers regarding instructional innovations and research. The acceptance rate for the proceedings was 88%. We are pleased to present these Proceedings as an important resource for the mathematics, science, and STEM education community.

Jonathan N. Thomas
Margaret J. Mohr-Schroeder
Co-Editor

TABLE OF CONTENTS
VOLUME 5

THE RELATIONSHIP OF MATHEMATICS ENJOYMENT AND CONFIDENCE TO INTEREST IN A STEM CAREER: THE IMPORTANCE OF THE "M" IN STEM

Rhonda Christensen
Rhonda.christensen@gmail.com
Gerald Knezek
gknezek@gmail.com
Institute for the Integration of Technology into Teaching and Learning
University of North Texas

Because mathematics functions as a gatekeeper content field for many science, technology and engineering career pursuits, it is critical that not only cognitive skill, but also affective attributes associated with mathematics are addressed. Negative mathematics feelings often begin at an early age and influence decisions students make in selecting upper level math and science courses. This paper presents a measure of mathematics enjoyment and confidence in school math and shows the relationship that these factors may have to interest in pursuing a STEM career. Gender differences in perceptions of mathematics are also addressed.

Introduction

Despite the United States' investment in science, technology, engineering and mathematics (STEM) education, there continues to be a growing shortage of STEM workers to fill the ever-growing number of job positions. The number of STEM positions in the US is expected to grow to 8.65 million by 2018 (Munce & Fraser, 2012).

Mathematics functions as a gatekeeper for many of the STEM content areas and students often report more negative attitudes toward mathematics, especially compared to the other STEM areas. Advanced mathematics courses are part of the degree plan for most engineering, computer science and science degrees. Many of the decisions to take advanced mathematics courses are decided by the time students reach high school. Student interest and attitudes regarding a STEM career are formed during their primary and middle school years (Meece, Wigfield, & Eccles, 1990). Math anxiety is often particularly high and the impact of that anxiety is significant in the decision making process of taking courses as well as pursuing degrees that include advanced mathematics courses. Researchers have demonstrated that math anxiety leads to avoidance behaviors that drive decisions to avoid advanced mathematics and science courses (Kier, Blanchard, Osborne, & Albert, 2014).

Thomas, J. N., & Mohr-Schroeder, M. J. (Eds.). (2018). *Proceedings of the 117th annual convention of the School Science and Mathematics Association* (Vol. 5). Little Rock, AR: SSMA.

Objectives

The purpose of this study was to explore the relationship between intentions to pursue a STEM career and mathematics measures including mathematics enjoyment and mathematics confidence. The research questions addressed in this paper are:

1. To what extent does math enjoyment influence an intention to pursue a career in STEM?
2. To what extent does math confidence influence an intention to pursue a career in STEM?
3. What gender differences exist regarding mathematics enjoyment and confidence in the intention to pursue a STEM career?

Related Literature

Attitudes toward mathematics have been studied for decades and have shown a strong relationship between attitudes (which include self-confidence, enjoyment, motivation) and mathematics achievement (Haciomeroglu, 2017). Neale (1969) referred to attitude towards mathematics as "liking or disliking of mathematics, a tendency to engage in or avoid mathematical activities, a belief that one is good or bad at mathematics, and a belief that mathematics is useful or useless" (p. 632). Positive attitudes improve student's willingness to learn, while their negative attitudes may cause resistance (Duda & Garrett, 2008).

Math anxiety is often developed in adolescence and stays with people most of their lives (Beilock, Gunderson, Ramirez, & Levine, 2010). Math anxiety relates negatively to math achievement (Meece, Wigfield & Eccles, 1990) and leads to avoidance behaviors that are a barrier to enrollment in advanced mathematics and science courses (Keir, Blanchard, Obsorne & Albert, 2014). Avoidance of mathematics courses restricts access to a career path in STEM fields. Student interest and confidence in mathematics are contributing factors in the participation of STEM activities (Jennings, McIntyre, & Butler, 2015). In a study on the impact of math anxiety and the pursuit of a STEM career, Smith (2016) found that high math anxiety predicted low interest in STEM fields. In particular, the impact was stronger on middle school females as they exhibited higher levels of math anxiety than their male peers (Smith, 2016). Attitudes toward mathematics are related to the level of confidence and interest in an ability to be successful.

Self-efficacy (one's beliefs in his/her capabilities) influences academic motivation, learning and achievement (Pajares, 1996). According to social cognitive career theory (Lent, Brown, & Hackett, 2002) interest in an area drives the choices people make and the actions they take in pursuing a career. Students will engage in activities or classes in which they feel confident and competent in achieving while avoiding those in which they feel anxious or unsure of success (Pietsch, Walker, & Chapman, 2003).

While there is a concern for both males and females entering STEM careers, a study of 6,000 students completed in 2012 indicated that by the end of high school the odds of being interested in a STEM career are 2.9 times higher for males than for females (Sadler, Sonnert, Hazari & Tai, 2012). Research shows that girls start losing interest in mathematics and science during middle school (U.S. Dept. of Ed., 2006) and prior research has shown that girls have lower interest in mathematics (Christensen, Knezek, & Tyler-Wood, 2014; Meelissen & Luyten, 2008; U.S. Dept. of Ed., 2006). Girls tend to prefer to learn in a more social context and need to see connections between school assignments and the real world (Christensen et al., 2014; Heemskerk, Brink, Volman & ten Dam, 2005).

Methods

Participants

Data were gathered from middle school students participating in hands-on, project-based learning activities that involved studying energy and monitoring stand-by power in their homes. This data set includes end-of-year data from 915 students representing 19 different classrooms in 13 different schools from six states in the U.S.

Instrumentation

The Mathematics in School survey contains nine items adapted from the Trends in International Mathematics and Science Study (TIMSS) 2007 Student Questionnaire. The survey was created to include Likert-type items asking participants to select the level of agreement with each of the nine statements. The item choices ranged from 1 (Strongly Disagree) to 5 (Strongly Agree). Internal consistency reliability estimates for F1 Mathematics Enjoyment = .89 and for F2 Mathematics Confidence Alpha = .82. Reliability for the total 9-item scale was Alpha = .89. These fall in the range "very good" to “excellent” according to guidelines provided by DeVellis (1991).

The STEM Semantics Survey is a second measurement instrument used to gather data for the analyses in this paper. The STEM Semantics Survey (Tyler-Wood, Knezek, & Christensen, 2010) has been used in many projects across the country over the past several years. It is an instrument used to assess general perceptions of STEM disciplines and careers using Semantic Differential adjective pairs. The STEM Semantics Survey is a 25-item semantic differential instrument that contains five scales assessing perceptions of Science, Technology, Engineering, and Mathematics, as well as STEM Careers. Each of five scales consists of a target statement such as “To me, science is:”

followed by five polar adjective pairs spanning a range of seven choices. For example, "To me, science is: exciting _ _ _ _ _ _ _ unexciting." Internal consistency reliabilities for participant perceptions of science, math, engineering, technology, and STEM as a career ranged from alpha = .85 to alpha = .95 for recent subjects. These numbers are in the range of "very good" to "excellent" according to guidelines provided by DeVellis (1991).

Analysis and Results

A factor analysis (Principal Components, Varimax Rotation) revealed two distinct factors were present in the nine-item Mathematics in School Survey. As shown in Table 1, items 2, 3, 5 and 8R (R = reversed) are related to one factor while items 1, 4, 6R, 7R, and 9 are related to a different component. Reading the items by factor it appears that factor 1 items are related to mathematics enjoyment while factor 2 items are related to confidence or self-efficacy in mathematics.

Table 1.

Factor Component Matrix for the Mathematics in School Survey

Item	Component 1	Component 2
3. I enjoy learning mathematics.	.875	.272
2. I would like to do more mathematics in school.	.846	.161
5. I like mathematics.	.840	.322
8. Mathematics is boring.*	.757	.191
6. Mathematics is harder for me than for many of my classmates.*	.169	.780
7. I am just not good at mathematics.*	.328	.740
4. I learn things quickly in mathematics.	.410	.726
1. I usually do well in mathematics.	.514	.650
9. I work mathematics problems on my own.		.604

Note: Rotation converged in 3 iterations. * Items are reversed for analysis.

In order to determine relationships between the two math factors (enjoyment and confidence) and the STEM Semantic scales, a Pearson product moment correlation analysis was conducted. As shown in Table 2, there is a moderately strong relationship (Cohen, 1988) between semantic perception of a career in the STEM field (STEM Career) and Math Enjoyment ($r = .304$, $p < .0005$), and also an equally strong relationship between perception of a career in the STEM field and Math Confidence ($r = .309$, $p < .0005$). This is especially noteworthy because it implies both enjoyment of mathematics, and confidence in one's ability in mathematics, are important among those who have a higher interest in STEM as a career.

Table 2.

Relationships Between Mathematics Enjoyment and Confidence and STEM Semantics Scales

		Math Enjoy-ment	Math Confi-dence	STEM Math Scale	STEM Sci Scale	STEM Tech Scale	STEM Career Scale	STEM Eng Scale
Math Enjoyment	Pearson Correlation	1	.618**	.783**	.114**	.149**	.304**	.170**
	Sig. (2-tailed)		<.001	<.001	.001	<.001	<.001	<.001
	N	915	915	909	913	910	914	903
Math Confidence	Pearson Correlation	.618**	1	.545**	.199**	.204**	.309**	.181**
	Sig. (2-tailed)	<.001		<.001	<.001	<.001	<.001	<.001
	N	915	915	909	913	910	914	903
STEM Math Scale	Pearson Correlation	.783**	.545**	1	.183**	.167**	.332**	.229**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001	<.001	<.001
	N	909	909	909	908	905	909	898
STEM Science Scale	Pearson Correlation	.114**	.199**	.183**	1	.387**	.539**	.391**
	Sig. (2-tailed)	.001	<.001	<.001		<.001	<.001	<.001
	N	913	913	908	914	909	913	902
STEM Technology Scale	Pearson Correlation	.149**	.204**	.167**	.387**	1	.433**	.371**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001		<.001	<.001
	N	910	910	905	909	910	910	901
STEM Career Scale	Pearson Correlation	.304**	.309**	.332**	.539**	.433**	1	.479**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001		<.001
	N	914	914	909	913	910	914	903
STEM Engineering Scale	Pearson Correlation	.170**	.181**	.229**	.391**	.371**	.479**	1
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	
	N	903	903	898	902	901	903	903

Note: ** Correlation is significant at the 0.01 level (2-tailed).

A regression analysis predicting scores for the two scales derived from the TIMSS math instrument revealed that the two scales together are quite good predictors of the semantic perception of math (STEM math) from the STEM Semantics Survey. As shown in Table 3, the two scales in combination can predict 62% ($R^2 = .619$) of a student's semantic perception. This level of association would be extremely rare by chance ($p < .0005$) and the magnitude of the correlation ($r = .783$ in Table 2) is very large according to guidelines by Cohen (1988) of .1 = small, .3 = moderate, and .5 or greater = large. As shown in Table 3, the regression analysis predicting semantic perception of math (STEM Math) from the two Likert scales of math enjoyment (F1) and math confidence (F2) revealed that the enjoyment portion of the TIMSS scale items are more closely aligned with semantic perception of math than the confidence items. The standardized regression coefficient (beta) for F1 math enjoyment is $\beta = .723$ ($t = 27.6$) while it is weaker ($\beta = .10$) for F2 math confidence ($t = 3.7$). Both variables are highly significant contributors ($p < .0005$) but math enjoyment is much stronger than math confidence as a predictor of semantic perception of math. This is a form of cross-validation for the STEM Semantic Survey mathematics scale based on the TIMSS school mathematics scale, the latter of which has been validated internationally in countries such as The Netherlands (Meelissen & Luyten, 2008).

Table 3.

Predicting STEM Semantic Math Scale by Mathematics in School Factors

	B	*SE B*	β	t	Sig.
(Constant)	.452	.129		3.491	.001
Math Enjoyment	1.028	.037	.723	27.638	.000
Math Confidence	.166	.045	.096	3.679	.000

Notes. $R^2 = .619$ ($p < .001$). Dependent variable: STEMMathScale

A regression analysis predicting STEM career as a function of math enjoyment and math confidence revealed that both enjoyment and confidence in mathematics are strong predictors of interest in STEM as a career (R^2=.116, p <.001), although confidence is slightly higher ($\beta = .196$) than enjoyment (β =.183). A linear combination of these two variables together is able to explain about 12% of interest in STEM as a career (R^2=.116).

Table 4.

Predicting STEM Career Scale by Two Mathematics in School Factors (Enjoyment and Confidence)

	B	*SE B*	β	t	Sig.
(Constant)	3.147	.182		17.264	.000
Math Enjoyment	.242	.052	.183	4.626	.000
Math Confidence	.313	.063	.196	4.944	.000

Note. $R^2 = .116$ ($p < .001$). Dependent variable: STEMCareerScale

Regression analyses predicting the STEM math scale from math enjoyment and math confidence showed similar trends for males and females. However, with respect to predicting STEM career from math enjoyment and math confidence there were gender differences. As shown in Table

5, for males math confidence is a stronger predictor of STEM career (R^2 = .113, β =.250). However, as shown in Table 6, for females math enjoyment is a stronger predictor of STEM career (R^2 = .127, β = .263).

Table 5.

Predicting STEM Career Scale by Two Mathematics in School Factors (Enjoyment and Confidence) for Males

	B	*SE B*	β	t	Sig.
(Constant)	3.163	.259		12.191	.000
Math Enjoyment	.161	.074	.119	2.172	.030
Math Confidence	.405	.089	.250	4.552	.000

Note. R^2 = .113 (p < .001). Dependent variable: STEMCareerScale

Table 6.

Predicting STEM Career Scale by Two Mathematics in School Factors (Enjoyment and Confidence) for Females

	B	*SE B*	β	t	Sig.
(Constant)	3.128	.255		12.247	.000
Math Enjoyment	.339	.074	.263	4.573	.000
Math Confidence	.200	.091	.127	2.206	.028

Note. R^2 = .127 (p < .001). Dependent variable: STEMCareerScale

Conclusions and Implications

The findings from this study regarding attitudes toward mathematics by gender are consistent with those from the Netherlands (Meelissen & Luyten, 2008) and Taiwan (Louis & Mistele, 2012) that were also based on the TIMSS mathematics scale. In general, boys have a more positive attitude than girls toward mathematics at the middle school level. However, for both genders, attitudes toward mathematics are low. The current study provides additional detail that should be useful for encouraging more girls and boys to consider STEM employment that relies on mathematics as a career. In particular, for boys, feeling that they are good at math is more strongly associated with interest in pursuing STEM as a career, while for girls enjoying math is more strongly associated with interest in pursuing STEM as a career. Findings imply that parents and educators in should concentrate on conveying math attitudes and experiences that will encourage students to enjoy mathematics (which will also build confidence). This appears to be essential for combatting the current trends toward low semantic perceptions toward math across middle school students in many parts of the U.S..

References

Beilock, S.L., Gunderson, E.A., Ramirez, G., & Levine, S.C. (2010). Female teachers' math anxiety affects girls' math achievement. *Proceedings of the National Academy of Sciences*, *107*(5), 1860-1863.

Christensen, R., Knezek, G., & Tyler-Wood, T. (2014). Student perceptions of science, technology, engineering and mathematics (STEM) content and careers. *Computers in Human Behavior, 34*, 173-186. http://dx.doi.org/10.1016/j.chb.2014.01.046

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. (2nd ed.) . Hillsdale, NJ: Lawrence Erlbaum.

DeVellis, R.F. (1991). *Scale development*. Newbury Park, NJ: Sage Publications.

Duda, G., & Garrett, K. (2008). Blogging in the physics classroom: A research-based approach to shaping students' attitudes toward physics. *American Journal of Physics, 76*(11), 1054-1065.

Heemskerk, I.M.C.C., Brink, A.M., Volman, M.L.L., & ten Dam, G.T.M. (2005). Inclusiveness and ICT in education: a focus on gender, ethnicity and social class. *Journal of Computer Assisted Learning, 21*(1), 1-16.

Kier, M.W., Blanchard, M.R., Osborne, J.W., & Albert, J.L. (2014). The development of the STEM career interest survey (STEM-CIS). *Research in Science Education*, *44*(3), 461-481.

Haciomeroglu, G. (2017). Reciprocal relationships between mathematics anxiety and attitude toward mathematics in elementary students. *Acta Didactica Napocensia, 10(*3), 59-68.

Jennings, S., McIntyre, J.G., & Butler, S.E. (2015). What adolescents think about engineering: Immediate and longer lasting impressions of a video intervention. *Journal of Career Development, 42*(1), 3-18.

Lent, R.W., Brown, S.D., & Hackett, G. (2002). Social cognitive career theory. In D. Brown (Ed.) *Career choice and development* (pp. 255-311). New York,NY: John Wiley.

Meece, J.L., Wigfield, A., & Eccles, J.S. (1990). Predictors of math anxiety and its influence on young adolescents' course enrollment intentions and performance in mathematics. *Journal of educational psychology*, *82*(1), 60.

Meelissen, M. & Luyten, H. (2008). The Dutch gender gap in mathematics: Small for achievement, substantial for beliefs and attitudes. *Studies in educational evaluation, 34(*2), 82-93.

Munce, R., & Fraser, E. (2012). Where are the STEM students? What are their career interests? Where are the STEM jobs? 2012-2013. My College Options & STEM connector, Washington, DC.

Neal, D.C. (1969). The role of attitudes in learning mathematics. *The Arithmetic Teacher, 16*, 631-640.

Pajares, F. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research, 66*(4), 543-578.

Pietsch, J., Walker, R., & Chapman, E. (2003). The relationship among self-concept, self-efficacy, and performance in mathematics during secondary school. *Journal of Educational Psychology, 95*(3), 589-603.

Sadler, P.M., Sonnert, G., Hazari, Z., & Tai, R. (2012). Stability and volatility of STEM career interest in high school: A gender study. *Science Education, 96*(3), 411–427.

Smith, C.J. (2016). *The effects of math anxiety and low self-efficacy on student's attitudes and interest in STEM*. Doctoral dissertation, University of Southern California.

Tyler-Wood, T., Knezek, G., & Christensen, R. (2010). Instruments for assessing interest in STEM content and careers. *Journal of Technology and Teacher Education*, 18(2), 341–363.

United States Department of Education. (2006). *The Condition of Education*. Washington, DC: National Center for Education Statistics, U.S. Government Printing Office.

Acknowledgement

This research was supported in part by the U.S. National Science Foundation Innovative Technology Experiences for Students and Teachers (ITEST) Grant #1312168.

STUDENT-INVENTED ALGORITHMS IN PROBLEM SOLVING

Victor V. Cifarelli
vvcifare@uncc.edu

David Pugalee
David.Pugalee@uncc.edu

University of North Carolina at Charlotte

The role that algorithms should play in mathematics teaching and learning has been a contentious topic of debate in mathematics education (NCTM, 2000; Schoenfeld, 2007; Fan and Bokhov, 2014). The current paper addresses the role that student-invented algorithms play in building a conceptual foundation for formal patterns through problem solving (Cai, Moyer, and Laughlin, 1998). Since most studies of student-invented algorithms have focused on elementary and middle students' reasoning, the current paper examines examples of student-invented algorithms at the secondary and postsecondary levels.

Introduction

The role that algorithms should play in mathematics teaching and learning has been a contentious topic of debate in mathematics education (NCTM, 2000; Schoenfeld, 2007; Fan and Bokhov, 2014). For example, in summarizing the various arguments, Fan and Bokhov (2014) concluded that the current perceptions of many mathematics educators with regard to the learning and teaching of algorithms at the K-12 level are overly negative. In particular, Givvin, Jacobs, Hollingsworth and Hiebert (2009) described some mathematics lessons, which they viewed negatively, by using phrases such as "very algorithmic," "rule-orientated," and "too focused on procedures and rules, with not enough attention to mathematical concepts and reasoning" (p. 42). According to Fan and Bokhov (2014), these kinds of negative comments are indicative of a dichotomy between the learning of formal procedures and the development of conceptual understanding.

Student-invented algorithms often demonstrate sound reasoning patterns that students generate through informal strategies. This paper takes the position that while the students' initial reasoning patterns may lack efficiency and generalizability, they can nonetheless serve as a conceptual foundation for the development of more formal action patterns and algorithms. Hence, the analysis presented in this paper is consistent with Campbell, Rowan and Suarez' (1998) findings that student-invented algorithms are most useful when they are based on procedures that are mathematically sound, address issues of efficiency, and are generalizable.

Research Questions

While the relevant research contains many examples of student-invented algorithms at the elementary and middle grade levels (see for example the work of Clarke, 2005), few studies involve older students in the secondary grades and beyond. Our research questions are:

1. What are some examples of student-invented algorithms in secondary and post-secondary mathematics classes?
2. What roles do the students' invented algorithms play in their problem solving?

Theoretical Framework and Related Literature

We incorporate a constructivist view of learning (Piaget, 1970, Glasersfeld 1991, Wheatley, 2004), which views mathematics learning as a problem-based process of building up one's mathematical knowledge; and we draw from the work of Steffe (2002) in developing our theoretical interpretations. Specifically, we are interested in goal-directed action patterns of learners, and in our analyses, we look to explain how goal-directed sensorimotor actions are transformed (or *interiorized*) into mental action patterns, or operations. We believe that the learners' development of formal algorithms has its source within these mental action patterns.

Methodology

This paper presents data from a study of problem solving of older students, conducted by the first researcher in collaboration with a former doctoral student (Cifarelli and Sevim, 2015). The data provide examples of how students sometimes employ informal reasoning when they engage in problem solving. For the purpose of the current study, we focus on the gradual introduction of formalization into the solvers' actions and show how these phases of problem solving can lead solvers to develop their own algorithms.

The two examples discussed here provide an answer to the first research question. The first example reports a classroom episode of high school geometry students finding a formula for the number of diagonals in an n-sided convex polygon. This example highlights how different solution approaches by students can lead to different yet equivalent formal algorithms. The second example reports the actions of a Mathematics Education graduate student as she solves an open-ended problem. This example highlights how a student with more sophisticated mathematical knowledge than a younger student can transform an idiosyncratic solution method into a formal algorithm.
In our discussion of these examples, we identify the particular roles played by the student-invented algorithms and thus provide an answer to the second research question.

Results and Discussion

A Student-Invented Algorithm in A High School Geometry Class

The first example we present comes from a high school geometry classroom (N=25) in which the first author worked. The class had completed an introductory lesson on properties of polygons and was assigned a homework problem that required them to find a formula for the number of diagonals in an n-sided convex polygon. The rationale for assigning the problem was to provide opportunities for students to explore the problem for particular cases of n-sided polygons with the ultimate goal of having them generate the formula, $D(n) = \frac{n(n-3)}{2}$. This particular problem proved quite challenging for these geometry students even though they had completed a year of Algebra I and thus were experienced at generating patterns.

Students worked on the problem at home and came to class with their solutions. Most students had made progress on the problem, iterating the total number of diagonals for several specific cases and then trying to develop a pattern from their actions. About half of the students were able to get the formula using a strategy summarized as follows.

1. There are n vertices;
2. From each vertex you can draw $(n-3)$ diagonals;
3. So, there are $n(n-3)$ diagonals;
4. To eliminate repetitions, the total in step 3 must be divided by 2. So, the total number of diagonals is $D(n) = \frac{n(n-3)}{2}$

The teacher, Mr. Davis (pseudonym) was an experienced teacher with more than 15 years teaching experience. After acknowledging the result as a possible solution, he looked to engage other students in discussion, with particular emphasis on illuminating the individual steps students carried out. So, for example, seeing the need to account for repetitions when iterating the diagonals (step 4), Mr. Davis was able to promote discussion where all students could see and appreciate the reasoning involved and thereby convince themselves that the solution did indeed work.

The teacher then asked if anyone used a different strategy to solve the problem. One student, Jared (pseudonym) stated that he came up with a different formula for the problem. The teacher asked Jared to show his approach on the blackboard. Jared wrote the following formula on the board:

$$D(n) = (n-3) + (n-3) + (n-4) + (n-5) + ... + (n-n)$$

Jared: So, in finding the answer, you keep going until you get to the number of sides and then you stop! So for $n = 4$, you get $D(4) = (4-3) + (4-3) + (4-4) = 2$ diagonals. Therefore, for n sides, you keep going in the numbers until you get up to n, so $D(n) = (n-3) + (n-3) + (n-4) + (n-5) + ... + (n-n)$.

Jared could provide few additional details concerning how he came up with the solution other than he had checked that the formula worked for several simple cases (Table 1). (He did however admit that he got help on the problem from his slightly older cousin, Stephen!)

Table 1:
Jared's Solution Applied to Several Cases

Number of Sides	Total as Sum of Diagonals from Each Vertex
$n = 4$	$D(4) = (4-3) + (4-3) + (4-4) = 2$
$n = 5$	$D(5) = (5-3) + (5-3) + (5-4) + (5-5) = 5$
$n = 6$	$D(6) = (6-3) + 6-3) + (6-4) + (6-5) + (6-6) = 9$
$n = 7$	$D(7) = (7-3) + (7-3) + (7-4) + (7-5) + (7-6) + (7-7) = 14$

Jared's solution appeared to involve a strategy where he first counted the number of diagonals from a particular vertex and expressed the total as a function of the number of sides. However, where the more popular solution of other students treated every vertex equally in the sense that it included repetitions in the count and corrected by dividing the total by 2, Jared's approach appeared to take into account repetitions by counting only those diagonals that were distinct as he moved from vertex to vertex. For example, in considering the case of a 4-sided polygon, ABCD, he started at vertex A and found that there is exactly one diagonal from A and expressing the total as 1=4-3. Moving to Vertex B, there is exactly one diagonal (distinct from the diagonal already found from vertex A) and 1=4-3. At vertex C, he found that there were zero diagonals distinct from those already found and 0=4-4. So for n=4 in polygon ABCD, he would express the total as $D(4) = (4-3) + (4-3) + (4-4) = 2$ diagonals.

In summary, compared to the more popular solution *D(n) = n(n-3)/2,* Jared's solution was more of a 'counting up' strategy to get the number of diagonals. The teacher looked to use this different solution to orchestrate a discussion with the class. He first asked if others agreed with this solution and, if so, to comment on its usefulness as compared with the first solution. After some lively discussion, the class reached consensus that: 1. the method appears to work; and 2. the method would involve iterating lengthy sequences for polygons having a large number of sides, and so may not be as effective or efficient as the first method. The teacher proceeded to lead students in a discussion of how one might show that the two solutions were equivalent, specifically that:

$$\frac{n(n-3)}{2} = (n-3)+(n-3)+(n-4)+(n-5)+\ldots+(n-n).$$

The resulting derivation summarized as follows:

1. In the sum, $(n-3)+(n-3)+(n-4)+(n-5)+\ldots+(n-n)$, observe that there are $(n-1)$ terms of n.
2. So it can be shown that:
   $$(n-3)+(n-3)+(n-4)+(n-5)+\ldots+(n-n) = n(n-1)-3-\left(\sum_1^n i - 3\right)$$
3. Since $\sum_1^n i = n(n+1)/2$, we have that:
   $$n(n-1)-3-\left(\sum_1^n i - 3\right) = n^2 - n - 3 - n(n+1)/2 + 3$$
4. Simplifying, we have that:
   $$n^2 - n - 3 - n(n+1)/2 + 3 = \frac{2n^2 - 2n - 6 - n^2 - n + 6}{2}$$
5. And:
   $$\frac{2n^2 - 2n - 6 - n^2 - n + 6}{2} = \frac{n^2 - 3n}{2} = \frac{n(n-3)}{2}$$

A Student-invented Algorithm by a Mathematics Education Graduate Student

Sarah (pseudonym) was a student in our mathematics education doctoral program. We present episodes of her work in solving a Number Array task (Figure 1). Our purpose in discussing her actions in this paper is to illustrate how a student with more sophisticated mathematical knowledge than a younger student can transform an idiosyncratic solution method into a formal method.

After an initial exploration of the array from which she stated some basic relationships, Sarah focused on the left-to-right diagonal entries of the array (i.e., 1, 4, 9, …, 100) and developed an informal method to find the sums of the entries of each NxN block that contained these numbers (Figure 2). (As an aid to the reader, a bracket notation is used that lists the top-to-bottom rows of the block being considered. For example, the top-left 2x2 block is indicated by [1, 2 : 2, 4])

Find as many relationships as possible among the numbers

1	2	3	4	5	6	7	8	9	10
2	4	6	8	10	12	14	16	18	20
3	6	9	12	15	18	21	24	27	30
4	8	12	16	20	24	28	32	36	40
5	10	15	20	25	30	35	40	45	50
6	12	18	24	30	36	42	48	54	60
7	14	21	28	35	42	49	56	63	70
8	16	24	32	40	48	56	64	72	80
9	18	27	36	45	54	63	72	81	90
10	20	30	40	50	60	70	80	90	100

Figure 1: The Number Array task

> **Sarah**: So, for a 1x1, I get a sum of 1 *(points to the sequence of square numbers on the diagonal, Figure 2*). For a 2x2 (*points to block [1, 2 : 2, 4]*), I get a sum of 9 … but what happened to 4? It has been <u>skipped</u>! Okay, let me try this, I will write down the sequence of squares of all numbers, all in a row (*writes the following sequence of square numbers*: 1, 4, 9, 16, 25, 36, 49, 64, 81, 100, 121, 144, 169, 196, 225). So, the first number, 1, tells the sum of the very first matrix, a 1x1. And the first 2x2 has a sum of 9. So, I *skipped* over 4 to get the next sum (*crosses out the 4 in the sequence*), going from 1x1 to a 2x2, a sum of 9. The 4 gets *skipped*? Interesting!

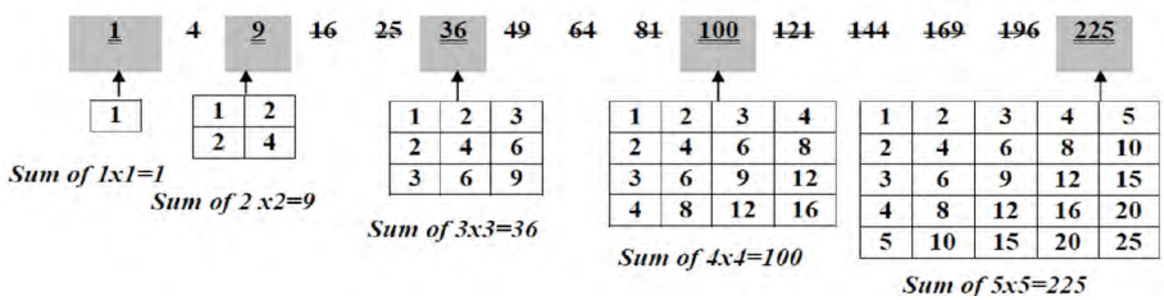


Figure 2: Sarah's informal method of 'skipping'

Sarah had posed a new problem to explore. She thinks there may be a relationship between the sequence of square numbers on the diagonal of the array and the successive sums of the entries of NxN blocks. Sarah was able to generalize her 'skip' method to generate the sequence of sums of the entries of all NxN blocks.

> **Sarah**: So, for the first 3x3 (*points to block [1, 2, 3 : 2, 4, 6 : 3, 6, 9]*), I already did this over here, so it is 36. So, in going from the 1x1 to the 2x2 to the 3x3, we go from 1, to 9, to 36 – so we skipped over the 16 and the 25, a skip of 2 in this sequence!! So, if this is true, then it looks like we will skip over the next 3 square numbers, and then

the sum for a 4x4 should be 100 (*crosses out the 49, 64, 81 in the square number sequence*). Cool! So, for a 5x5, we skip over the next 4 numbers in the sequence, (*points to the sequence* 121, 144, 169, 196) and get 225.

Sarah then looked to make sense of her informal method with some further exploration of the blocks.

Sarah: I wonder why this skipping works. Let's see it another way, for the 6x6, we add the entries in the rows to get 21+42+…+126 = 21(1+2+3+4+5+6) = 21x21 = 441. Do we get 441 by skipping the next 5 in the square sequence? (*Sarah extended her original sequence beyond 225, crossed out the corresponding 'skips,' and got a result of 441 as the next number in the sequence*). (Figure 3). But I also notice that 21 over here (*points to the factored form 21• (1+2+3+4+5+6)*) is the sum of the first 6 numbers in that first row. Yes!

1	2	3	4	5	6	21
2	4	6	8	10	12	42
3	6	9	12	15	18	63
4	8	12	16	20	24	84
5	10	15	20	25	30	105
6	12	18	24	30	36	126

Sum of rows: *21(1+2+3+4+5+6)=21(21)=441*

Skipping in the sequence: Finding the sum for the 6x6 block

225	~~256~~	~~289~~	~~324~~	~~381~~	~~400~~	441
15^2	16^2	17^2	18^2	19^2	20^2	21^2

Figure 3: Sarah's computation of sums in a 6x6 block

Sarah: So to find the sum of these NxN blocks, I bet you just need to look at the sum of 1 to N and then square that total to get the sum. Let's try an 8x8. It would be 1+2+…+8 = 36, I don't know why I am adding these individual numbers since I know the sum is (8x9)/2, and then I take 36^2? That comes out to be 1296. Does it check with my skipping over here? Let's see, I first skip 6 over 21 to get 28^2 for 7x7, and then skip 7 more to get the one for 8x8, so 7 more is 35, and the next one is 36! My algorithm works! The algorithm is efficient for large numbers beyond all these – how about a 100x100 grid! – But I thought that the skipping relationship was cool!

With her idiosyncratic actions, Sarah progressed from the original problem of finding relationships in the array to the problem of finding the sum of entries in an NxN block via a process of 'skipping' or traversing through a sequence of square numbers. In this way, she had developed an informal method. She further developed her initial idea of 'skipping' by checking its applicability with simple cases and then drew upon the metaphor into her subsequent investigations. She was able to generalize her method from skipping within a simple sequence to a formal algorithm that was more efficient for finding the sums of entries in any NxN block beyond the 10x10 array. This finding is consistent with research that identifies informal methods as playing a prominent role in the development of formal algorithms (Cai, Moyer, & McLaughlin, 1998; Saenz-Ludlow, 1995).

Implications

We must be careful not to infer too much from the actions of these students for two reasons. First, the different contexts of the situations emphasize different aspects of mathematics teaching and learning. Jared's solution was introduced within a classroom setting and the role of the teacher in addressing how it might be best utilized to enhance the classroom discussion was highlighted. While Jared's formula for finding the number of diagonals in an *n*-sided convex polygon was an interesting and different approach for solving the problem, it is difficult to conclude that it added appreciably to the other students' overall understanding of the algorithm. However, the teacher's decision to conduct a discussion of whether or not the two solutions were equivalent is certainly consistent with reform-based recommendations for teaching geometry (NCTM, 2000) that call for students to explore relationships (including congruence and similarity) among classes of two- and three-dimensional geometric objects, make and test conjectures about the relationships, and solve problems involving them.

In contrast, Sarah's problem solving within the open-ended Number Array task had more of an evolutionary arc to her conceptual development. She developed an interesting informal solution method based on her 'skipping' metaphor and then transformed the results to a more sophisticated algorithm based on sound mathematical principles. This more sophisticated algorithm was clearly more efficient for solving problems than her 'skipping' method. In terms of algorithm development, Sarah demonstrated persuasive evidence that if given the opportunity, students inventing their own algorithms can have substantial conceptual benefits.

References

Cifarelli, V. V., & Sevim, V. (2015). Problem posing as reformulation and sense-making within problem solving. In Singer, F. M., Ellerton, N. F., & Cai, J. (Eds.), *Problem posing: From research to effective practice* (pp. 177-194). Springer-Verlag Publishers.

Cai, J., Moyer, J. C. & Laughlin, C. (1998). Algorithms for solving non-routine mathematical problems. In Morrow, L. (Ed.), *The teaching and learning of algorithms in school mathematics: The 1998 yearbook of the National Council of Teachers of Mathematics* (pp. 218-229). Reston, VA:NCTM.

Campbell, P., Rowan, T. E., & Suarez, A. R. (1998). What criteria for student-invented algorithms? In Morrow, L. (Ed.), *The teaching and learning of algorithms in school mathematics: The 1998 yearbook of the National Council of Teachers of Mathematics* (pp. 49-55). Reston, VA:NCTM

Clarke, D. (2005). Written algorithms in the primary years: Undoing the "good work"? In M. Coupland, J. Anderson, & T. Spencer (Eds.), *Making mathematics vital: Proceedings of the twentieth biennial conference of the Australian Association of Mathematics Teachers* (pp. 93–98). Adelaide: Australian Association of Mathematics Teachers.

Fan, L. & Bokhov, C. (2014). Rethinking the role of algorithms in school mathematics: A conceptual model with focus on cognitive development. *ZDM –The International Journal on Mathematics Education*, *46*(3), 481-492.

Givvin, K. B., Jacobs, J., Hollingsworth, H., & Hiebert, J. (2009). What is effective mathematics teaching? International educators' judgments of mathematics lessons from the TIMSS 1999 Video Study. In J. Cai, G. Kaiser, B. Perry, & N. -Y. Wong (Eds.), *Effective mathematics teaching from teachers' perspectives: National and cross-national studies* (pp. 37–69). Boston, MA: Sense.

Glasersfeld, E. von (1991). *Radical constructivism in mathematics education*. Dordrecht, The Netherlands: Kluwer Academic.

National Council of Teachers of Mathematics (NCTM). (2000). *Principles and standards for school mathematics*. Reston, VA: NCTM.

Piaget, J. (1970). *Genetic epistemology* (3rd ed.). New York: Columbia University Press.

Sáenz-Ludlow, A. (1995). The emergence of the splitting metaphor on a fourth grade classroom. *Proceedings of the seventeenth annual meeting of the American Chapter for the International Group for the Psychology of Mathematics Education* (pp. 152-157). Columbus, OH: Ohio State University.

Schoenfeld, A. H. (2007). Problem solving in the United States, 1970–2008: Research and theory, practice and politics. *ZDM –The International Journal on Mathematics Education*, *39*(5–6), 537–551.

Steffe, L. P. (2002). A new hypothesis concerning children's fractional knowledge. *The Journal of Mathematical Behavior, 20*, 267-307.

Wheatley, G. H. (2004, February). *Mathematics learning from a philosophic and psychological perspective,* Paper presented at the 2004 annual conference of Research Council on Mathematics Learning. Oklahoma City, OK.

Acknowledgements

Research reported in this paper was made possible by a Faculty Research Grant from the University of North Carolina at Charlotte.

BUILDING RELATIONSHIPS TO IMPROVE PROFESSIONAL DEVELOPMENT WORKSHOPS

Elliott S. Elliott
selliott@utm.edu
John Overcash
joverca1@utm.edu
University of Tennessee at Martin

A mathematics professor and a chemistry professor became responsible for providing professional development workshops for K-12 teachers. Neither professor had much knowledge of K-12 education practices. Relationships with state department of education personnel, university department of educational studies faculty, teachers, and administrators informed decisions to include pedagogy topics with STEM content in the workshops. Inclusion of these topics led to improved satisfaction among workshop participants.

Introduction

In 2016 two college faculty members, a mathematician and a chemist, became co-directors of a STEM Center for teaching and learning. They were charged with conducting professional development (PD) workshops focused on mathematics and science content knowledge for K-12 teachers. Neither had formal training or experience with K-12 education. Nonetheless, they managed to design and conduct workshops that achieved high levels of satisfaction among participating teachers.

Recognizing their own lack of expertise, the STEM Center directors built relationships to understand the needs of K-12 mathematics and science teachers attending PD. They reached out to state department of education staff, colleagues in the department of educational studies at their university, school administrators and K-12 teachers themselves. In addition, they extended their membership in professional organizations. Already members of the Mathematical Association of America and the American Chemical Society, they joined organizations such as their state affiliates of the National Council of Teachers of Mathematics and the National Science Teachers Association as well as the School Science and Mathematics Association. The various publications and meetings of these organizations helped the directors understand the needs of teachers and the requirements for effective PD.

Purpose of the Paper

The purpose of this paper is to encourage collaborations among K-12 teachers, teacher educators, mathematicians, and scientists. This paper describes how a chemist and a mathematician learned to work effectively with K-12 teachers. Through relationships and experience they learned many of the lessons which they now realize are well established in the literature on effective PD.

Most mathematicians and scientists do not know how to contribute directly to K-12 education, but they can learn. The depth of content expertise that mathematicians and scientists can provide is worth the effort to have them as partners in K-12 education.

Significance and Related Literature

Calls for collaborations among K-12 educators and scientists and mathematicians have existed for at least two decades, and these calls persist (Druger & Allen, 1998; Conference Board of the Mathematical Sciences, 2012). The collaboration is not necessarily a natural one. Doctoral programs in mathematics or the sciences typically include no pedagogical training even at the college level (Sunal, 2001). These programs certainly do not prepare college faculty to deal with the issues faced in K-12 classrooms. A scientist wishing to work with K-12 teachers may have little idea of what will be useful.

Teachers need a deep knowledge of the subjects that they teach, and focused PD can help them achieve this depth (Borko, 2004). Workshops that involve active learning and encourage participants to adapt activities for their particular students can be a useful part of PD (Guskey & Yoon, 2009). For PD to measurably improve student achievement, it needs to occur over a significant amount of time, perhaps many days over the course of months (Darling-Hammond, Chung Wei, Andree, Richardson, & Orphanos, 2009). The publication dates of the citations here indicate that these ideas were known to education researchers long before the STEM Center directors began their work in 2016. These ideas were not known to the STEM center directors.

Practice or Innovation

The STEM Center sponsored short-term workshops in June during the years 2016 through 2018. Workshops in even numbered years focused on mathematics content, while the 2017 workshops focused on science. Participants were K-12 teachers from West Tennessee. The number of participants was 77 in 2016, 97 in 2018, and 86 in 2018. The STEM Center directors recruited university faculty with a variety of expertise to conduct the workshops. Faculty leading workshops included number theorists, graph theorists, a topologist, a physicist, a geologist, and an astronomer. The variety of experts provided a depth of content knowledge that no one person could offer.

For each summer, the directors tried to determine particular content areas for which teachers needed PD. The directors would describe these needs in terms of K-12 education standards to the recruited faculty and ask these workshop leaders to design approximately 10 lessons. The directors translated these lesson ideas into lesson plans suitable for classrooms at the targeted grade level. College faculty presented the lessons to the participating teachers. In each workshop participants received electronic copies of the lesson plans to modify for their own classrooms. In the second two summers, workshop leaders made a point of having teachers discuss each lesson. After completing an activity, teachers would discuss how it related to standards, how effective they thought the activity would be for their students, and how they might modify the lesson or activity for their students. Several different groups of people helped the directors learn how to design PD workshops.

The Northwest Center of Regional Excellence (CORE) is a regional office of the Tennessee Department of Education and is located on the same campus as the STEM Center. Staff at the CORE office were helpful in many ways, but two were significant. First, the director was instrumental in getting teachers to respond to a survey about the topics on which they needed PD. Her request appeared more compulsory to the teachers and their principals than a similar request from the directors of the STEM Center. With survey results STEM Center directors were able to design, for example, a workshop specifically focused on just four middle school mathematics standards. Second, CORE office staff secured an invitation for the STEM Center directors to attend state training sessions. When the state introduced new science standards, the STEM Center directors were able to attend training in the same room with principals and K-12 teachers. That event was helpful in understanding their needs for the upcoming year's workshop.

One of the first relationships that the STEM Center directors sought was with faculty in their university's department of educational studies. These colleagues provided the directors with a format for lesson plans and introduced them to the idea of differentiated instruction. These colleagues also encouraged the directors to become Classroom Organization and Management Program (COMP) leaders (Evertson & Harris, 1995). By participating in and then leading COMP training, the directors became aware of many issues facing K-12 teachers that they had not previously considered. Leading COMP training sessions exposed them to a greater number of teachers and allowed even more collaboration.

Teachers provided two critical types of information. First, they could identify their equipment needs better than anyone else. The STEM Center directors were fortunate to have grant funding to purchase such equipment. Workshop attendees practiced using the equipment and then could keep it to use with their own students. Second, teachers were also best at identifying the mathematics and science topics on which they needed training. While teachers could best answer these questions, principals were helpful in getting questions to teachers and answers to the directors. Both teachers and administrators were important partners.

Ultimately, a larger pool of collaborators came from participation in a wider array of professional organizations. Annual conferences of the Tennessee Science Teachers Association and The Tennessee Mathematics Teachers Association provided opportunities to gauge the mood of the community as the state introduced new education standards in mathematics and science. One of the directors first learned of the research findings on the lack of effectiveness of short-term PD during the 2017 convention of The School Science and Mathematics Association. Subsequent reading of that organization's journal and some of the references cited therein began to give the directors a theoretical framework for their activities two years into the project.

Classroom Examples

In the absence of a research-based theoretical framework, the STEM Center directors attempted to assess the quality of PD through participant satisfaction surveys. In addition, the directors sent a query by email to participants six months after each workshop. The message asked teachers how many workshop lessons they had used with their students and invited them to provide whatever feedback they wanted.

The satisfaction survey called for teachers to express a level of agreement with each of 17 statements using a 5-point Likert scale with 1 representing "strongly disagree" and 5 representing "strongly agree." Figure 1 shows the mean response to each statement in each year and reflects a high degree of satisfaction with the workshops. As examples, Statement 2 was "The workshop was interactive and hands-on," and Statement 7 was "The topics covered in this workshop were appropriate for the advertised grade band." Written comments about these issues in 2016 led to revisions for the 2017 and 2018 workshops. The directors encouraged workshop leaders to include hands-on activities. In 2016, there were just three "advertised grade bands," elementary, middle, and high school. In 2018, after poling teachers for their needs, the directors designed more focused workshops such as one on real-world problems tied to just four Grade 6 and Grade 7 expressions and equations standards. Teachers appreciated this increased level of specificity.

Figure 1

The response rate to the email survey at the six-month follow-up point was disappointing. In each of 2016 and 2017, only 29 teachers replied. The respondents had implemented an average of one workshop lesson or activity in their classrooms. The low response rate itself indicated to the directors that they would need to design more formal follow-up in future PD plans. The low rate of implementation indicated the need for long-term encouragement for teachers to convert their initial high levels of satisfaction into action in the classroom.

Implications

In the absence of formal training or familiarity with the extensive literature on teacher PD, the STEM Center directors built and relied on relationships to conduct PD. Their workshops were short-term and thus failed to meet a requirement for effective PD as described in the literature. In hindsight, the directors recognized the need for long-term follow-up from the low response rates to their surveys of teachers after the workshops. On the other hand, by working with education studies faculty and listening to workshop participants, the directors' workshop design gradually came to include several practices that are supported by research. In particular, workshops after the first year were focused on specific content knowledge and involved active learning where teachers had to plan how to use workshop lessons with their students. Ultimately, through the dissemination provided by professional organizations, the directors became aware of some of the research that supported their anecdotal discoveries.

Mathematicians and scientists can make meaningful contributions to K-12 education. Getting their involvement often requires recruiting, and they will often need help. However, help is available. Mathematicians, scientists, and professionals involved in K-12 teaching or the preparation of K-12 teachers can build rewarding relationships when they work together.

References

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher*, 33(8), 3-15.

Conference Board of the Mathematical Sciences (2012). *The mathematical education of teachers II*. Providence, RI and Washington, D.C.: American Mathematical Society and Mathematical Association of America.

Darling-Hammond, L., Chung Wei, R., Andree, A., Richardson, N., & Orphanos, S. (2009). *Professional learning in the learning profession: A status report on teacher development in the United States and abroad*. Stanford, CA: National Staff Development Council and The School Redesign Network.

Druger, M. & Allen G. (1998). A study of the role of research scientists in K-12 science education. *The American Biology Teacher, 60(5), 344-349*.

Evertson, C. M., & Harris, A. H. (1995). *Classroom organization and management program: Revalidation of submission to the Program Effectiveness Panel (PEP), U.S. Department of Education*. Nashville, TN: Vanderbilt University, Peabody College (ED 403 247).

Guskey, T. R., & Yoon, K. S. (2009). What works in professional development? *Phi Delta Kappan*, 90(7), 495-500.

Acknowledgements

This work was supported by U.S. Department of Education grant U336S140076. The views expressed are the authors' and do not necessarily reflect the views of the U.S. Department of Education.

SHAPING SIXTH-GRADERS' ATTITUDES TOWARD SCIENCE VIA EXPERIENTIAL EDUCATION

Leigh M. Harrell-Williams
Leigh.Williams@memphis.edu

Christian E. Mueller
cemuellr@memphis.edu

Cheryl A. Goudie
cgoudie@memphis.edu

Jessica Webb
Jessica.Webb@memphis.edu

Shelby G. Roberts
Shelby.Roberts@memphis.edu

University of Memphis

Recently, some researchers have suggested that the best way to enhance and strengthen the STEM education pipeline is through fostering early interest and helping students develop an identity that is centered around science. Additional research has indicated that interest and identity can be enhanced through field experiences that allow students to "do science" or to "be scientists," and that these can serve as important complements to traditional classroom instruction. In this paper, we describe results from a program where researchers from a local university partnered with faculty and students from a middle school to participate in day-long experiential education sessions.

Introduction

An increased focus on the promotion of student interest in science, technology, engineering, and mathematics (STEM) fields, especially at the middle school and high school levels, has resulted in the development of experiential learning programs where students "conduct science" outside of a classroom lab setting. There has been some evidence that these programs have positive results with regards to achievement and STEM-related career goals. Hiller and Kitsantas (2014), for example, found that 8th graders' participation in a horseshoe crab citizen science program (Blue STEM Camp), conducted at a national park facility with a naturalist center and a private beach, positively impacted science achievement as compared to students only receiving classroom instruction. Additional findings showed that student science self-efficacy significantly increased after participation in the program, which positively influenced science-related career goals.

Objectives of the Study

The purpose of this study was to evaluate the effectiveness of an outdoor, experiential environmental science program conducted at a university extension station using the Social-Cognitive Career Theory framework.

Theoretical Framework

Increasingly, as the nation continues to struggle with maintaining its competitive place among developed countries in the STEM fields, and as racial and ethnic diversity increase in the United States, educators and researchers alike are exploring high impact ways to attract and retain traditionally underserved and under-examined student populations along the STEM-education pipeline. Fortunately, there exists a well-established framework for examining the factors that impact STEM-related student interest, attitudes, and achievement; that of Social-Cognitive Career Theory (SCCT) (Lent, Brown, & Hackett, 1994, 2000). SCCT utilizes an adapted version of Bandura's (1986) social-cognitive theory to examine career development and career-related choices among many student populations, including ethnically diverse middle and high school populations (e.g., Navarro, Flores, & Worthington, 2007). Primarily, the focus in SCCT is on examining how career interests (and subsequent choices) are impacted by student beliefs (efficacy and outcome expectancy), previous experiences, and perceived external barriers and supports (see Figure 1).

In the present study, we utilized SCCT to examine the impact that participation in an experiential learning program had on sixth-grade student attitudes and achievement in science. The program, which was developed in partnership with two local schools, an environmental non-profit agency, and a local university all located in the mid-South, focused on delivering experientially-based science education at a university-owned research station in a local state forest. The study was conducted and funded as part of a university engaged scholarship award.

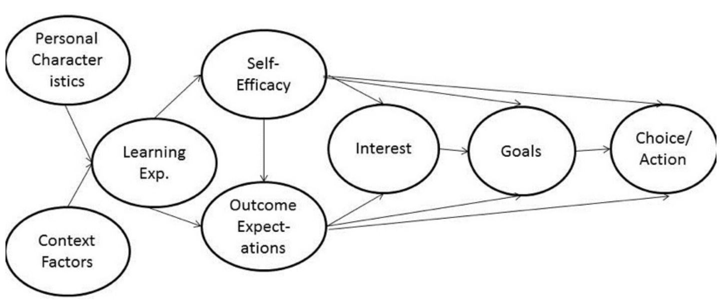


Figure 1. Social Cognitive Career Theory Model, adapted from Lent et al. (1994)

Methodology

The Program

The Mid-South Outdoor Recreation & Education (MORE) Program is an environmental education pilot developed by the Mississippi River Corridor – Tennessee (MRCT), a 501(C)(3) non-profit organization, to expand early learning opportunities for students through an experiential education curriculum. The *MORE* Program at the Meeman Biological Station was developed around the Project Learning Tree Program (PLT) curriculum, an award-winning environmental education program for students in grades pre-K through 12. Three enhanced lessons were developed by a university staff member, who is a certified PLT trainer, and a university faculty member. The lessons covered the topics of trees/biomes, watersheds, and soils. Each lesson plan included a short lecture that tied into the state 6th grade science standards, walks through the forest to illustrate key points in the lecture, and hands-on outdoor activities. The pilot implementation of the program was run during the Spring 2016 semester.

Participants

Two urban that had previously worked with *MORE* Program were chosen for the pilot program at Meeman Biological Station. One school is a charter school, while the other is part of a special school district serving the lowest performing 5% of schools in the state. All students that attended the charter school are minority and approximately 81% of students are considered economically disadvantaged. Approximately 95% of the students at the other school are minority students and 95% are receiving free/reduced lunch. In total, 45 6th graders across the two schools participated in the treatment group (attended the outdoor learning days) and 82 students served as the control group for the study.

Participant Selection

The study involved a "treatment" group of 6th graders who participated in 3 lessons at the Biological Station and a "control" group who did not attend the program. A two-step process was used to select students in the 6th grade to attend the program dates at the research station in order to ensure that both high and low performing students were part of the "treatment" group. Students at each school were stratified by the quartiles of their scores from an administration of the Measures of Academic Progress assessment. Random samples of students were drawn within each quartile to identify approximately 30 students to attend each trip (the "treatment" group students). Attrition from the initial treatment group at each school occurred during the study due to student transition (to another school or district), loss of off-campus privilege as part of school disciplinary action, and student absence. This attrition resulted in the groups being treated as "existing groups" instead of randomized groups in the analysis. IRB approval for this study was obtained from the university prior to the actual stratification and selection of students.

Measures

The 6th grade science teachers at both schools administered a knowledge measure and a science attitudes/interest/beliefs survey to all 6th graders, prior to the first trip date and after the last trip was completed. The 19 item, multiple-choice knowledge measure was written by the certified PLT trainer, based on both the lesson plans for the program, sample assessments from a participating 6th grade science teacher, and the 6th grade science standards. The survey contained 42 self-report items that measured students' outcome expectations, goal intentions, interest in math and science related activities, and feelings towards science and science careers. Scale scores were obtained by averaging across a student's responses for each scale.

Outcome Expectations. O utcome expectations were measured using 7 items (alpha = .81) from the Middle School Self-Efficacy Scale (Fouad, Smith & Enochs, 1997). These items address students' beliefs "Regarding the consequences of their potential mathematics and science-related course activities and achievements" (Navarro et al., 2007, p. 325). Students indicate their level of agreement, such as "If I do well in science classes in middle school, then I will do well in high school science classes", using a 5 point scale from "strongly disagree" to "strongly agree".

Goal Intentions. Goal intentions were measured using 6 items (alpha = .73) from the Middle School Self-Efficacy Scale (Fouad, Smith & Enochs, 1997). These items address students' intentions towards science-related opportunities in the future. Students indicate their level of agreement, such as "I intend to pursue a career that will use science", using a 5 point scale from "strongly disagree" to "strongly agree".

Science Interest. Science interest was measured using 20 items (alpha = .84) from the Math/Science Interests Scale (MSIS; Fouad & Smith, 1996). These items address students' interest in science and math-related activities. Only science interest items were used in the present study. Students indicate how much they enjoy specific activities, such as "visiting a science museum" and "watching a science program on TV", using a 3 point scale from "dislike" to "like".

Semantics. Students' attitudes about science and careers in science were measured using two of the five item semantic differential subscales from the STEM Semantic Survey (Tyler-Wood, Knezek, and Christensen, 2010). Each of the five items in the subscales consists of a pair of adjectives. Students are instructed to "Choose one circle between each adjective pair to indicate how you feel about the object.", with the circles containing values from 1 to 7. For this study, the stems for the subscales used were "To me, science is:" and "To me, a CAREER in science, technology, engineering, or mathematics (is)". An example of an adjective pair is "boring" and "interesting". Separate scores were given for each semantic subscale.

Analysis

Repeated measures analysis of variance was used to determine if a difference existed in any outcome measure across treatment groups and administration time.

Results and Discussion

Table 1 reports descriptive statistics for the pre- and post-test scale scores for treatment and control groups for each measure. Only the science semantic scores were significantly different across groups, with the treatment group having higher scores at both the pre-test and post-time administrations. Table 2 presents the results of the repeated measure analysis of variance on each measure. As seen in Table 2, scale scores were significantly different across time for science interest, science semantics and career semantics. Science interest scores increased over time for both groups. Even though the treatment group had a larger gain (about 1.5 times) than the control group, the treatment effect was not significant, most likely due to almost equivalent post-test scores. In addition to a time effect, a treatment effect was also significant for scale scores for science and career semantics. Scores on both semantic scales decreased across time for both treatment and control groups. The amount of decrease in science semantic scores was equivalent across groups. However, the treatment group experienced a greater decrease than the control group. Post-test scores for the treatment group remained higher than the control group for both semantic scales (see Figure 2).

Implications

The results provide mixed evidence regarding the impact of 6th graders attendance at three outdoor experiential learning days on student knowledge, interest and attitudes towards science and science careers. As with most pilot studies of educational interventions, the smaller sample size in the treatment group (roughly half the control group) and low dosage (the number of outings) may have contributed to the lack of power needed to find significant differences between study groups. Estimated power for non-significant effects ranged from .05 to .27. However, in spite of power issues associated with attrition, participation in the program was associated with more positive attitudes towards science careers at the end of the school year as compared to control group students.

Table 1.
Descriptive Statistics for Measures

Measure	Time	Treatment Mean	Treatment SD	Treatment N	Control Mean	Control SD	Control N
Knowledge (19 question test)	Pre-test	8.02	3.60	45	7.49	3.33	82
	Post-test	8.56	4.04	45	7.90	3.70	82
Outcome Expectations (5 point scale)	Pre-test	2.49	1.34	39	2.80	1.31	78
	Post-test	2.52	1.37	39	2.78	1.28	78
Goal Intentions (5 point scale)	Pre-test	2.52	1.29	39	2.85	1.24	75
	Post-test	2.62	1.35	39	2.80	1.18	75
Science Interest (3 point scale)	Pre-test	1.77	.70	34	2.04	.65	54
	Post-test	2.53	.55	34	2.51	.57	54
Science Semantics (7 point scale)	Pre-test	5.81**	1.33	33	5.07**	1.51	61
	Post-test	5.00**	1.21	33	4.24**	1.26	61
Career Semantics (7 point scale)	Pre-test	5.69	1.56	31	4.93	1.51	58
	Post-test	4.59	1.25	31	4.28	1.22	58

** indicates significant difference across treatment groups at $\alpha = .01$.

Table 2.
Summary of Individual Repeated Measure ANOVA Results

Response Variable	Effect	F test statistic	Degrees of Freedom	p-value	Partial Eta-squared	Estimated Power
Knowledge	Time	1.349	1, 125	.248	.011	.211
	Treatment	1.225	1, 125	.270	.010	.196
	Time*Treatment	.021	1, 125	.885	.000	.052
Outcome Expectations	Time	.001	1, 115	.980	.000	.050
	Treatment	4.119	1, 115	.264	.011	.200
	Time*Treatment	.024	1, 115	.128.	.001	.065
Goal Intentions	Time	.146	1, 112	.703	.001	.067
	Treatment	2.194	1, 112	.288	.010	.185
	Time*Treatment	1.273	1, 112	.262	.011	.201
Science Interest	Time	41.315	1, 86	< .001*	.325	1.000
	Treatment	.866	1, 86	.137	.025	1.000
	Time*Treatment	.692	1, 86	.180	.021	.267
Science Semantics	Time	26.777	1, 92	< .001*	.225	.999
	Treatment	9.504	1, 92	.003*	.094	.862
	Time*Treatment	.003	1, 92	.956	.000	.050
Career Semantics	Time	19.410	1, 87	< .001*	.182	.992
	Treatment	5.155	1, 87	.026*	.056	.612
	Time*Treatment	1.270	1, 87	.263	.014	.200

* indicates significance at $\alpha = .05$, ** indicates significance at $\alpha = .01$.

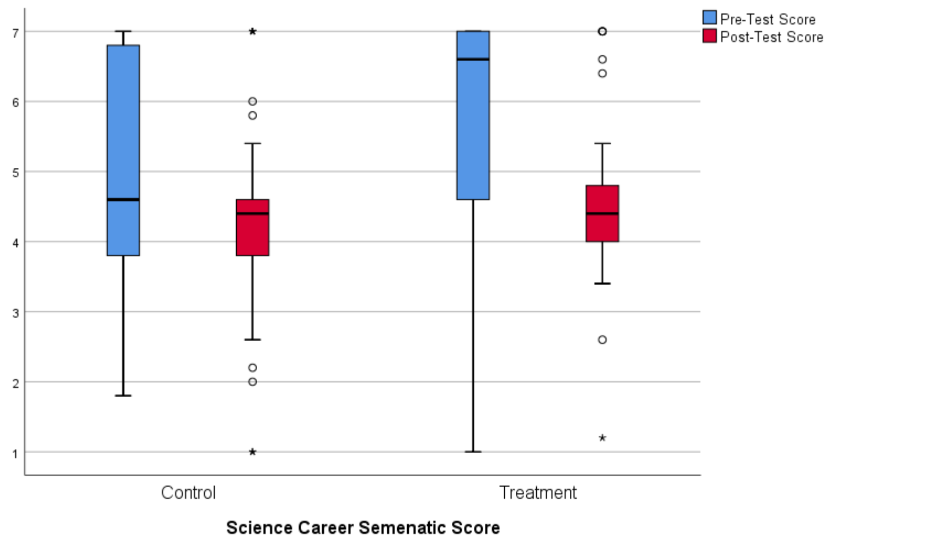


Figure 2. Post-Test Scores for Semantic Scales for Treatment and Control Groups

Given the heightened focus on nurturing and retaining student interest in STEM learning and careers for traditionally underserved populations, findings from present study are encouraging and lend credence to the importance of experiential learning environments in fostering early adolescent, minority student interest and attitudes towards science and science careers. Specifically, results showed a change in interest over time but no change in outcome expectancy. Perhaps future research should explore more direct relationships between predictors of interest (e.g., experiential learning), rather than through indirect paths predicted by SCCT through self-efficacy and outcome expectancy. There is precedent for this in previous research. For example, Maltese & Tai (2010) found in a retrospective study that interest in science developed during the middle school years and was different for males and females. For females, interest in science emerged out of school-based activities, where for men interested in science developed more as a result of self-initiated activities. Collectively, these results point to the importance of structuring out-of-school experiential activities to match the developmental needs of the middle school student who often are exploring future career options (Wyss, Heulskamp, & Siebert, 2013).

References

Bandura, A. (1986). Social foundations of thoughts and action: A social cognitive theory. Englewood Cliffs, NJ: Prentice-Hall.

Fouad, N. A., & Smith, P. L. (1996). A test of a social cognitive model for middle school students: Math and science. *Journal of Counseling Psychology*, *43*, 338-346.

Fouad, N. A., Smith, P. L., & Enochs, L. (1997). Reliability and validity evidence for the Middle School Self-Efficacy Scale. *Measurement and Evaluation In Counseling And Development*, *30*, 17-31.

Hiller, S. E., and Kitsantas, A. (2014). The Effect of a Horseshoe Crab Citizen Science Program on Middle School Student Science Performance and STEM Career Motivation. *School Science and Mathematics, 114:* 302–311. doi: 10.1111/ssm.12081

Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a unifying social cognitive theory of career and academic interest, choice, and performance. *Journal of Vocational Behavior, 45*, 79–122. doi: 10.1006/jvbe.1994.1027

Lent, R. W., Brown, S. D, & Hackett, G. (2000). Contextual supports and barriers to career choice: A social cognitive analysis. *Journal of Counseling Psychology, 47,* 36-49.

Maltese, A.V. & Tai, R.H. (2010). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. Students. *Science Education, 95*, 877-907.

Navarro, R. L., Flores, L. Y., & Worthington, R. L. (2007). Mexican American middle school students' goal intentions in mathematics and science: A test of social cognitive career theory. *Journal of Counseling Psychology, 54,* 320-335.

Tyler-Wood, T., Knezek G., & Christensen, R. (2010). Instruments for Assessing Interest in STEM Content and Careers. *Journal of Technology and Teacher Education, 18*(2), 341-363.

Wyss, V. L., Heulskamp, D., & Siebert, C. J. (2013). Increasing middle school student interest in STEM careers with videos of scientists. *International Journal of Environmental and Science Education, 8*(1), 501–522.

Acknowledgements

This work was partially funded through a Strengthening Communities Initiative Capacity Building Grant from the University of Memphis, funded by a partnership between the Community Foundation of Greater Memphis, United Way of the Mid-South, and the University of Memphis Engaged Scholarship Committee.

INFORMAL STEM LEARNING CHANGING PRESERVICE TEACHERS' BELIEFS

Cathrine Maiorca
Cathrine.Maiorca@csulb.edu
California State University Long Beach

O. Thomas Roberts
otrober@bgsu.edu
Bowling Green State University

Preservice teachers' beliefs influence how they teach integrated STEM. This study examined 28 preservice teachers' beliefs about STEM education after participating in informal STEM learning experience. Data included the Teacher Efficacy and Attitudes Toward STEM Survey. To compare the pre-and post-scores for mathematics teaching efficacy and beliefs, elementary STEM instruction, 21st century learning attitudes, STEM career awareness, and science teaching efficacy and beliefs a paired t-test was conducted. All categories were significantly different except 21st century learning attitudes. Implications of this study are the importance of informal STEM learning, and engaging students in belief challenging activities during preservice teacher education.

Introduction

Preservice elementary teachers' beliefs are important as they influence their willingness and ability to teach integrated STEM. The connection between beliefs and practices teachers implement in the classroom is well documented in the research literature (Ball and Cohen, 1999; Philipp, 2007; Wilkins, 2008). The literature also provides examples of the difficulties in changing elementary preservice teachers' beliefs of teaching mathematics and science, with the preservice teachers' personal experiences often remaining the default for providing mathematics instruction (Foss & Kleinsasser, 1996; Thomas & Pederson, 2003). This is especially true for STEM subjects. Other studies (e.g., Williams, & Roberts, 2018) have explored the use of service learning in field placements as ways to shape preservice teachers' beliefs while developing their pedagogical abilities. Our study takes a similar approach by using an informal STEM learning experience as a way to positively affect the beliefs of preservice teachers enrolled in an elementary mathematics methods course.

Objectives of the Study

The purpose of this paper is to examine how informal STEM learning environments can be used to positively influence preservice teachers' beliefs. While the literature on preservice teachers' dispositions toward mathematics is broad, how those beliefs are shaped through the use of informal STEM environments is not as prevalent. For the purpose of this study informal STEM learning environments refers to experiences that take place outside of the classroom for K-12 students. Characteristics of this informal STEM learning environment include a) to provide underrepresented students opportunities to engage in informal STEM learning; b) increase student interest in STEM education; c) use hands-on activities to engage students and motivate them to pursue careers in STEM (Mohr-Schroeder, Jackson, Miller, Walcott, Little, Speler, Schooler & Schroeder, 2014). This study reports on initial quantitative results of a larger, ongoing study that seeks to illustrate the impact of informal STEM learning environments on preservice teachers' beliefs about STEM education. For the purpose of this study, beliefs are defined to be "psychologically held understandings, premises, or propositions about the world that are thought to be true… Beliefs might be thought of as lenses that affect one's view of some aspect of the world or as dispositions toward action" (Philipp, 2007, p. 259). The primary research question for this study is: How does participating in an informal STEM learning experience influence preservice teachers', enrolled in an elementary mathematics methods course, beliefs about STEM education?

Theoretical Framework and Related Literature

Preservice teachers' beliefs about teaching are shaped by their own mathematical learning experiences (Yackel, & Rasmussen, 2002). These beliefs will impact their future teaching practices, especially in STEM education (Stohlmann, Moore, & Roehrig, 2012). Traditionally, STEM subjects are taught in isolation of each other. In order to create authentic STEM learning experiences, STEM content should be integrated (Stohlmann et al., 2012). Teachers, however, have not had sufficient support using integrated STEM (Bybee, 2013; Stohlmann et al., 2012). This lack of experience influences preservice teachers' beliefs about integrated STEM education. When preservice teachers see children's' mathematical thinking, their beliefs about teaching mathematics change (Philipp, 2007). This is also true for preservice teachers' beliefs about STEM (Maiorca & Mohr-Schroeder, Accepted).

Situated learning theory was used to examine how the preservice teachers' beliefs were influenced by their participation in the informal STEM learning experience. Mathematics learning is socially situated; both the learning and teaching of mathematics is influenced by the learning activity and the social setting in which it takes place (Lave, 1988). Learning is an active process where individuals need to interact with their environment and discover concepts for themselves.

Situated learning theory has been used similarly to explore connections between student attitudes toward STEM and informal STEM learning (e.g., Roberts, Jackson, Mohr-Schroeder, Bush, Maiorca, Cavalcanti, Schroeder, Delaney, Putnam, & Cremeans, 2018) and learning and attitudes toward STEM (e.g., Guzey, Moore, Harwell, & Moreno, 2016). Preservice teachers' first experienced STEM activities as learners in their elementary math methods class. Situated learning theory can be applied to this study because the preservice teachers' beliefs about STEM education were influenced their participation as both the learner and the teacher in a STEM learning experience.

Methodology

In order to examine how participating in an informal STEM learning experience affected the pre-service teachers' dispositions towards STEM education, data was collected from pre-service teachers enrolled in an elementary mathematics methods course during the summers of 2017 and 2018. This present study took place at a public university in Southern California and is part of a larger study examining integrated STEM education in teacher education.

Twenty-eight pre-service teachers, seven males and 21 females, participated in the study. Nine participants were special education credential students, 18 were elementary education credential students and one was a bilingual education credential student. The participants were enrolled in an elementary mathematics methods course where they received instruction on how to teach mathematics, including the implementation of integrated STEM education activities. In the elementary methods course the preservice teachers completed engineering design activities as learners. During the week-long informal STEM learning experience, the preservice teachers worked middle school students from local Title I schools with more than 40% of students from low income families. During the informal STEM learning experience the preservice teachers helped facilitate hands-on, integrated STEM activities with local STEM professionals, and They helped facilitate hands-on, integrated STEM activities with local STEM professionals, and supervised the middle school students as they designed and built robots for robotics challenge activities.

Multiple sources of data were collected from the preservice teachers, including interviews, reflections, and integrated STEM lesson plans. For this paper, we analyzed data from a pre and post administration of the *Teacher Efficacy and Attitudes Toward STEM (T-STEM) Survey* (Friday Institute for Educational Innovation, 2012). The T-STEM survey was administered the first day of the semester and after the informal STEM learning experience. The composite scores for each participant were calculated averaging the scores for each question in the category. Then, a paired t-test was conducted to compare the pre-and post-scores for the following categories: mathematics teaching efficacy and beliefs, elementary STEM instruction, 21st century learning attitudes, STEM career awareness, science teaching efficacy and beliefs. The Bonferroni method was used to control for type I error, and the adjusted alpha was 0.01 (Hinkle, Wiersma, & Jurs, 2003).

Results and Discussion

A paired t-test was conducted to compare the pre and post scores for the following categories of the T-STEM survey: mathematics teaching efficacy and beliefs, elementary STEM instruction, 21st century learning attitudes, STEM career awareness, science teaching efficacy and beliefs (Table 1). There was a significant difference between the pre and post scores for all of the categories except 21st century learning attitudes ($p < 0.001$).

Table 1.

Results from T-STEM Survey

Category	Mean		SD		Significance
	Pre	**Post**	**Pre**	**Post**	**p-value**
Mathematics Teaching Efficacy and Beliefs	3.31	3.98	0.70	0.43	$p < 0.001$
Elementary STEM Instruction	3.06	3.91	0.43	0.56	$p < 0.001$
21st Century Learning Attitudes	4.28	4.35	0.82	0.85	$p = 0.447$
STEM Career Awareness	2.7	4.75	0.98	0.38	$p < 0.001$
Science Teaching Efficacy and Beliefs	3.19	3.96	0.60	0.56	$p < 0.001$

For the categories, mathematics teaching efficacy and beliefs and science teaching efficacy and beliefs, participants scored higher on the post-survey [$M= 3.98, SD = 0.43; M = 3.96, SD = 0.56$] than the pre-survey [$M= 3.31, SD = 0.70; M = 3.19, SD = 0.60$]. After the integrated STEM learning experiences, participants had higher self-efficacy and confidence towards teaching mathematics and science. This can be partially explained by the preservice teachers' typical beliefs about teaching mathematics and science when they enter a methods class. For example, Stohlmann, Cramer, Moore, and Maiorca (2014) initially found that preservice teachers held beliefs that did not support teaching mathematics in a conceptual way, like through STEM, but after working with students their beliefs changed and supported teaching conceptual understanding versus procedural. Jaipal-Jamani, and Angeli (2017) found preservice teachers' self-efficacy to teaching science using robots improved after working with robotics. These findings are similar to those of different studies (e.g., Foss & Kleinsasser, 1996; Maiorca & Mohr-Schroeder, Accepted). Stohlmann et al. (2012) found teachers' beliefs did change but that the teachers needed long term support to maintain these changed beliefs. Some suggested supports included professional development and time to collaborate with other STEM teachers.

For the category elementary STEM instruction, participants also had higher scores on the post-survey [$M= 3.91, SD = 0.56$] than on the pre-survey [$M= 3.06, SD = 0.43$]. Participants reported that they would use more STEM instructional practices in their teaching after the informal STEM learning experience. This suggests interacting within a community of practice with content experts while doing authentic activities (Kelley & Knowles, 2016) positively influenced the preservice teachers' conceptions of STEM.

STEM Career Awareness also showed a significant improvement between the pre and post survey [$M= 2.7, SD = 0.98; M = 4.75, SD = 0.38$], respectively. STEM Career Awareness category saw an increase of over two points, on average. STEM Career Awareness also saw the largest decrease in standard error, suggesting a more uniform awareness of STEM careers. The informal STEM learning experience emphasized the variety of STEM careers and this increase in awareness is important because of the context it created for the content. This is important because preservice teachers' beliefs about what STEM is greatly influences how they implement STEM activities (Mohr-Schroeder, Cavalcanti, & Blyman, 2015).

Of the five categories in the T-STEM survey, only 21st Century Learning Attitudes did not show a significant difference between the pre and post surveys. This could be due to scores which were already high on the pre [$M = 4.28, SD = 0.82$] and post [$M = 4.35, SD = 0.85$] surveys. The standard deviation also remained relatively steady. One possible explanation is the informal STEM learning environment reinforced the preservice teachers' beliefs about 21st Century Learning Attitudes. Thus, not only did the presurvey results leave limited room for growth, what the preservice teachers experienced reinforced their previously held beliefs about 21st Century learning. Ultimately, the results of this study demonstrate the importance of preservice teachers having experiences in informal STEM learning environments as they positively impact their beliefs about teaching science and mathematics.

Implications

One implication of this study is the importance of using informal STEM learning environments in preservice teacher education. As the preservice teachers participated in the informal STEM learning environment, their beliefs about STEM changed. This is incredibly important as preservice teachers learn and think about instructional methods. When their default teaching strategies derive from the way they were taught (Foss & Kleinsasser, 1996), the preservice teachers are not always open to other ways that could be effective for their future students. Participating in the informal STEM learning environment not only engaged them but allowed them to see the effectiveness of the pedagogy in action.

A second implication is the importance for students to engage in belief challenging activities. Philipp (2007) recounted the importance of changing beliefs to change behaviors. In this case, the behaviors we sought to change are STEM pedagogy strategies preservice teachers enact. By providing preservice teachers with this nontraditional field experience, their learning was situated in a community of practice that was participating in authentic STEM activities (Kelly & Knowles, 2016). By immersing the preservice teachers in this environment and allowing them to experience authentic STEM activities as both the learner and the teacher they were provided an opportunity in which their beliefs could change. As evidenced by the significant changes in mathematics teaching efficacy, elementary STEM instruction, STEM career awareness, and science teaching efficacy. A future direction for this study is to follow the preservice teachers and see how they enact pedagogy in STEM subjects when they begin teaching and to determine any lasting impact of the experience.

While the sample size in this study is small, results have been consistent from year to year. Due to the consistently positive results from this pilot study, future research will focus on scaling up the program to determine the effectiveness at a larger scale. Relatedly, this paper only presents the quantitative data analysis of a larger mixed methods study. The qualitative data analysis is ongoing, with preliminary findings supporting the quantitative results. Thus, future work will provide a more complete picture of the preservice teachers' experiences in the informal STEM learning environment and how those lived experiences shaped their beliefs about teaching STEM content.

References

Ball, D. L., & Cohen, D. K. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional education. In G. Sykes & L. Darling-Hammond (Eds.), Teaching as the learning profession: Handbook of policy and practice (pp. 3–32). San Francisco: Jossey Bass.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA press.

Friday Institute for Educational Innovation (2012). *Teacher Efficacy and Attitudes Toward STEM Survey*, Raleigh, NC: Author.

Foss, D. H., & Kleinsasser, R. C. (1996). Preservice elementary teachers' views of pedagogical and mathematical content knowledge. *Teaching & Teacher Education*, *12*(4), 429-442.

Guzey, S. S., Moore, T. J., Harwell, M., & Moreno, M. (2016). STEM integration in middle school life science: Student learning and attitudes. *Journal of Science Education and Technology*, *25*(4), 550-560.

Hinkle, D. E., Wiersma, W., & Jurs, S. G. (2003). *Applied statistics for the behavioral sciences* (5th ed.). New York, NY: Houghton Mifflin Company.

Jaipal-Jamani, K. & Angeli, C. (2017). Effect of Robotics on Elementary Preservice Teachers' Self-Efficacy, Science Learning, and Computational Thinking. *Journal of Science Education and Technology* 26(2). 175–192. Retrieved from https://doi.org/10.1007/s10956-016-9663-z

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 11.

Lave, J. (1988). *Cognition in practice: Mind, math, and culture in everyday life.* Cambridge University Press.

Maiorca, C. & Mohr-Schroeder, M. (Accepted). Elementary Preservice Teachers' Integration of Engineering into STEM Lesson Plans. *School Science and Mathematics*

Mohr-Schroeder, M. J., Cavalcanti, M., & Blyman, K. (2015). STEM education: Understanding the changing landscape. In A. Sahin (Ed.), *A practice-based model of STEM teaching* (pp. 3-14). Rotterdam, The Netherlands: Sense Publishers.

Mohr-Schroeder, M. J., Jackson, C., Miller, M., Walcott, B., Little, D. L., Speler, L., ... & Schroeder, D. C. (2014). Developing Middle School Students' Interests in STEM via Summer Learning Experiences: See Blue STEM Camp. *School Science and Mathematics*, *114*(6), 291-301.

Philipp, R. A. (2007). Mathematics teachers' beliefs and affect. In F. K. Lester (Ed.), Second handbook of research on mathematics teaching and learning (Vol. 1, pp. 257–315). Charlotte, NC: Information Age Publishing.

Roberts, T., Jackson, C., Mohr-Schroeder, M., Bush, S., Maiorca, C., Cavalcanti, M., Schroeder, C., Delaney, A., Putnam, L., & Cremeans, C. (2018) *Students' perceptions of STEM learning after participating in a summer informal learning experience.* International Journal of STEM Education.

Stohlmann, M., Cramer, K., Moore, T., & Maiorca, C. (2014). Changing preservice elementary teachers' beliefs about mathematical knowledge. Mathematics Teacher Education and Development

Stohlmann, M., Moore, T., & Roehrig, G. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering (JPEER), 2*(1), 28-34.

Wilkins, J. L. M. (2008). The relationship among elementary teachers' content knowledge, attitudes, beliefs, and practices. Journal of Mathematics Teacher Education, 11(2), 139–164.

Jackson, C., Mohr-Schroeder, M., Cavalcanti, M., Albers, S., Poe, K. Delaney, A., Chadd, E., Williams, M., & Roberts, T. (2018). Prospective mathematics teacher preparation: exploring the use of service learning as a field experience. *Fields Mathematics Education Journal*, *3*(5). https://doi.org/10.1186/s40928-018-0010-5

Yackel, E., & Rasmussen, C. (2002). Beliefs and norms in the mathematics classroom. In *Beliefs: A hidden variable in mathematics education?* (pp. 313-330). Springer, Dordrecht.

Acknowledgements

Without Fluor's generous support this work this summer learning experience wouldn't have been possible.

STUDENT AUTHORED STORY PROBLEMS FOR FRACTION NUMBER SENTENCES

Nesrin Sahin
nesrins@uca.edu
James Fetterly
jfetterly@uca.edu
Wesley Martsching
wmartsching1@cub.uca.edu
University of Central Arkansas

We investigated how instructions on fraction concepts and operations, and instructions on writing story problems changed prospective teachers' (PTs) knowledge of writing story problems for fraction number sentences. Results showed that receiving instructions had a significant effect on PTs' knowledge. They showed the highest improvement in writing story problems for fraction subtraction and division number sentences, however writing story problems for fraction multiplication number sentences remained a challenge for most PTs. We also compared the effect of two instructional approaches for writing story problems; error analysis and direct instruction. However, there was no significant difference between the two instructional approaches.

Introduction

In mathematics education, problem posing is related to both the creation of questions in a mathematical context, and to the reformulation of existing ill-structured problems (Pirie, 2002). Posing story problems requires a deeper understanding than the symbolic manipulation of the mathematical content. However, it is not an easy task, and teachers face problems in drawing meanings from symbolically represented mathematical content for some certain curriculum areas in primary and lower secondary mathematics (Rubenstein &Thompson, 2001). Fraction concepts are one of those curriculum areas (Ma, 2010), and teachers' knowledge of writing story problems should be enhanced for fraction number sentences.

Objectives of the Study

The goal of this study is to examine the effect of instruction (instruction on fraction concepts and operations, and instruction on writing story problems) on prospective teachers' (PTs) knowledge of writing story problems for fraction number sentences, and to compare the effect of two different instructional approach (error analysis and direct instruction) for writing story problems on PTs' knowledge. To achieve this goal, we examined PTs' knowledge of writing story problems on three occasions; (a) before they receive any instruction, (b) after they receive instruction on fraction concepts and operations and (c) after they receive instruction on writing story problems. This study sought to answer the following research questions:

1. Was there a mean difference between the number of correct story problems written by PTs (a) before and after receiving instruction on fraction concepts and operations (b) before and after receiving instruction on writing story problems for fraction number sentences?
2. Was there a mean difference between the number of correct story problems written by PTs who received instruction that focused on error analysis and who received a direct instruction on writing story problems for fraction number sentences?

Related Literature

In 2008, the National Mathematics Advisory Panel stated that proficiency with fractions should be a major goal for K-8 mathematics. They stated that the proficiency with fractions is foundational for algebra, yet it seems to be severely underdeveloped. Teachers' conceptual knowledge of fraction concepts and how they teach them to their students are important factors for students' conceptual development of fractions. In the U.S., the conventional instruction with fractions is usually procedural or rule-based (NRC, 2001), and U.S. teachers are more likely to emphasize algorithmic processes and much less likely to create story problems to help their students understand fractions than their Chinese counterparts (An, Kulm, & Wu, 2004). However, students are less likely to make a conceptual error when either a visual model or a story problem context is present in scaffolding (Rittle-Johnson & Koedinger, 2005). Therefore, they need to learn fractions in real-world contexts that are meaningful to them (Cramer & Whitney, 2010). However, Ma (2010) reported that U.S. teachers were not able to create a story problem for a fraction division number sentence. McAlister and Beaver (2012) identified 40 distinct errors found in story problems generated by their PTs for specified fraction number sentences. Many of their participants reported that they had never written a story problem before, and also many had no idea how to even attempt to write one, particularly for multiplication and division. Student-authored story problems can reveal a variety of students' misconceptions (Alexander & Ambrose, 2010). For example, Dixon et al. (2014) examined the story problems generated by PTs, and reported that PTs represented fraction subtraction number sentences by an incorrect redefinition of the whole.

Methodology

Participants and Data Collection

Participants were 65 PTs who were enrolled in two sections of mathematics content course designed for elementary/middle-school teachers. One section was randomly chosen as the treatment group and the other section served as the control group. PTs in both groups were given two number sentences for each of the four basic operations for which the first number sentence included two fractions, and the second number sentence included two mixed numbers, totaling eight number sentences. They were asked to write a story problem for each number sentence in August, before they received any instruction; in October, after they received instruction on fraction concepts and operations; and in November, after they received instruction on writing story problems for specified fraction number sentences.

Class Instruction

For both the treatment and control groups, the first part of the class instruction focused on making sense of fraction concepts and operations using different strategies with emphasis on modeling strategies. Class instructions usually started with PTs working on contextualized problems in their small groups, and then sharing variety of solution strategies as a whole class. When the classes finished fraction concepts and operations, the two groups received different types of instruction on writing story problems. In treatment group, we used an error analysis approach. In this approach, PTs were provided with story problems (problems that we collected from our PTs in previous semesters), which included several errors and were asked to identify errors first in their small groups. Next, these errors and how to change the wording of the problem to eliminate the errors were discussed as a whole class. While determining the errors, PTs were encouraged to use modeling strategies to solve the problems if needed. Then, PTs wrote their own problems for specified number sentences and we shared several problems and discussed the errors, if any, as a whole class. In the control group, a direct teaching approach was used. PTs were asked to write story problems. Then, we strategically chose several problems with errors for each operation, explain what the error(s) was, and had a class discussion about how to change the wording of the problems to eliminate the error(s). The instructional time for control group was about 4 hours, and it was about 5.5 hours for the treatment group.

Data Analysis

Student authored story problems were coded by two researchers independently into two categories as correct and incorrect story problems. The percent agreement method used for inter-rater reliability and it was calculated to be 0.86. The researchers met twice to discuss all discrepancies and came to an agreement on the final coding. Descriptive statistics were obtained for each type of operation at each data collection point. Repeated measures ANOVA was conducted to compare the differences in scores among three data collection points, and ANCOVA analysis was conducted to compare the treatment and control groups with respect to their November scores in which the October scores were used as the covariate.

Results and Discussion

The line plots in figures 1 and 2 show proportions of correct answers obtained by treatment and control group PTs separately for each operation at each data collection point.

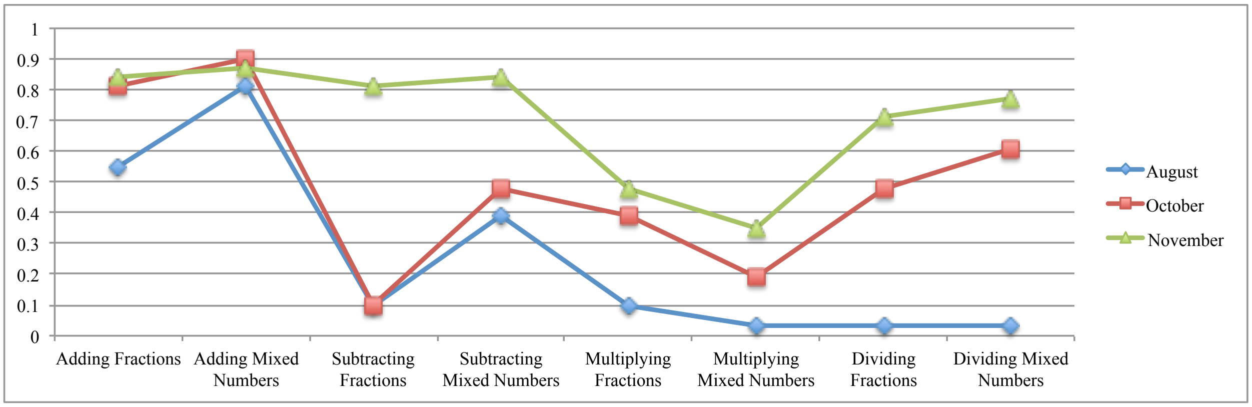


Figure 2: The proportions of correct answers for each operation at each data collection point in the treatment group

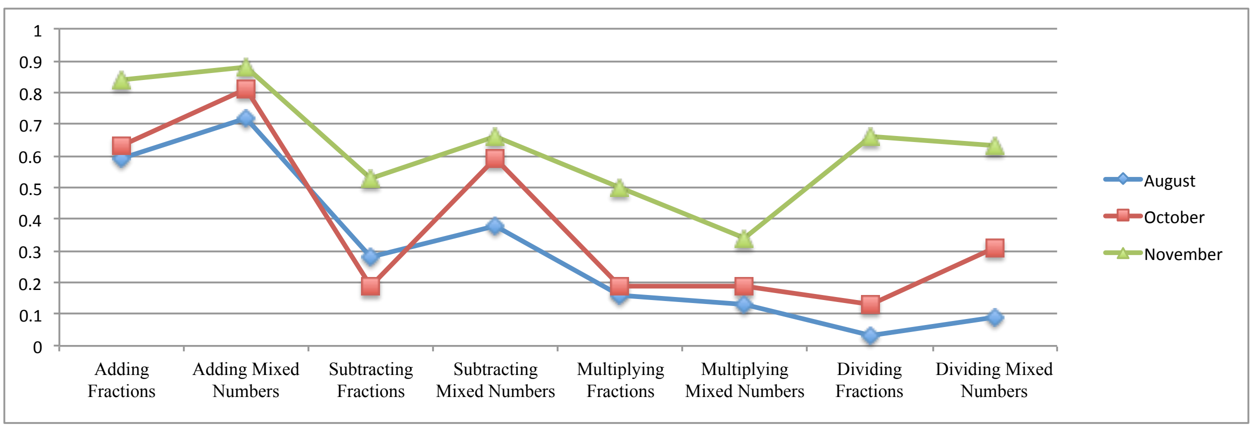


Figure 2: The proportions of correct answers for each operation at each data collection point in the control group

The proportions presented above show that for both groups, the highest proportion (.5 or more) of correct story problems was for the addition number sentences in August, before they received any instruction. The proportion of correct story problems for subtraction number sentences was very low, and the proportions were the lowest for multiplication and division number sentences. This revealed that writing story problems for multiplication and division number sentences were the most challenging tasks for PTs in August. Comparison of proportions at different data collection points revealed that, in general, there was an increase in the proportions of correct problems for all operations in October, after PTs received instructions on fraction concepts and operations. There was a higher amount of increase in the proportion of correct answers for all operations in November, after PTs received instructions on writing story problems. PTs in the treatment group showed the highest improvement in writing story problems for subtraction and division number sentences from August to November. PTs in the control group showed the highest improvement in writing story problems for division number sentences from August to November. The least improvement from August to November was seen on story problems for multiplication number sentences in both groups.

To compare the differences in scores (August, October, and November), we used repeated measures ANOVA. The Mauchly's Test of Sphericity was not significant. Table 1 displays the mean number of correct story problems in August, October and November.

Table 1:

Descriptive Statistics

	Mean	Std. Deviation	N
August Score	2.2063	1.46087	63
October Score	3.4762	1.78576	63
November Score	5.3492	1.8242	63

Table 2 shows that there were significant differences in scores (i.e. significant effect of instruction on fraction concepts and significant effect of instruction on writing story problems) (F_2= 86.52, $p < .001$). Approximately 58% of the variance in score can be accounted for by repeated trials.

Furthermore, table 3 shows that instruction on fraction concepts and operations, and instruction on writing story problems had a significant effect on PTs' knowledge of writing story problems. PTs obtained significantly lower scores in August than they obtained in October, and their scores from October were significantly lower than the scores they obtained in November.

To compare the differences between the treatment and control groups, we performed an ANCOVA analysis where we used the November scores as the dependent variable, and October scores as the covariate. Table 4 shows that there was no statistically difference between the two groups ($F=0.111$, $p>.05$).

Table 2:

Tests of Within-Subjects Effect

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Testing_Time	Sphericity Assumed	314.963	2	157.481	86.519	0.00	0.583	173.038	1
	Greenhouse-Geisser	314.963	1.942	162.151	86.519	0.00	0.583	168.056	1
	Huynh-Feldt	314.963	2	157.481	86.519	0.00	0.583	173.038	1
	Lower-bound	314.963	1	314.963	86.519	0.00	0.583	86.519	1
Error(Testing_Time)	Sphericity Assumed	225.704	124	1.82					
	Greenhouse-Geisser	225.704	120.429	1.874					
	Huynh-Feldt	225.704	124	1.82					
	Lower-bound	225.704	62	3.64					

[a] Computed using alpha =

Table 3:

Pairwise Comparisons

(I) Testing Time	(J) Testing Time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-1.270*	0.222	0.00	-1.714	-0.826
	3	-3.143*	0.258	0.00	-3.658	-2.627
2	1	1.270*	0.222	0.00	0.826	1.714
	3	-1.873*	0.24	0.00	-2.353	-1.393
3	1	3.143*	0.258	0.00	2.627	3.658
	2	1.873*	0.24	0.00	1.393	2.353

Based on estimated marginal means

* The mean difference is significant at the

[b] Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 4:

Tests of Between-Subject Effect

Dependent Variable: November Score								
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Powerb
Corrected Model	51.488a	2	25.744	8.276	0.001	0.203	16.551	0.954
Intercept	178.188	1	178.188	57.28	0.00	0.468	57.28	1
S2	47.238	1	47.238	15.185	0.00	0.189	15.185	0.97
TC	0.346	1	0.346	0.111	0.74	0.002	0.111	0.062
Error	202.203	65	3.111					
Total	2149	68						
Corrected Total	253.691	67						

a R Squared = .203 (Adjusted R Squared = .178)

b Computed using alpha =

Implications

In our study we investigated the PTs' knowledge of writing word problems for specified fraction number sentences. PTs showed a significant increase in their knowledge after receiving instruction on fraction concepts and operations. Furthermore, their knowledge continued to improve significantly when they received instruction on writing story problems. Therefore, we recommend mathematics educators to include tasks about writing story problems for specified fraction number sentences in their content classes.

We also examined the effect of two types of instructions (error analysis and direct instruction) on writing story problems, but did not find any significant differences between these two approaches. In both groups, PTs were provided with an opportunity to write story problems for fraction numbers sentences, which might have contributed to this result. It is important to note that, PTs who received the error analysis approach had a higher proportion of correct story problems for fraction subtraction and fraction division number sentences (82.5%, and 74% respectively) than the PTs were in the control group (60% and 65% respectively). Both groups had similar proportion of correct story problems (43%) for fraction multiplication number sentences. Writing story problems for fraction multiplication number sentences remained as a challenge for most PTs in our study. Further investigation is needed to understand how this lack of improvement in writing multiplication story problems relates to PTs' level of understanding of what it means to multiply two fractions.

References

Alexander, C. M., & Ambrose, R. C. (2010). Digesting Student-Authored Story Problems. *Mathematics Teaching in the Middle School*, *16*(1), 27-33.

Ann, S., Kulm, G. & Wu, Z. (2004). The Pedagogical content knowledge of middle school mathematics teachers in China and the U.S. *Journal of Mathematics Teacher Education*, 7, 145-172.

Cramer, K., & Whitney, S. (2010). Learning rational number concepts and skills in elementary school classrooms. *Teaching and learning mathematics: Translating research for elementary school teachers*, 15-22.

Dixon, J. K., Andreasen, J. B., Avila, C. L., Bawatneh, Z., Deichert, D. L., Howse, T. D., & Turner, M. S. (2014). Redefining the whole: Common errors in elementary preservice teachers' self-authored word problems for fraction subtraction. *Investigations in Mathematics Learning*, *7*(1), 1-22.

Ma, L. (2010). *Knowing and teaching elementary mathematics: Teachers' understanding of fundamental mathematics in China and the United States*. Routledge.

McAllister, C. J., & Beaver, C. (2012). Identification of error types in preservice teachers' attempts to create fraction story problems for specified operations. *School Science and Mathematics*, *112*(2), 88-98.

National Mathematics Advisory Panel. (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel*. Washington, DC: U.S. Department of Education.

National Research Council, & Mathematics Learning Study Committee. (2001). *Adding it up: Helping children learn mathematics*. National Academies Press.

Pirie, S. (2002). Problem posing: What can it tell us about students' mathematical understanding? In D. Mewborn, P. Sztajn, E. White, H. Wiegel, R. Bryant & K. Nooney (Eds.), Psychology of Mathematics Education North America (PME-NA), Athens, GA (pp. 927–958, vol 1-4). Columbus, OH: Eric Clearinghouse for Science, Mathematics, and Environmental Education.

Rittle-Johnson, B., & Koedinger, K. R. (2005). Designing knowledge scaffolds to support mathematical problem solving. *Cognition and Instruction*, *23*(3), 313-349.

Rubenstein, R. N., & Thompson, D. R. (2001). Learning mathematical symbolism: Challenges and instructional strategies. *The Mathematics Teacher*, *94*(4), 265.

THE IMPACT OF TECHNOLOGY BASED MATHEMATICAL MODELING ON MIDDLE SCHOOL STUDENTS' MINDSETS

Micah Stohlmann
University of Nevada, Las Vegas
micah.stohlmann@unlv.edu

Xing Huang
University of Florida
xing.huang@ufl.edu

Lina DeVaul
University of Nevada, Las Vegas
lina.devaul@unlv.edu

Growth mindset is a vital belief for students to be successful in mathematics. Mathematical modeling as well has many positive benefits for students. Little research has been conducted on growth mindset and mathematics at the middle school level and particularly growth mindset with mathematical modeling. This study explored middle school students' mindsets before and after a four-week Saturday program that incorporated mathematical modeling. We also looked at the quality of solutions developed by the students. It was found that the students generally had growth mindsets at the beginning of the student that were improved through the four weeks.

Introduction

One of the main factors that affects whether students do well in mathematics is their mindset. A student's mindset is a collection of beliefs on if he or she feels that intelligence is something that can be changed and if continual learning is possible. The concept of a growth mindset has received more attention since Dweck's (2006) book on the subject. A growth mindset is the belief that intellectual skills can be cultivated through effort while on the opposite spectrum a fixed mindset is believing that your qualities are carved in stone or fixed (Dweck, 2006). Fixed mindsets are particularly troubling because "fixed mindsets beliefs contribute to inequalities in education as they particularly harm minority students and girls; they also contribute to overall low achievement and participation" (Boaler, 2013, p. 150).

In addition to instilling in students a growth mindset, incorporating mathematical modeling has been recommended as a way to reduce inequities in mathematics education and to give students the opportunity to demonstrate mathematical understanding that may not be captured on typical assessments (Lesh & Doerr, 2003). Implementing mathematical modeling enables teachers to employ best practices for mathematics teaching including cooperative learning, assessment integrated in instruction, building on prior knowledge of students, and a focus on students' capabilities.

Since growth mindsets can be an important factor to continued success in mathematics, it is vital to determine how to develop this belief in students. In the past research, teaching students directly about growth mindset through computer programs, readings, and brain research has been used to develop growth mindsets in students (e.g. Paunesku et al., 2015). Little research though has focused on mathematical modeling being used as an intervention to help students hold growth mindset beliefs. Participating in mathematical modeling has the potential to develop growth mindsets. In one study, freshmen engineering students worked on an open-ended project and the researchers found this project had a positive effect on helping students develop a growth mindset (Reid & Ferguson, 2014). Through mathematical modeling students can persevere in problem solving, use multiple representations in their solutions, see there is more than one right answer to a problem, that there is not one type of person that can be successful in mathematics, and learn from others.

Objectives of the Study

This study investigated middle school students' mindsets, using Dweck's (2006) growth mindset Likert questionnaire, before and after a four-week Saturday science, technology, engineering, and mathematics(STEM) program offered at a large research university in the Southwestern part of the United States. The program focused on having students participate in mathematical modeling. For this study our definition of mathematical modeling problems are real world or game-based tasks that have multiple possible answers that students make sense of with mathematics using multiple representations. The research questions that guided this study were the following: What are middle school students' mindsets before and after participating in a four-week Saturday program focused on mathematical modeling? Using the Quality Assurance Guide (Lesh & Clarke, 2000), how is the quality of solutions related to the groups' mindsets?

Related Literature

Growth Mindset

Theories of mindset enable us to understand how mindset fosters goals, attributions, and reactions to setbacks (Dweck, 2017). Students who hold growth mindsets set self-improvement as achievement goals, attribute failures to something that is under their control, and work harder when faced with setbacks. These students actively try new learning strategies and seek all available resources. However, students who hold fixed mindsets aim for performance-oriented goals, see failures as something that is beyond their control, and give up when they experience setbacks.

Research has shown that fostering growth mindsets improves students' academic performance, increase students' motivation, and reduce social, gender, and social class gaps. For example, a mindset intervention significantly helped at-risk students raise their semester grade point average in core academic courses (Paunesku et al. 2015). In a sample across all of the socioeconomic levels in Chile, Claro, Paunesku, and Dweck (2016) found that growth mindset was a relative strong predictor of math and language performance. It is suggested that students' growth mindset might play a role in mediating the effects of economic disadvantages.

Growth Mindset and Mathematics

Few studies have examined how growth mindset impacts students' mathematics performance particularly at the middle school level, but there have been promising results. Good and her colleagues found that a growth mindset intervention increased both 7th grade boys' and girls' mathematics performance, and that such increase was higher for girls (Good et al., 2003). Blackwell, Trzesniewski, and Dweck (2007) examined the role of growth mindset in 373 seventh grade students' mathematics achievement and found that a growth mindset was a significant predictor of students' mathematics achievement for the students as they were followed into 8^{th} grade. Bostwick et al. (2017), in a study of 4,411 Australian students in 7th grade to 9th grade, found that even when students' background factors were included, students' growth orientations were positively associated with both their academic engagement and achievement.

This previous research demonstrates the importance of helping students to develop a growth mindset. More research is needed specifically on growth mindset and mathematical modeling though. In a review of research on secondary mathematical modeling, Stohlmann et al. (2016) proposed a question that requires further investigation in regards to student mindsets. "What is the potential of mathematical modelling to support both students and teachers in their development of appropriate beliefs about and attitudes towards mathematics? (p. 21)" This study serves to provide insight into this question.

Methodology

This study was conducted with 19 middle school students (age 11-13) that voluntarily enrolled in a Saturday STEM program at a large research university in the Southwestern part of the United States. The students were ethnically diverse and from a large urban school district. The purpose of the Saturday STEM program was to provide a series of inquiry experiences designed to provide interesting and exciting opportunities in STEM education. Fourteen out of the nineteen students reported typically receiving an A or A- in mathematics, with the other five students typically receiving a B+ or B. The first and third authors were the instructors for this program and had been instructors for this program for several years.

The program lasted four Saturdays (Table 1) and involved different activities, mathematical modeling activities, and also videos of general social skills that students need to work effectively in groups. Each day had an overall topic: day 1 focused on equations and expressions, day 2 on ratios and proportions, day 3 linear equations, and day 4 systems of equations. The Ker-splash game is played against a partner and involves collecting coins that have x values, y-values, and constant values. The waffle choices activity involves determining which box of waffles to buy. Polygraph lines is a game played with a partner to determine which linear graph a partner has chosen out of 16 possible graphs. Polygraph linear systems is similar just with graphs of linear systems. The stairs or elevator activity has students determine which is the better choice.

Table 1

Saturday STEM program activities by day

Day	Activities
1	-Growth mindset likert questionnaire (Dweck, 2006) -Communicating and listening video (FlowMathematics, 2012) -Dirt Dash (Calculation Nation, 2018) -Ker-splash (Calculation Nation, 2018)-mathematical modeling activity
2	-Decision making video (FlowMathematics, 2011) -Waffle choices activity (When Math Happens, 2018)-mathematical modeling activity -Marcellus the giant (Desmos, 2018) -ST Math 7th grade proportional relationships-monster ratios and build a monster (ST Math, 2018)
3	-Polygraph lines (Desmos, 2018)-mathematical modeling activity -Polygraph lines part 2 (Desmos, 2018) -Marbleslides line (Desmos, 2018) -Lego prices (Desmos, 2018)
4	-Stairs or elevator problem (When math happens, 2018)-mathematical modeling activity -Polygraph linear systems (Desmos, 2018)-mathematical modeling activity -Systems of two linear equations (Desmos, 2018) -Growth mindset likert questionnaire (Dweck, 2006)

Data Collection and Analysis

The data collection involved student work, a pre and post growth mindset Likert questionnaire (Dweck, 2006), and researcher field notes. Of the 19 students, 15 fully completed the pre and post growth mindset Likert questionnaire. The growth mindset questionnaire was analyzed by assigning a point value of 0 to 5 for each question, with a higher score being more closely aligned to a growth mindset. For example, two questions are listed below with the point values included.

-No matter who you are, you can significantly change your intelligence level.

Strongly agree (5) Agree (4) Mostly agree (3) Mostly disagree (2) Disagree (1) Strongly Disagree (0)

-You have a certain amount of intelligence, and you can't really do much to change it.

Strongly agree (0) Agree (1) Mostly agree (2) Mostly disagree (3) Disagree (4) Strongly Disagree (5)

The students pre and post questionnaire were summarized using descriptive statistics and a paired t-test was conducted to see if there was a significant difference between the pre and post scores. Table 2 summarizes general categories for individual total scores on the growth mindset questionnaire.

Table 2

Growth mindset questionnaire categorizations

Categorization	**Points value**
Strong growth mindset	61-80 points
Growth mindset with some fixed ideas	41-60 points
Fixed mindset with some growth ideas	21-40 points
Strong fixed mindset	0-20 points

The other data was analyzed using the Quality Assurance Guide (QAG) to give students' solutions on the mathematical modeling activities a quality ranking (Lesh & Clarke, 2000). The QAG was designed to evaluate products that are developed from mathematical modeling activities (Table 3). Two of the researchers coded the students' solutions. The Cohen's K coefficient of inter-rater agreement was .80, and thus within an acceptable range (Fleiss, 1981; Landis & Koch, 1977). Once coding differences were identified, the raters came to agreement on the discrepancies so that full agreement was reached.

Table 3

Quality assurance guide

Performance level	**Description**
(0) Requires redirection	The product is on the wrong track. Working longer or harder won't work. The students may require some additional feedback from the teacher.
(1) Requires major extensions or refinements	The product is a good start, but a lot more work is needed to respond to all of the issues.
(2) Requires only minor editing	The product is nearly ready to be used. It still needs a few small modifications, additions, or refinements.
(3) Useful for the specific situation given	No changes will be needed for the current situation.
(4) Sharable or reusable.	The solution not only works for the immediate situation, but it also would be easy for others to modify and use it in similar situations.

Results and Discussion

A paired t-test indicated that there was a statistically significant difference between the pre and post growth mindset questionnaire: pre-test (M= 59.47, SD = 15.9) and the post-test (M= 66.07, SD= 14.55), $t(14) = 1.576$, $p = 0.069 < .10$. The mean increased compared to the post-test and moved from a categorization of growth mindset with some fixed ideas to a strong growth mindset. The Cohen's d effect size was .43, which is a medium to small effect size. Table 4 details the descriptive statistics.

Table 4

Pre and post-questionnaire descriptive statistics

Pre-Questionnaire					Post Questionnaire				
n	M	Min	Max	SD	n	M	Min	Max	SD
15	59.47	20	80	15.9	15	66.07	38	80	14.55

There were five groups for each of the open-ended problems the students completed and each group was given a score based on the Quality Assurance Guide (Table 5). The majority of scores of 2 or greater on the activity means indicates that the students on average developed useable solutions or only needed small modifications or refinements. The students also improved in their scores from the first to the last modeling activity. A Wilcoxen signed-rank test indicated that students did better on the last activity (mean =3.2) than the first activity (mean = 1.8), $Z = -1.84$, $p = .066 < .10$.

Table 5

Quality assurance guide scores per group for the mathematical modeling problems

	Ker-splash	Waffle choices	Polygraph lines	Stairs or elevator	Polygraph linear systems	Group mean
Group 1	1	2	1	1	2	1.4
Group 2	4	2	4	4	4	3.6
Group 3	1	2	1	1	2	1.4
Group 4	2	4	4	3	4	3.4
Group 5	1	0	2	2	4	1.8
Activity mean	1.8	2	2.4	2.4	3.2	

Table 6 displays the pre and post assessment averages for each group on the growth mindset Likert questionnaire. Results of a Spearman correlation indicated that there was not a significant correlation between the groups' post questionnaire average and the groups' activity average, ($r_s(3) = -.564$, $p > .10$)

Table 6

Pre and post group averages on the growth mindset Likert questionnaire

	Group 1	Group 2	Group 3	Group 4	Group 5
Pre-score	48.3	59.6	67	56	65.6
Post score	70.3	65.3	74	65	63.6

Implications

This study was conducted to determine the mindsets of middle school students before and after a 4-week Saturday program that incorporated mathematical modeling; as well as the quality of solutions the students developed. The class average significantly increased from the pre to the post assessment on the growth mindset questionnaire. The Saturday program helped improve the students' mindsets. This is an important finding as having students participate in mathematical modeling can be another way to help students develop growth mindsets. When students are participating in mathematical modeling they need to persevere in problem solving, try new approaches, use all of their resources, and continue to develop their ideas when encountering setbacks or failures. These are all characteristics that are connected with a growth mindset. The students in this study were on-task while working on the mathematical modeling problems and used the Internet when needed, their group members, and other groups to persevere in problem solving.

For the second research question there was not a significant correlation between the groups' growth mindset average and the quality of solutions. Since this study had a small sample size future research is needed to investigate how growth mindset is related to the quality of solutions developed during mathematical modeling. Future research can also focus on mathematical modeling with students who have strong fixed mindsets and/or lower mathematics ability.

References

Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development, 78*(1), 246-263.

Boaler, J. (2013). Ability and mathematics: The mindset revolution that is reshaping education. *Forum, 55*(1), 143-152.

Bostwick, K., Collie, R., Martin, A., & Durksen, T. (2017). Students' growth mindsets, goals, and academic outcomes in mathematics. Zeitschrift Fur Psychologie-*Journal of Psychology, 225*(2), 107-116.

Calculation nation (2018). Calculation nation. Retrieved from https://calculationnation.nctm.org

Claro, S., Paunesku, D., & Dweck, C. (2016). Growth mindset tempers the effects of poverty on academic achievement. *Proceedings of the National Academy of Sciences of the United States of America, 113*(31), 8664-8668.

Desmos (2018). Desmos classroom activities. Retrieved from https://teacher.desmos.com

Dweck, C. (2017). The journey to children's mindsets—and beyond. *Child Development Perspectives, 11*(2), 139-144.

Dweck, C. (2006). *Mindset: The new psychology of success.* New York: Random House.

Fleiss, J. (1981). *Statistical methods for rates and proportions.* New York: John Wiley.

FlowMathematics (2012). Communicating and listening. Retrieved from https://www.youtube.com/watch?v=2sQmRPVAf54&t=8s

FlowMathematics (2011). Decision making. Retrieved from https://www.youtube.com/watch?v=MXd5U0Q9-Vk&t=197s

Good, C., Aronson, J., & Inzlicht, M. (2003). Improving adolescents' standardized test performance: An intervention to reduce the effects of stereotype threat. *Journal of Applied Developmental Psychology, 24*(6), 645-662.

Landis, J. & Koch, G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1), 159-174.

Lesh, R. & Clarke, D. (2000). Formulating operational definitions of desired outcomes of instruction in mathematics and science education. In A.E. Kelly & R. Lesh (Eds.), *Handbook of research design in mathematics and science education.* (pp.113-149). Mahwah, NJ: Lawrence Erlbaum.

Lesh, R. & Doerr, H.M. (2003). Foundations of a models and modeling perspective on mathematics teaching, learning, and problem solving. In R. Lesh & H. Doerr (Eds.), *Beyond constructivism* (pp.3-38). Mahwah, NJ; Lawrence Erlbaum Associates.

Paunesku, D., Walton, G. M., Romero, C., Smith, E. N., Yeager, D. S., & Dweck, C. S. (2015). Mind-set interventions are a scalable treatment for academic underachievement. *Psychological Science, 26*(6), 784-793.

Mind Research Institute (2018). ST Math. Retrieved from www.stmath.com

Reid, J. & Ferguson, D.M. (2014). Do design experiences in engineering build a "growth mindset" in students? *2014 IEEE Integrated STEM Education Conference*, (pp.1-5). Princeton, NJ.

Stohlmann, M., DeVaul, L., Allen, C., Adkins, A., Ito, T., Lockett, D., & Wong, N. (2016). What is known about secondary grades mathematical modeling-a review. *Journal of Mathematics Research, 8*(5), 12-28.

When math happens (2018). When math happens. Retrieved from https://whenmathhappens.com