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Rayelynn Brandl
Georgia Cobbs
Melanie Shores

Editors

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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).

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Suzanne M. Nesmith

Suzanne Nesmith
SSMA President

PREFACE

These proceedings are a written record of some of the research and instructional innovations presented at the 119th Annual Meeting of the School Science and Mathematics Association held in Salt Lake City, Utah, November 7-9, 2019. The blinded, peer reviewed proceedings includes seven papers regarding instructional innovations and research. The acceptance rate for the proceedings was 70 %. We are pleased to present these Proceedings as an important resource for the mathematics, science, and STEM education community.

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Rayelynn Brandl
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EXAMINING STUDENTS' USE OF INFORMAL MODELING STRATEGIES TO SOLVE NON-TRADITIONAL MATHEMATICS PROBLEMS

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This paper reports on a study of pre-service middle-grades mathematics teachers (PMMT) that examined how they used informal modeling methods to solve non-traditional mathematics problems. Participants came from a Mathematics course for PMMTs (N=35) at a four-year university. Data included results of the students' performance on a mathematics placement exam and written records from interviews conducted with a subset (N=15) of the original sample. Protocols were examined to identify: (1) the role that the student's informal modeling strategies play in solving non-traditional mathematics problems; and (2) the iterative cycles of modeling characterizing the students' solutions.
Keywords: modeling processes, problem solving, mathematical understanding.

Introduction

Mathematical modeling is the process of using mathematics to analyze functional relationships in empirical situations, to gain understanding so that problems can be solved (NCTM, 2000; Common Core Standards, 2011). Noting the practical role that modeling plays in academic disciplines such as physics and engineering, the mathematics education community has called for studies to examine how having students engage in modeling might help them develop as problem solvers (NCTM 2000; Ernest, Greer, & Sriraman, 2009).

Some researchers have gone so far as to recommend revising our perspectives of problem solving (i.e., as the application of formal strategies) to adopt a focus on the modeling actions of solvers, to show how problem solving can then be explained as iterative cycles of goal-directed activity (Doerr & Lesh, 2011; Lesh and Zawojewski, 2007; Ärlebäck & Doerr, 2015) (Figure 1).

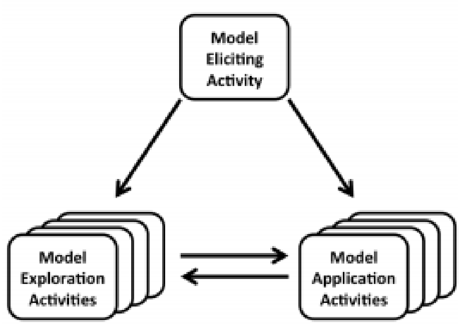


Figure 1: Problem solving as modeling (taken from Ärlebäck and Doerr, 2015)

The suggestion that modeling is best studied within project-based problems (Lesh and Zawojewski, 2011) is only one view of how we should consider problem solving. Alternatively, constructivist views of knowledge consider problem solving as a form of learning common to most mathematical situations (Cobb & Steffe, 2011). In hypothesizing that these cycles of problem solving can be seen in other types of mathematical tasks than those proposed by Lesh and his colleagues, the current study views these modeling activities as having roots within informal activity that helps the solver develop an initial model of the problem that then is re-produced as iterative cycles as problem solving commences. Hence, an important goal of the study is to highlight the constructive nature of the modeling process throughout problem solving, across a range of tasks.

Research Questions

The study examined how students used modeling to solve non-traditional mathematics problems. Unlike typical textbook story problems, non-traditional problems have solutions that do not depend on the application of formal algorithms and thus may be solved with a variety of informal methods (such as the construction of diagrams, organized lists, systematic trial-and-error, and iterative patterns). Of particular interest is a focus on how students use informal strategies to explore these problems and develop the modeling cycles proposed by Lesh and Zawojewski. The research questions are:

1. What are the informal modeling strategies students use to solve non-traditional mathematics problems?
2. What role do the student's informal modeling strategies play in the solution of non-traditional mathematics problems?
3. How does adopting a modeling focus improve our analyses of problem solving?

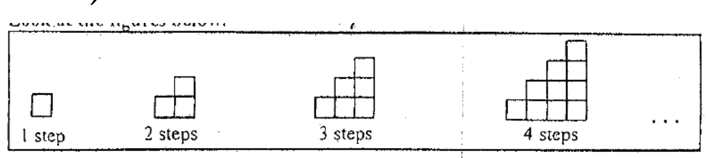
Theoretical Framework and Related Research

The study incorporates a constructivist view of learning (Cobb & Steffe, 2011), which views mathematics learning as a problem-based process of building up one's mathematical knowledge. The study focuses on the cognitive actions of students as they solve non-traditional problems, particularly their goal-directed action patterns of action such as their planning and the development of goals. The analysis looks to explain how goal-directed sensorimotor actions are transformed (or *interiorized*) into mental action patterns, or operations (Steffe, 2002).

While the research on mathematical modeling does not address the kinds of informal actions hypothesized in the current study (Dossey, 2010), the current study is based on the view that the learners' modeling development has its source within these mental action patterns.

Methodology

Participants in the study came from a mathematics course (taught by the researcher) for PMMTs (N=35) at a four-year university in the Southeast United States. A total of 15 students were chosen for interviews that enabled the researchers to observe the students as they solved a set of non-traditional mathematics problems that involve numerical reasoning and general physical situations (Table 1). Data consisted of videotaped protocols, the researchers' field notes, and the subjects' written work. Written transcripts of the tapes were generated and verbal protocol analytic techniques were used in the analysis (Stake, 2006). Protocols were examined to identify: (1) the informal modeling strategies students used to solve the problems; and (2) the role that the student's informal modeling strategies played in the eventual solution of mathematics problems.

	Table 1: Sample of Non-Traditional Modeling Tasks
Physical situation	<u>Canoe task</u>: Sally, an avid canoeist, decided one day to paddle upstream 6 miles. In 1 hour, she could travel 2 miles upstream, using her strongest stroke. After such strenuous activity, she needed to rest for 1 hour, during which time the canoe floated downstream 1 mile. In this manner of paddling for 1 hour and resting for 1 hour, she traveled 6 miles upstream. How long did it take her to make the trip? **(9 hrs)** Suppose after 4 hours on the river, Sally took a lunch break for 1 hour, during which time she floated downstream. How long did it take her to go the 6 miles up the river? **(12 hrs)**
Physical situation	<u>Stair-building task</u> Using the figures, determine the number of blocks needed to build staircases of 5 steps and 20 steps. Explain your answers. **(** $f(n) = (n^2 + n)/2$, so **15 blocks and 210 blocks)** 
Number reasoning	<u>Chinese Dinner task</u> At a Chinese dinner, every 4 guests shared a dish of rice, every 3 guests shared a dish of vegetables, and every 2 guests shared a dish of meat. There were 65 dishes in all. How many guests were there? **(60 guests)**

The interviews followed principles of teaching experiments underlying contemporary studies of mathematics learning (Roth, 2005; Thompson, 2008). Protocol analytic techniques were used in the analysis of the interview data (Ericsson & Simon, 1993; Roth, 2005). Viewing videotape gives the researcher an opportunity to 'step back' and analyze the dialogue from an observer's perspective and allows for ongoing interpretation and revision of the subject's activity in the course of the analysis (Cobb & Steffe, 2011; Roth, 2005), thus allowing for continual communication between the theory and the data.

Results and Discussion

In consideration of our first research question, the study found that the students demonstrated a variety of informal modeling strategies that helped them construct solutions, including making lists, organized tables and diagrams (Table 2).

Table 2: Summary of Informal Modeling Strategies

	Canoe	Stair-Building	Chinese Dinner
Correct Solutions (N=15)	12	14	8
Informal Strategies	Linear diagrams Iterative patterns Organized lists and tables	Physical diagrams Pattern generation Tables	Mental-image diagrams Tables

Examples from students Matt and Christine's work on the Canoe and Stair-Building tasks help to illustrate these strategies and address the second research question, to highlight the role played by the modeling strategies in the students' solutions.

Students Solving the Canoe task

In solving the Canoe task, Matt generated a pattern to model a single two-hour cycle and used a table to keep track of the hourly cumulative totals (Figure 2). In Figure 2, column 2 of Matt's table indicates the cumulative totals to solve part a while column 3 indicates the total for solving part b of the task.

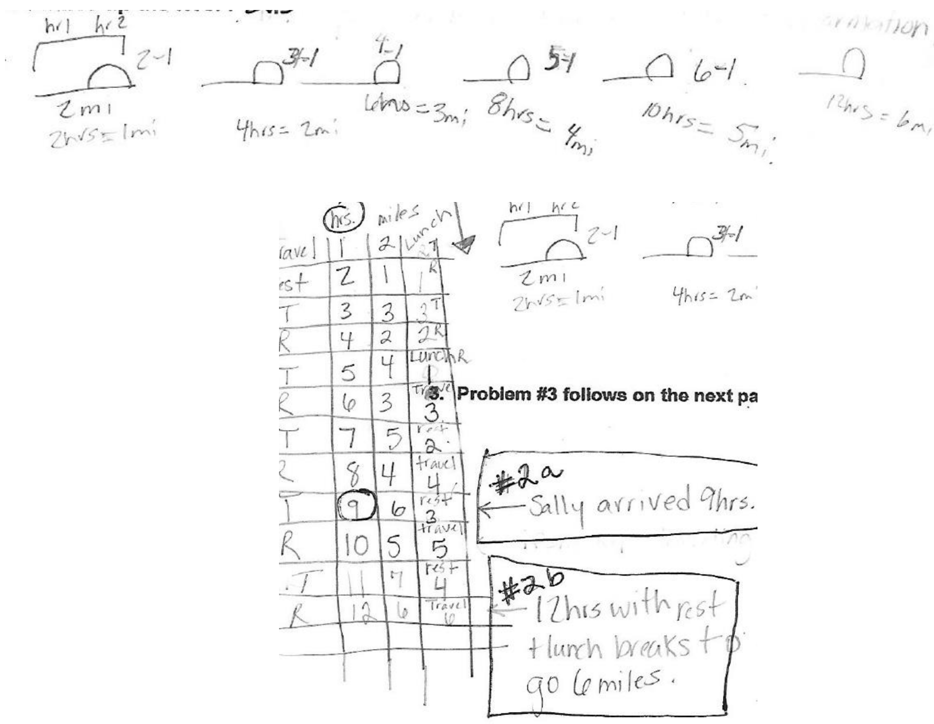


Figure 2: Matt's 'counting up' to solve the Canoe task

In solving the Canoe task, Christine employed an iterative strategy similar to Matt's to unitize each two-hour segment and then iterate the number of segments (Figure 3). She did not require a table to organize the data she generated and so she appeared bit more efficient than Matt in her solution.

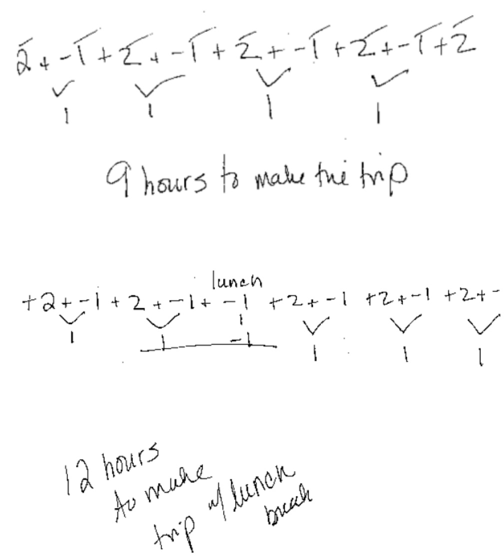


Figure 3. Christine's iterative counting solution to the Canoe task

Noteworthy in Christine's solution (and in contrast to Matt's evolving solution) is that she generated her diagram only after she had spent almost two minutes reflecting on the problem situation.

> **Christine**: I know I have to set up an equation then (*reflection*) (*makes hand gestures*) Okay! So she paddles first, then she rests. She goes +2, then -1, she goes +2, -1, she goes +2 and 1, 3, and she goes + 2 again. So 1, 2,...9 hours to make the trip (Figure 4).That's not how they did it in class! But when I tried to do with distance formulas it didn't work. I had to try something else. I applied logic to it, +2, -1, +2, -1, then set up an equation (sic) to see if it works.

Students Solving the Stair-Building task.

In solving the Stair-Building task, Matt solved part a by continuing the pattern of the illustrative cases and then generated a list to extend the pattern to solve part b (Figure 4).

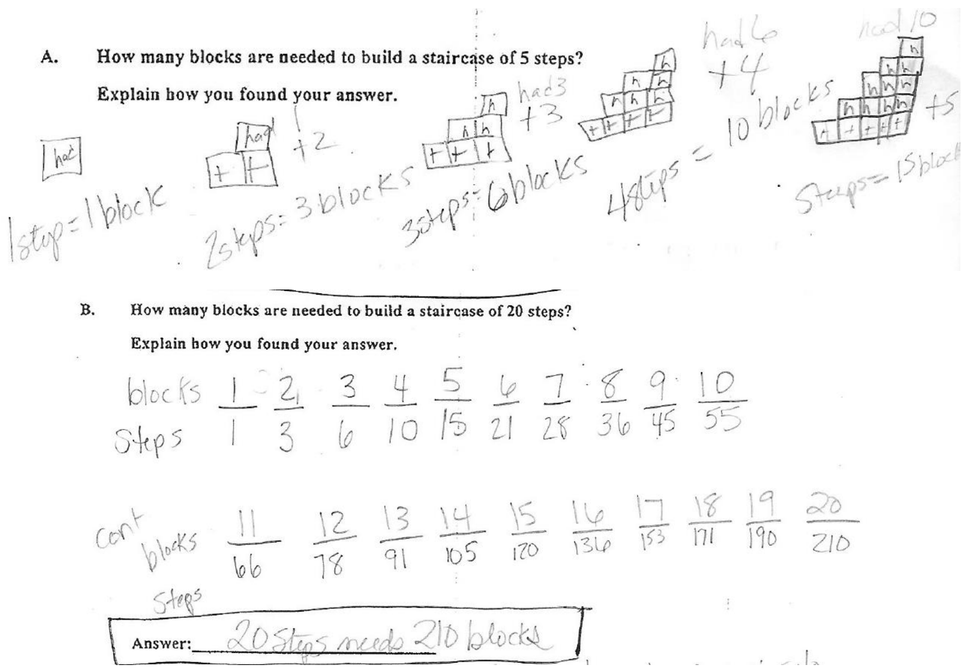


Figure 4: Matt's solution to Stair-Building task

Noteworthy in Matt's solution of part b is that he did not require diagrams of the actual staircases to extend the pattern from a staircase of 5 stairs to a staircase of 20 stairs.

In solving part a of the Stair-Building task, Christine made notes on the table of the illustrative cases (Figure 5a) and generated a diagram for the case of a 5-step staircase. She observed and iterated the pattern to find the solution of 15 blocks. In solving part b, unlike Matt, she tried to solve the more general problem of building a staircase of *n* stairs although she made a mistake in her reasoning (Figure 5b).

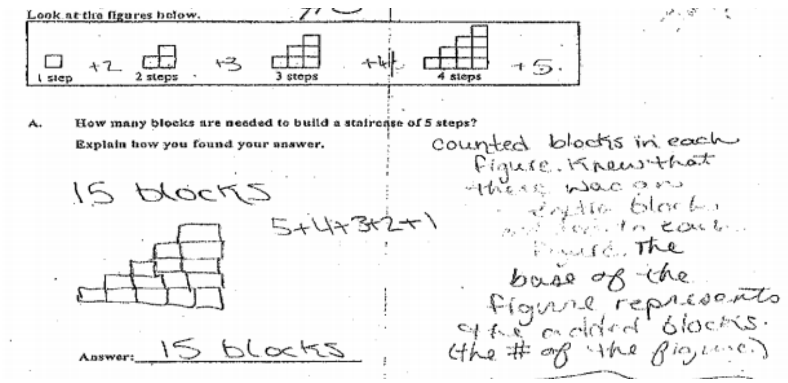


Figure 5a: Christine's solution to a 5-step staircase

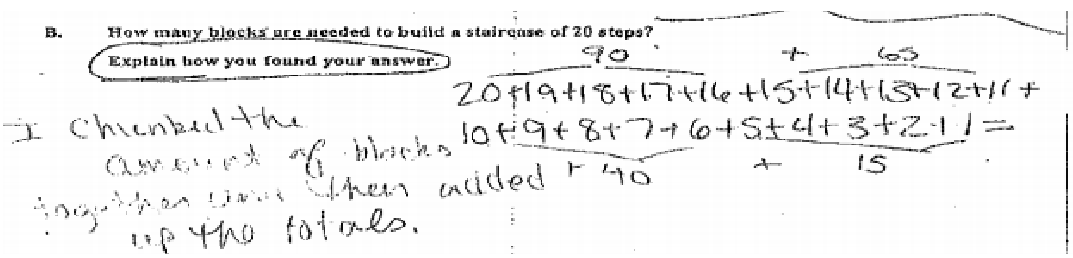


Figure 5b: Christine's solution to a 20-step staircase

Finally, in addressing out our third research question, Figure 6 shows how the results illustrate and elaborate on the exploration and application phases of problem solving as proposed by Ärlebäck and Doerr (2015) and also extends problem solving research that documents how students' interpretations of the problem evolve as chains of problem posing and re-posing (Cifarelli & Sevim, 2015).

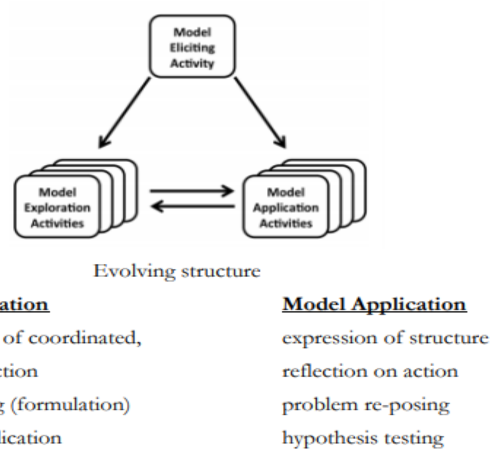


Figure 6: Modeling exploration and application processes (adopted from Ärlebäck & Doerr, 2015)

Implications

The study identified a variety of informal modeling strategies, including organized lists, tables, external and inferred internal diagrams. In addition, the results help clarify the different roles that diagrams can play in the solution of problems. In solving the Canoe task, Christine seemed to spend more time than Matt reflecting before generating her diagram. Her diagram then was less a picture (and starting point) and more a richly structured expression of her reflective actions. By the time she drew an external diagram, she had made important progress towards a solution. In contrast, Matt's diagrams were more of a starting point for him as he used the diagrams to determine cumulative distance totals (counted up) and documented his results in a table.

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HOW A PARTNER TEXT INFORMED OUR MATHEMATICS AND SCIENCE METHODS COURSEWORK

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The Wenger et al., (2011) claim that shared repertoire allows members to have a deeper learning experience was the framework for this faculty collaboration. The National Council for Teachers of Mathematics (NCTM) released two versions of the Five Practices for Orchestrating Productive Discussions: one for mathematics (Smith, M. S., & Stein, M. K, 2018) and one for science (Cartier, Smith, Stein, & Ross, 2013). A locally funded grant allowed us to explore how implementation of these partner texts across a mathematics methods and a science methods course may impact students' connections across program coursework. The collaboration helped inform our course design as a team and created an opportunity for a longitudinal study around the partner texts.

Keywords: faculty collaboration, partner texts, teacher education, productive discussions

Introduction

We have been working as a department to be more intentional in creating connection points for students, throughout their program coursework. During a faculty retreat we created a curriculum map for our Elementary Education program. The mapping activity helped us see an opportunity to collaborate, as a cross content faculty team, and build connections across our coursework. To inform this work we explored the implementation of a partner text in both the mathematics and science methods courses. The National Council for Teachers of Mathematics (NCTM) released two versions of the *Five Practices for Orchestrating Productive Discussions*: one for mathematics (Smith, M. S., & Stein, M. K, 2018) and one for science (Cartier, Smith, Stein, & Ross, 2013). The mathematics version was already in use in the Elementary Education mathematics coursework and the science version was launched in the science methods course at the beginning of the grant. Using the partner texts we could look deeper into student outcomes from the shared repertoire. The notion being that students could expand their understanding of the five practices learned during their mathematics coursework by applying them to a science context.

Objectives/Purpose

Our use of the partner texts is to inform two areas: how students connect knowledge across their courses and how using a partner text can guide our course design as a collaborative team. Here we discuss lessons learned during the initial semester from the faculty and student perspective.

Theoretical Framework and Related Literature

Our Elementary Education program is a cohort model, where students progress together through a similar plan of coursework. Therefore, our exploration is situated in Wenger's (1998) community of practice framework. He uses three dimensions to discuss the idea of community: joint enterprise, mutual engagement, and shared repertoire. Furthermore, Wenger et al., (2011) claim that shared repertoire allows members to have a deeper learning experience. Wenger (1998) postulates that the community of practice negotiates what is meaningful simply by sharing the experience together which aligns with Warhurst, R.P.'s (2006) "learning as belonging" idea. An impetus of the faculty instructional collaboration was to model for students an example of shared repertoire.

Undergraduate cohort programs have steadily increased since the Danforth Foundation grants began in the mid-1980's (Ross et al., 2006). The literature lauds the benefits of learning communities as a structure for building support networks and collaboration among students. This idea of community helps to shift students to the idea of a supportive team, united by a common goal, rather than individual competition (Maher, M. A. 2005; Ross et al., 2006; Warhurst, R. P. 2006; Knorr, R. 2012). There is still minimal information about how a cohort model impacts faculty collaboration. (Beck, C., & Kosnik, C., 2001; Knorr, R. 2012,).

In Practice

We have a teaching and learning center at our university that empowers faculty to explore and implement innovative teaching strategies into their courses. Support from the center includes workshops, teaching circles, teaching resources, and internal grants to put ideas into practice. The grant resource provided an opportunity to be more intentional about faculty collaboration within our Elementary Education cohort program. It also allowed us to begin to model for our students how to build a shared repertoire (Wenger et al., 2011) within a community of practice. The curriculum map created at our faculty retreat gave us a concrete tool to see connections across courses. The partner texts helped inform two areas: how students connect knowledge across their courses and how using a partner text can guide our course design as a collaborative team. The hope being that students could expand their learning in the science methods course by utilizing a discussion structure that they were already familiar with, from their mathematics methods course, and applying it to a new context. The intended benefit for students is that they could now think deeper about the familiar five practices instructional strategy instead of learning a whole new method.

Classroom Examples

The five practices as discussed in the NCTM's books for both mathematics (Smith, M. S., & Stein, M. K, 2018) and science (Cartier, Smith, Stein, & Ross, 2013) are as follows:

1. **Anticipating** student ideas related to the task and potential ways students might solve or engage with the task
2. **Monitoring** students' thinking and work during their class work
3. **Selecting** examples of student work to use in whole class discussion
4. **Sequencing** the order in which you want to discuss the student work examples
5. **Connecting:** plan questions that will elicit key ideas and support connections between ideas and key disciplinary concepts

For a class assignment (see Appendix) students were asked to compare what evidence of productive talk, learned from the coursework, would look like in both mathematics and science. Students discussed similarities across both areas such as: students engaged in discussions using key content terms, demonstrations of student curiosity, explaining ideas to peers, students working in pairs or groups, and students using multiple approaches to a problem or investigation. Distinctive examples of evidence for mathematics discussed were: wanting to know an answer and focused on a solution. Examples of evidence unique to science included: exploring ideas and thinking about setting up investigations.

Lastly, students were asked to rank order the practices in anticipation of implementation difficulty (1-5 with 5 being the most challenging). The average rankings from the class were:

Math	**Science**
1. Monitoring (1) 2. Anticipating (3.5) 3. Selecting (3.5) 4. Sequencing (3.5) 5. Connecting (3.5)	1. Selecting (2) 2. Monitoring (2.25) 3. Connecting (3) 4. Sequencing (3.75) 5. Anticipating (5.0)

The rankings show that students expect "monitoring" student thinking and work during class to be one of the easiest practices to implement with a rank of 1 in mathematics and a 2 in science. Additionally, "selecting" was ranked as easier to implement in science than math. Students unanimously selected the practice of "anticipating" as the most difficult to implement in science. Students stated that this was due to the difficulty in being able to identify all the possibilities of preconceptions that students may have around a science concept. Students felt that it would be easier to anticipate students' approaches to a mathematics concept. During our final class discussion, students agreed that they had a deeper understanding of the practices by applying them to a new content area versus having to learn an additional set of classroom practices for science. They stated a desire to have faculty think about more ways to implement similar strategies within the Elementary Education program.

Implications and Next Steps

After the semester, we met as a faculty team to discuss the student feedback. We agreed that using the partner texts was valuable for our students. The idea of applying the five practices to a new content helped students feel more flexible with a teaching strategy supporting small group discussions. Additionally, we became curious about how student ideas would evolve over time around the five practices. Going back to the department curriculum map we identified four data collection points throughout the elementary education program. We will begin a longitudinal study in the fall semester with students who are taking the first of the 4 courses. Here are the data snapshots we plan to capture:

1. Freshman year: pre-assessment in the beginning mathematics class (see Appendix)
2. Sophomore year: mathematics classroom observation evidence with reflection journals (as part of mathematics methods coursework)
3. Junior/Senior year: application to the science classroom and science classroom observations (as part of science methods coursework)
4. Internship: We will collaborate as a faculty to develop a tool to use during field observations to assess how students are putting the five practices into action in their mathematics and science classrooms (faculty observations with student self-reflections and post assessment, Appendix)

Finally, we look forward to the longitudinal study informing how students process and compare the five practices in each subject area over time and what components of the practices are demonstrated in their internships.

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Appendix

Original Class Assignment (Future Pre/Post Assessment)

5 Practices for Orchestrating Productive Science Discussions Summary

The 5 practices:

1. **Anticipating** student ideas related to the task and potential ways students might solve or engage with the task
2. **Monitoring** students' thinking and work during their class work
3. **Selecting** examples of student work to use in whole class discussion
4. **Sequencing** the order in which you want to discuss the student work examples
5. **Connecting:** plan questions that will elicit key ideas and support connections between ideas and key disciplinary concepts

Key Ideas for Task Design around the 5 practices:

- Students produce artifacts that reveal their thinking and can be made public
- Task places high cognitive demand on students
- Multiple approaches, interpretations, or solutions are possible
- Students often work in pairs or collaborative groups

5 Practices Discussion- what would evidence of productive talk look like	
Math	Science

5 Practices Ranking- Rank order the practices in terms of implementation difficulty (5 being most challenging)	
Math	Science
1. 2. 3. 4. 5.	1. 2. 3. 4. 5.
Do you think these practices will be easier to implement in Math or Science? Why?	

DIFFERENTIATING THE TEACHING OF STATISTICS

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Abstract

A broader understanding of statistical concepts is necessary in STEM research, giving rise to the need for teaching statistics in earlier grade levels. We advocate that the teacher can leverage instructional time through using resources such as historical vignettes, trade books, authentic writing, and technology investigations as methods for developing differentiation that supports every student. The learning of statistics encompasses the integration of many different skill sets; therefore, supporting each learning aspect adds value to all students' learning.

Keywords: Statistics, differentiation, literacy, history, technology

Introduction

The role of statistics within STEM education is evolving; this evolution motivates the discussion of additional teaching strategies. Specifically under discussion in current P-16 curricula conversations is the role that statistics could/should play; in particular, an opinion is that statistics is a more direct, modern, and concrete entrance into STEM areas than College Algebra (Bryk & Treisman, 2010; Salsburg, 2002). While it remains to be seen how this transition develops (if it does), there is a compelling case for including more statistics (loosely including probability and counting) into the P-16 curriculum. All academic disciplines validate experimental findings using statistical analysis; as such, a well-grounded understanding of the principles for the proper use of statistical analysis is vital for all post-secondary careers. The proponents for a "statistics early" approach identify the need to develop in teachers, students, and the general population an outlook and perspective that will help them change their world perspective from Newtonian (calculus) towards an Einsteinian (statistical) approach (Salsburg, 2002).

Objectives/Purpose

The purpose of this paper is to identify some teaching processes/resources that can help the teacher enhance his/her own skills while enabling the construction of scaffolds and supports along the way to the expansion of the students' skills and persistence. Currently practicing teachers, especially P-8, have some exposure to counting principles and probability; their knowledge of statistics is rudimentary, at best, and certainly not fluid (Shaughnessy, 2007, p.995). This is mostly a result of the licensure curricula defined at the time of their training. Causing additional complications is the fact that, by definition, statistics is not a branch of mathematics. While often taught in mathematics departments by mathematicians, and while requiring the use of reasonably sophisticated mathematics, statistical work additionally blends reading comprehension, logical analysis, and inductive thinking far more often than is found regularly in algebra. There are strategies available in the literature for improving the teaching of statistics and for improving teacher readiness and understanding of particular teaching techniques (Daiga, 2017; Kerschen, Shelton, & Wilkerson, 2017). Statistical learning necessitates understanding abstract skills: numeracy, contextual thinking, complex reasoning and synthesis, for example. This work is generally considered more abstract and consequently necessary (to engage in higher Webb/Bloom levels (Noble, 2004).

All of the skills needed for functional use of statistics are valuable; hence, teaching statistics as a gateway to both mathematics and science has a rational basis. A touchstone for planning a lesson are the practices that are elucidated for mathematics education in *Principles to Actions: Ensuring mathematical success for all* (Leinwand, 2014). The strategic application of these methods can help both teachers and students approach, acquire and extend statistical reasoning skills. From this discussion, we see that the boundaries between mathematics and statistics in teaching are blurring (Cobb & Moore, 1997; Groth, 2015); teachers must prepare to traverse this common area.

Instructional Framework /Related Literature

Developing an effective approach to teaching statistics is going to require far more than just a "knack for mathematics" or an ability to "read the details;" teachers and students alike must learn to switch between methods of interacting with the information that they are trying to acquire and analyzing it (Shaughnessy, 2007). Descriptions and analogies are often used to describe the learning process; for the purpose of this paper, consider the analogy of "spiraling." John Denker (2014) has a monograph discussing various approaches to spiral thinking as demonstrated in the acquisition of learning in physics. William Perry (King, 1978) avers that all learning is analogous to ascending spiral staircases in which each spiral enhances and connects to corresponding areas on the previous level. Advanced learning skills simply mean that each spiral level is accomplished in less time. Beginners must move through the first level spiral very slowly and carefully.

The complications involved with statistics is that one must function on multiple spirals and differing levels at the same time. One might need to access reading, calculations, and comparative analysis skills simultaneously and yet function in each of these areas at a different level of expertise. For example, in a problem requiring the analysis of temperature extremes for a week (technically a univariate statistical question), one must deal with data, a definition of "best" or "most usable" statistic, appropriate mathematical calculations, at least 3 obvious definitions of center of data, and possibly the need for a new measure. The task culminates with the analysis of the competing methodologies along with the justification of a final selection.

The authors advocate using a combination of resources to help move all learners through the various stages of the spiral; this simultaneously helps use the different actions of each of the stages in the spiral to support the learning throughout the spiral. An entry level, for example, one can use a historical perspective and/or trade book to support the students' interest and general understanding of the problem. Skills in reading can support areas that require statistical justification and/or explanation; they can also support effective memory and analysis through paraphrasing. Technology can support intermediate mathematical calculations and reduce cognitive load (Mayer & Moreno, 2010). For this layering to work, it must be used at all levels, including introductory. The process of switching between learning patterns/skills and learning focus is the major endeavor to be orchestrated by the teacher and to performed by the student; the actual acquisition of statistical knowledge is a nice by-product.

Practice/Innovation

Figure 1 below illustrates a single spiral through learning a concept. Ultimately, we will consider the application of this spiral to a temperature example. In parentheses is a sample of the scaffolding process that could be selected to occur in that step. Comprehension of the nuances might require several passes through the process, perhaps even changing the differentiation for each step of the scaffold. The entire process, including variations in the individual steps, depends upon the consideration of where the bulk of the new material is occurring. For example, as more advanced analysis is required, introduce additional writing or additional exploration may be required, depending on the needs of the class and the type of material being learned (Beyth-Maron, Fidler, & Cumming, 2008). The content, strategy, and pairing are the purview of the teacher initially. The learners eventually want to develop their own selection and pairing choices.

The Classroom Examples (in Figure 1) contain two examples of a learning situation. The first is a univariate activity; the second deals with bias and experimental design. A figure as well as a table accompany each example. The selection of the types of differentiation for this example vary from the generic example in Figure 1 and will be based on the differing attributes of each stage of the example problem. These pairings are illustrated in the tables.

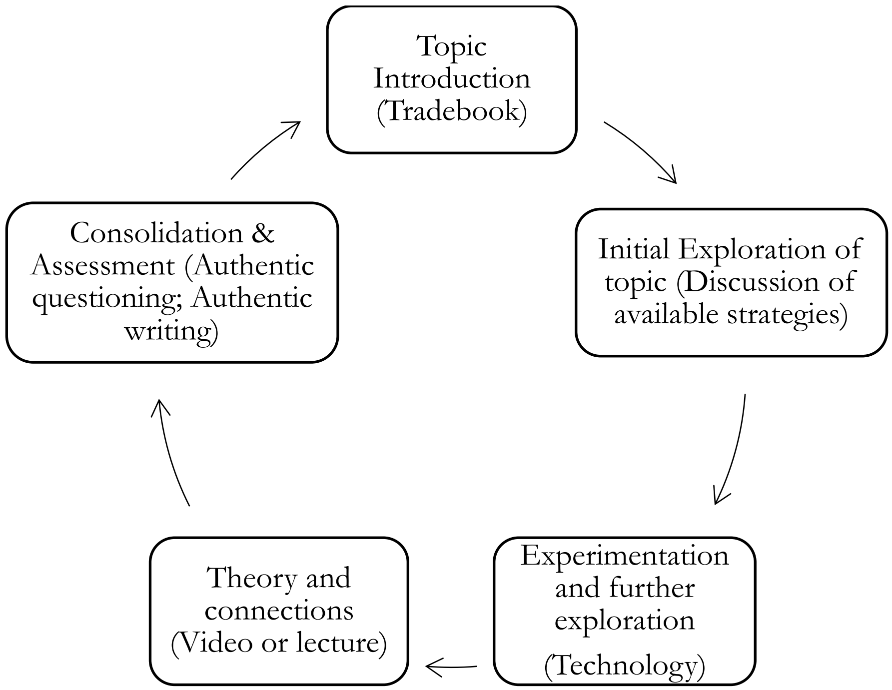

Figure 1. Sequence of Learning, General Classroom Examples

Illustration 1: *Consider a univariate example dealing with temperatures: An individual has a week of temperature data for a vacation destination. How should she pack for the trip? Provided is a table of data.*

The intervening methodologies are story-telling questioning, review of mastered material through authentic questioning, technology for repetition and pattern deduction, authentic writing, authentic questioning, and deductive analysis. Which technique is chosen, and the step of the process in which it is used, is determined by the topic and the portion and nature of the support needed at that step. These pairings are constructed by the teacher, with the selection based upon which portion of the learning is new and which resources are available to support that particular skill.

Table 1. Details of Pairing Stages with Tools, Univariate Statistical Example

Stage	**Context**	**Differentiation Tool**
Introduction	The need for a representative statistic	Story-telling or conversation[1]
Exploration	Mean, median, mode calculations	Authentic questioning[2]
Experimentation	Changing the data set/changes in the statistic	Technology; active modeling[3]
Theory & Connections	Reinforce Measures of Central Tendency; sensitivity to changes	Direct instruction[4]
Consolidation & Assessment	Conclusions and analysis	Authentic writing[5]

[1](Lemonidis & Kaiafa, 2019); [2](Jones & Texas, 2016); [3](Lee, 2019); [4](Stein, 2006); [5](Ediger, 2006)

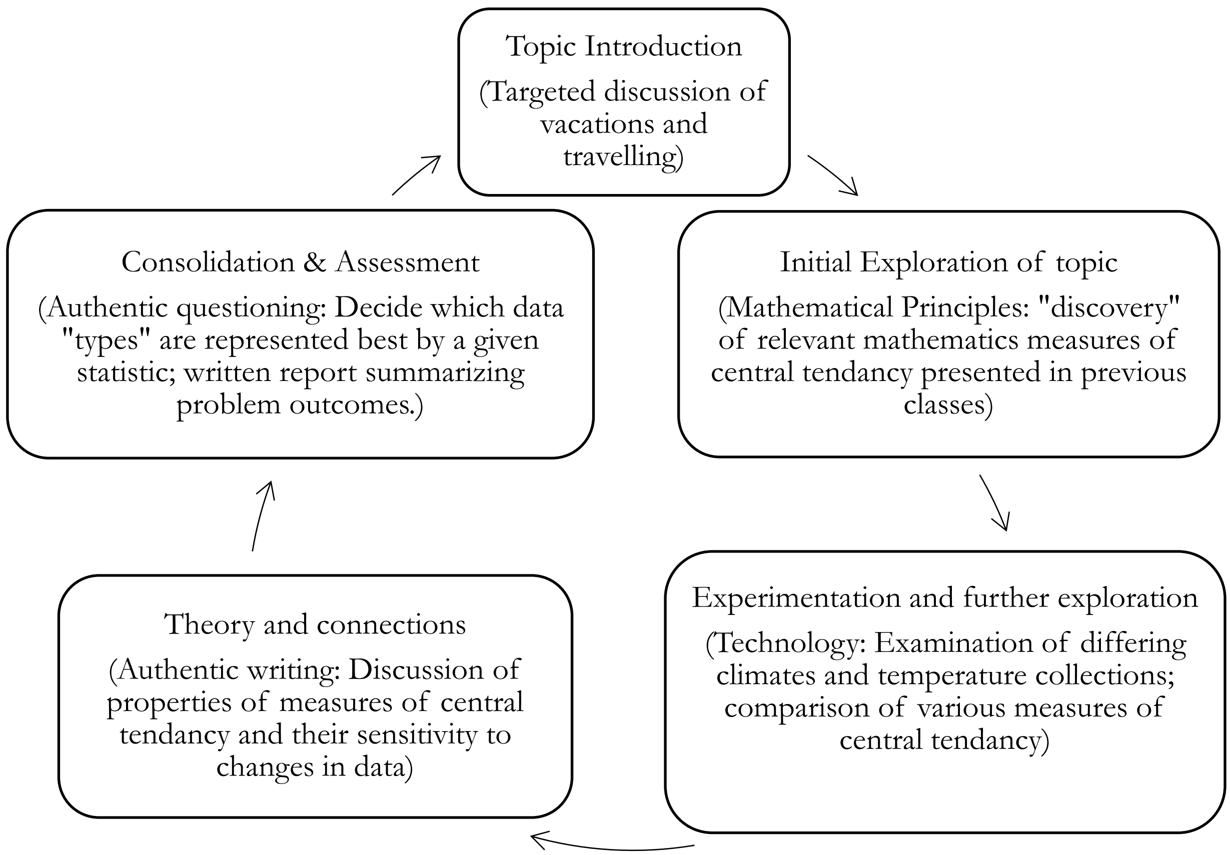

Figure 2. Sequence of Learning, Univariate Statistical Analysis Example

Illustration 2: *Introduce the concepts of bias and experimental design.*

This example illustrates different choices and reflects the use of the book *The Lady Tasting Tea* by David Salsburg (2001) to introduce the concept of bias and experimental design. In fact, this book could be used to introduce several different statistical topics. Given the nature of the topic, multiple passes around the spiral could occur to support the development of more advanced analytic and logic skills.

Table 2. Details of Pairing Stages with Tools, Bias and Experimental Design Example

Stage	**Context**	**Differentiation Tool**
Introduction	Bias in Statistics	Book and Video[1,6]
Exploration	Discovery and example of Bias	Story-telling[2]
Experimentation	Changing the data set/detecting suspicious elements	Direct instruction; Technology[3,6]
Theory & Connections	Measures of Central Tendency; sensitivity to changes	Direct instruction[4]
Consolidation & Assessment	Conclusions and analysis	Authentic writing[5]

[1](ChangSchool, 2011); [2](Lemonidis & Kaiafa, 2019); [3](Lee, 2019); [4](Stein, 2006); [5](Ediger, 2006), [6](Jones, 2014)

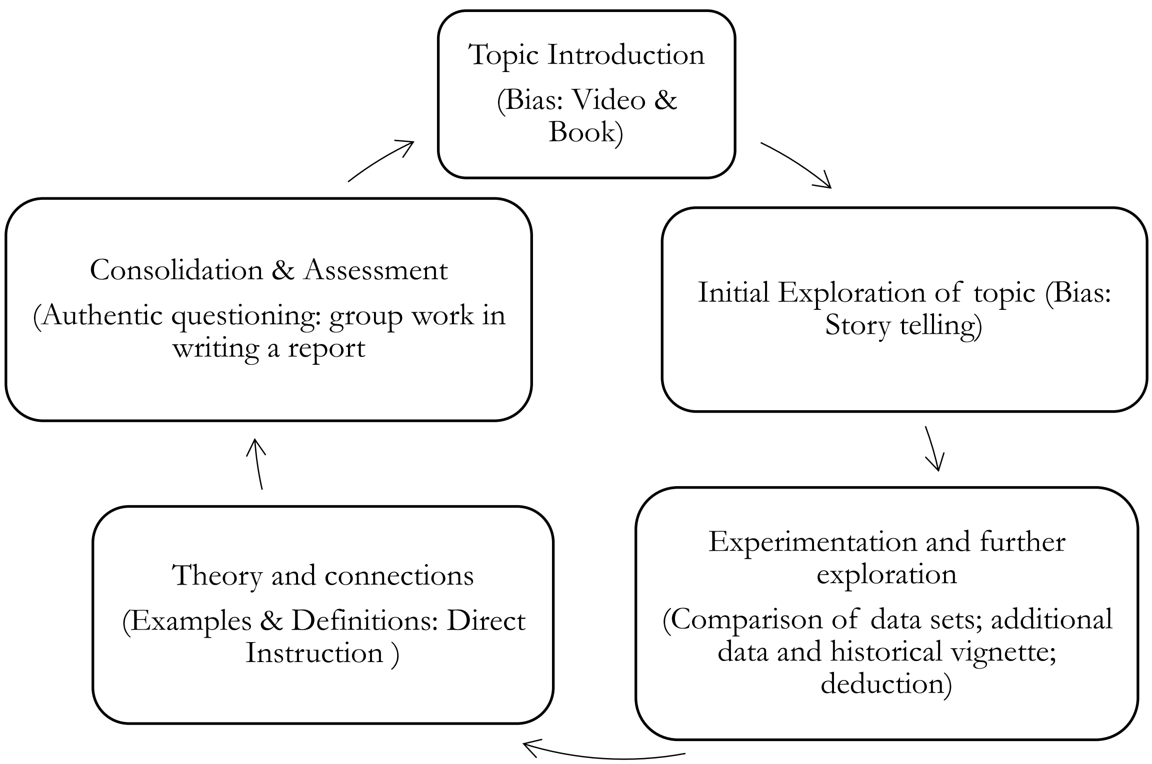

Figure 3. Sequence of Learning, Bias and Statistical Design Example

Implications

Teaching statistics as an introductory body of knowledge certainly accelerates the integration of a variety of skills and cognitive areas. Students will need the assistance of the teacher to develop their various abilities to even out various deficiencies and allow all skills areas to be enhanced (Gal, Ginsburg & Schau, 1997). When students work with "interesting" questions, they typically focus on process instead of creating an authentic analysis. To master statistics, students must rise above the level of rote calculation and shallow logic. All of this will be a challenge to the teacher, who is not necessarily equally trained in teaching writing skills and teaching mathematical skills. On the positive side, the benefit accruing to the student from mastering these skills has been documented from a variety of perspectives (Asempapa, 2017; Cifarelli & Pugalee, 2018; Little, 2009; Roberts, 2017).

The resources available to the teacher, primarily through the internet, have never been more copious. On the other hand, the ability to organize, customize, and re-order learning material requires experience and time from the teacher – both of which are in short supply for teachers (Hamid, 2001). For those already teaching statistics and those who may be in the future, customizing their individual sections of material will be critical. Moving between reading and math skills will help students with different areas of strength; encouraging them to "fix" the writing while the math is "easy" (and vice versa) will be a challenge. The outcome will be the acquisition of a good life skill and a good STEM skill. At the same time, the patterns developed in the area of computational thinking will be critically valuable (Lee, 2019). The ultimate question is can our schools and resources develop and sustain the increased integration and depth of logic that "statistics early" differentiated learning will imply…or will we return to previous practices.

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ANALYZING STORY PROBLEMS IN MATHEMATICS: THE IMPACT ON GENDER NONCONFORMING LEARNERS

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Abstract

Our team of doctoral students and STEM education faculty focus on promoting equitable mathematics for gender nonconforming students and the LGBTQIA community. Our team explored language and assumptions concerning gender pronouns and sexuality commonly found in state model curriculum and testing materials to promote gender inclusivity for all students in mathematics. The most prevalent themes discovered were assumptions of gender, gender stereotyping, and an overwhelming lack of LGBTQIA (Lebsian, Gay, Bisexual, Trannsexual, Queer, Intesex, Asexual) visibility in model curriculum.

Introduction

Our team responded from a call to action to incorporate gender and sexual identity within equity and diversity in mathematics education. Several scholars have discussed the need to expand our scope of equity and diversity in the mathematics classroom (Moorhead, 2018; Rands, 2013; Rubel, 2016). The demand for inclusive education for the LGBTQIA community is further represented in the GLSEN 2017 National School Climate Survey. Based on the experiences of the LGBTQIA youth in our nation, a mere 19.8% of LGBTQ students have been taught positive representations of LGBTQ people, history, events in their curriculum, and 42% of transgender and gender nonconforming students had been prevented from using their preferred name or pronoun. Our work focuses on examining the language used in K-12 mathematics word problems that oppress gender nonconforming students. Supporting gender nonconforming students along with the entire LGBTQIA community is an area within equity and diversity that our team strives to encourage in the mathematics community.

Purpose of Paper

The purpose of this paper is to illuminate the practices that support gender inclusivity for all students in mathematics. This paper will provide varied examples of language used in mathematics curriculum and state testing materials. Our objective is to provide mathematics teachers and teacher educators with an understanding of how to better promote gender inclusivity with modifications to the model curriculum. We specifically look at common gender stereotyping, assumptions of gender pronouns, and assumptions of sexuality frequently found in K-12 curricula materials and state testing materials.

Significance and Related Literature

Engaging all students in more equitable curriculum and word problems in mathematics has been advocated for by several mathematics scholars in recent years (Esmonde, 2011; Rands, 2013; Rubel, 2016). The language used in math story problems and state testing materials have historically promoted gender stereotypes and identities, reinforced gender binaries and thus further oppress gender nonconforming students (Esmonde, 2011). Mathematics story problems and curriculum have the opportunity to resist genderism, valuing gender normative people over those that are seen as non-normative (Esmonde, 2011).

Researchers illuminate the conflation of sex with gender as problematic, as that it reinforces that individuals are born either male or female, that sex and gender are fixed qualities, and that gender is always equal to sex. This also can contribute to gender normativity, the idea that there is only one way to be male, and another different way to be female (Rubel, 2016; Esmonde, 2011). Esmonde called attention to the gender inequities in math classrooms as more than just achievement gaps and that gendered power relations need to be addressed through specific modifications to the curriculum.

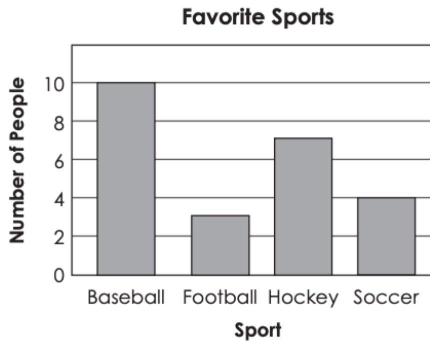
Innovative curriculum reform has been introduced to challenge gender normativity through the use of gender-complex education. Gender-complex education, described by Rands (2013) as directly acknowledging gender diversity by making curriculum and pedagogy reflect the existence of transgender and gender non-conforming people. Moorhead (2018) supports this view "excluding LGBTQ+ people and issues from the curriculum disregards this reality and denies young people a view into themselves and into their world" (p. 22). Rubel (2016) also advises teachers to analyze story problems and rewrite them to better reflect gender diversity as well as using math to analyze gender privilege (salary gaps) and oppression (rates of harassment/violence targeted against transgender or gender non-conforming people).

Practice or Innovation

As mentioned, our purpose remains to increase awareness of how math story problems are upholding genderism and biases. We specifically analyzed common gender stereotyping, assumptions of gender pronouns, and assumptions of sexuality frequently found in K-12 curricula materials and state testing materials. Provided are published questions that embody of our concerns and potential ideas to change the way genderism is portrayed within mathematics problems. In addition, an example is given to show how mathematics can be used to communicate inequities and lack of inclusion for LGBTQIA students. We hope teachers, principals, curriculum administrators and parents consider inclusivity when planning and using curriculum materials.

Classroom Examples

15. Fatima asks people what their favorite sports are. She records their answers on the bar graph shown.



How many more people like baseball than hockey? Enter the number in the response grid.

(Ohio State Tests)

Gender Issues: This question is a released state assessment question. Males primarily play the favorite sports listed in this question, with the exception of soccer.

Recommendations: Sports played by males or females, such as basketball, swimming, volleyball, or track and field, should be included.

Problem Print

After some discussion, Grandmother Brown's children have decided to purchase a dishwasher as a holiday gift for their mother.

- Mark believes that each of them should contribute the same amount, and has agreed to pay 20% of the total cost of the dishwasher.
- Sorin has recently graduated from college and is still trying to find the right job. He can only afford to contribute $75 toward the gift.
- Raymond knows that Stephanie's family is having trouble making ends meet. He suggests that each of the others pay 25% of the total cost of the dishwasher so that Stephanie does not have to contribute.
- Stephanie tells Kristin that she appreciates Raymond's generous offer but insists on paying the same amount as Sorin. However, she does not want to hurt Ray's feelings, and so they agree to allow him to pay 25% of the total cost.
- Kristin, who is the oldest, wants to contribute one-third of the total cost of the dishwasher.

Kristin will order the dishwasher and arrange to have it delivered before their next holiday gathering. She will also collect the amount each sibling has indicated he or she wishes to pay.

Your job is to figure out the total cost of the dishwasher and the amount that each of the 5 children will contribute.

Gender Issues: This question is on a teacher resource site. The question depicts that children are buying their mother a dishwasher as a gift.

Recommendations: The dishwasher could easily have been purchased for the children's "parents," instead of just their mother.

(National Council of Teachers of Mathematics)

24 The frequency table shows the number of points scored by each player on a basketball team during a game.

Points Scored

Player	Tally
Stephen	𝍸 𝍸 IIII
Alfred	IIII
Kenji	𝍸 𝍸 II
Pete	𝍸 III
Eric	𝍸 𝍸 II
Wesley	𝍸 I
Hayes	𝍸 𝍸

What is the combined number of points scored by Stephen, Alfred, Pete, and Wesley?

Record your answer and fill in the bubbles on your answer document. Be sure to use the correct place value.

Gender Issues: This question is a released state assessment question. The frequency table is used to total the number of points scored by each male player on the basketball team.

Recommendations: While females could also be used in this problem as players, we bring attention to this problem as one that could be used to bring awareness and promote gender inclusivity by changing the content of the problem. For example, they could find the frequency of students who felt included in different school settings, such as the classroom, clubs, the arts, sports, or other activities.

(State of Texas Assessments of Academic Readiness Grade 3 Mathematics)

What is 58% of 18?

Gender Issue: None, but we would like for problems such as this one to be used to support gender inclusivity and promote visibility of the LGBTQIA community.

Recommendations: Utilize GLSEN (2017) data to calculate percentages about school climate for LGBTQIA students. **For example,**

> Of the 23,001 students who participated in the 2017 GLSEN survey, 42% of transgender and gender nonconforming students had been prevented from using their preferred name or pronoun. How many students were prohibited from using their preferred name or pronoun? How might this make students feel?

Implications

Math educators and math teacher educators have the opportunity to resist genderism and gender-binaries by mindfully choosing and changing the language used in mathematics word problems. A second, more progressive approach might be for math educators and math teacher educators to be inclusive of transgender and gender nonconforming students' identities when choosing mathematics story problems. In figure 1, providing students the opportunity to explore real-world data surrounding the LGBTQIA community allows for real world conversation that might otherwise be avoided in mathematics classrooms. When students and allies in the LGBTQIA community are provided with math story problems that illuminate the inequities these groups face, all students have the opportunity to study sampling, fractions, percentages, and proportional reasoning in a way that can foster real social change in the mathematics classroom.

The final sample consisted of a total of 23,001 students between the ages of 13 and 21. Students were from all 50 states and the District of Columbia and 5 U.S. territories. About two-thirds of the sample (67.5%) was White, a third (34.1%) was cisgender female, and 4 in 10 identified as gay or lesbian (41.6%). The average age of students in the sample was 15.6 years and they were in grades 6 to 12, with the largest numbers in grades 9, 10, and 11.

Figure 1. (GLSEN 2017 National School Climate Survey)

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NONTRADITIONAL TEACHING APPROACHES IN MATHEMATICS: A CASE STUDY OF MATHEMATICS TEACHERS

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This paper highlights two case studies of mathematics teachers who have successfully implemented nontraditional teaching approaches. Specifically, we focused on findings from each case and their implications for members of the mathematics education community in terms of authentic pedagogies.

Keywords: authentic teaching; mentorship; innovative practices; care; collaboration

Introduction

Nontraditional teaching and learning practices have been part of the educational landscape for many years and include areas such as authentic teaching and learning and emergent curricular designs (Newmann, Secada, & Wehlage 1995; Stanic & Kilpatrick, 1992). Envisioning classroom practices alternative to those often associated with high stakes accountability culture comes laden with constraints and limitations that teachers must overcome. Literature often defines alternative pedagogical constructs without discussing cultural contexts and learning environments. This case study of purposefully selected participants separately examined four mathematics teachers in two different settings. The first study was conducted in two suburban schools, while the second was conducted in a culturally diverse, urban school. This paper will focus on significant findings from each case that include how teachers extend practice associated with authentic teaching and learning, culturally relevant pedagogies, and the importance and value of mentoring and mutual inquiry in their continued classroom success. Findings for this study also include teachers enacting curricula that are driven by both students' and teachers' interests, integrating high levels of care for others into mathematics curriculum and instruction, and sharing responsibility for student learning. Further, all four participating teachers were observed co-creating unique classroom cultures with their students. These findings were connected to teachers' vulnerability with students, while also demonstrating perseverance through internal and external constraints and limitations.

Objectives of the Study

The purpose of this paper is to showcase four cases of mathematics teachers' alternative classroom practices, while also highlighting the constraints and limitations they face in current school climates. Realities faced in today's mathematics classrooms can be overwhelming for many teachers; therefore, by detailing participating teachers' unique approaches, their approaches can potentially inspire practitioners to think about the constraints and limitations in their own work. Our research questions were as follows:

1. What teaching and learning approaches do participating teachers use when implementing authentic curriculum?
2. What do participating teachers consider to be contributing factors to their practice?

Theoretical Framework

The US has seen a myriad of reforms in mathematics education come and go due in part to "consistent reform rhetoric with little actual reform of the mathematics curriculum" (Stanic & Kilpatrick, 1992, p. 407). While this was true in the early 1990s and is still true today, it is not to say there has been no change. Some educators have felt empowered to transcend mandated curricula to teach mathematics in non-traditional ways.

Authentic teaching and learning practices are built on constructivists' epistemologies and theories for how curriculum ought to be enacted in schools (Newmann et al., 1995). Progressive constructivists, like Dewey (1899), have been vocal advocates for learner-centered curricula designed to provide students with meaningful learning experiences that have intrinsic value. As constructivist teaching theory was becoming more formalized, Vygotsky's social learning theory provided a basis for intentional collaboration and meaningful discourse in classrooms (1978) and showed that students' learning is a social endeavor, built around students' zones of proximal development. In 1995, Newmann and colleagues published their seminal work on authenticity, and other work followed to help clearly define what it meant in terms of instruction, learning, and evaluation. These publications formalized authentic pedagogy into three core components: construction of knowledge, disciplined inquiry, and value beyond school.

In an effort to clarify what may be considered authentic mathematics, scholars redefined their framework to include both professionally and personally meaningful connections (Garrett, Huang, & Charleton, 2016). These categories serve as an umbrella over which authentic contexts, authentic tasks, and authentic impacts lie. These categories take pressure off teachers so they no longer have to ensure they are teaching mathematics as it relates to the job market. Additionally, teachers are freed from making contrived arguments for how mathematics might be used in the "real world."

Dennis and O'Hair (2010) noted several obstacles to implementations of authentic lessons. These include teachers' lack of time, lack of materials and funding, along with inflexible and untrained teachers. We would add to these a lack of cultural connections to students' lived experiences and little recognition of teachers' cultural references, along with constraints and limitations teachers face when implementing what they consider to be authentic work. Large-scaled reforms around accountability in education have successfully quashed individuals' voices and promoted cultures of fear and uncertainty. To complicate matters, more teachers are not well prepared to teach due to efforts to ameliorate the teacher shortage with alternative and emergency certification initiatives (Houser, Krutka, Roberts, Pennington, & Coerver, 2017).

Methodology

In order to meet the goals of our research, a qualitative case study was most appropriate. Implementing qualitative case studies allows researchers to approach problems from a holistic standpoint by focusing on a single unit within a "bounded system" (Merriam, 1998; Stake, 1995). For our study, we had four participants, each thought of as its own case. While each case involved an individual, we also looked at the four cases as a whole in order to find comparative themes. All public school teachers involved in this study taught in the same state in suburban and urban school districts. Nicole was a fourteen-year veteran high school mathematics teacher of color. Her colleague, Bailey, on the other hand, was a first-year teacher who interned with Nicole the previous year. Both Nicole and Bailey taught at the same culturally diverse, urban high school during this study. In the other study, Wesley was a twenty-year veteran middle school mathematics teacher while Kathleen was a twenty-two-year veteran teacher who taught second grade. While Wesley and Kathleen taught in suburban school districts in the same state, the socio-economic status of their students varied significantly.

Our data collection involved three approaches: semi-structured interviews, numerous classroom observations, and document collection. Each point of data collection provided a different angle in order to more clearly see the data set as a whole while generating thick descriptions of each participant. We were able to generate themes from both open and axial coding processes. These codes served to form categories associate with participants' teaching practices. In order to capture the essences of teachers' approaches, responses and conversations within semi-structured interviews provided the basis of several themes. Interviews were scheduled multiple times throughout data collection with each participant as a method for understanding teachers' perspectives of practices. Interviews, along with observations and documents, allowed us to capture several vantage points for describing teachers as completely and as fully as possible. This provided insights into participants' ways of looking at the world. Frank (1999, p. 56) outlines several focal points for observations that assisted in generating a thick description of teachers' environments and interactions. This process is what she refers to as "the descriptive review" and includes taking detailed field notes around the following: 1) physical presence and gestures of participants, 2) participants' dispositions, 3) relationships between teachers, students, and others, 4) classroom activities and interests, and 5) formal learning.

Results and Discussion

Consistent with extant literature, participants were observed implementing curricula using instructional methods that fit with theoretical authenticity constructs defined above (Garrett et al., 2016; Newmann et al., 1995). They tended to be adamant about students learning best when they could construct meaning for themselves. This included teachers creating spaces in their classrooms through collaborative group work wherein they could listen to students to better understand their thinking. Wesley recalls that it "was important for me to listen to the students while they worked on problems in their groups so I could try to understand what they were understanding and what they didn't have figured out." Like Wesley, Kathleen felt that listening to her students would help her better understand how they learn. She stated:

> Once I started having my students work in groups, I could listen to how they were thinking about problems and really learn how they were and were not understanding certain things – I was hooked! I knew I needed to be listening a lot more and the only way to listen was to give them something to talk about and that meant interesting and challenging math problems.

All participants shared similar interests in engaging students in mathematics, providing opportunities for them to problem solve with one another, and collaborating on projects in support of students constructing mathematical knowledge.

To help students construct knowledge for themselves, participating teachers engaged students by using meaningful questions and by encouraging students to have substantive conversations. Engaging students in authentic problem-solving tasks involved teacher-to-student and student-to-student discourse that was infused and sustained by the use of meaningful questions. For instance, one particular project in Nicole's class involved students working collaboratively over the course of several weeks to analyze and discuss personal finances for volunteer friends of Nicole. These volunteers would share their financial situation with small groups of students in Nicole's classroom along with their goals for financial planning. Students were instructed to examine their finances in light of their goals in order to provide the volunteers with a reasonable financial plan. Students had to engage with one another and with Nicole in substantive conversations to ensure their plans were reasonable and fit the needs of those volunteering their time. Likewise, Wesley engaged his students in problem-solving and teacher-to-student and student-to-student discourse daily. Somewhat different than Nicole's class, Wesley's class followed a routine on most days that began with a class opener to help student further develop their number sense and engagement. Class openers were typically in the form of math squares, two-ways or fraction benchmarks (Wheatley & Reynolds, 1999; Wheatley & Abshire, 2002). Following work and discussion on the class opener, Wesley typically introduced a non-routine problem-solving task for students to work on in pairs. For example, Wesley introduced his students to the Greek Cross figure which is a figure comprised of two colors of blocks that are added incrementally as part of an iterative pattern. The initial figure shared with students presents what would be considered the first three iterations of the patterns. Based on that information, students were asked to determine how many of each color of blocks would be needed to extend the shape to the next few iterations and then ultimately, how might they determine the number of colored blocks would be needed for any iteration. This problem invited students to consider iterative rules, patterns, and explicit rules through authentic problem solving and sustained discourse (Reeder & Abshire, 2012).

Further, throughout observations in classrooms, participating teachers were observed sitting with students rather than standing over them. They sat and engaged them in conversation by asking pertinent questions to help students articulate what it was they were learning. For Nicole in particular, engaging students in this way also included having students fulfill roles within projects, working with students to help them better understand their mistakes, and helping students solidify their mathematical thinking. All four participating teachers mentioned their approaches were influenced by problem-centered learning, project-based learning, and discovery learning. While no teacher overtly stated they were "authentic," their work aligned well with relevant literature around authenticity by engaging students in tasks involving meaningful questions, substantive conversations centered on mathematics, and helping students make connections with mathematics in various contexts.

For participating teachers, there was a sense of pride that came from their less-traditional approaches to teaching mathematics. Participants seemed to wear this as a badge of honor. There were several factors that participating teachers believed contributed to their practice. They found that risk-taking, cultivating classroom cultures of care, mentorship, and a continual search for innovative materials contributed to their effectiveness in their teaching practices.

Although the teachers in this case study were found to teach in ways that were consistent with most authenticity frameworks, using terms like "authentic" seems to be reductive in describing what was happening in their classrooms. Our observations found students to be highly engaged in mathematics learning through meaningful lessons that were carefully crafted to meet their needs. Students were observed being listened to consistently by their teacher and peers. As a result, each classroom in this study became a culture of its own that embraced "other" voices within their classroom culture. To do this, teachers had to take risks to try new approaches. In particular, and consistent with all participant teachers, Nicole shared that her style of teaching required the teacher to "be cool with not controlling every aspect of what happens [in the classroom]." The pedagogic practices of the teachers in this study extended existing authenticity frameworks to include curricula that was driven by both teachers and students predicated on shared responsibility for learning.

Furthermore, teachers valued individuals' cultural identities which helped create unique classroom cultures. This was determined by teachers' and students' willingness to be vulnerable with one another. Classrooms were built around relationships that were founded on transparency and trust. Bailey articulated that her students responded well to how much she cared about their classwork. She shared the following sentiment about the value of care: "I think having care while I teach, having care while I plan, and having care while I'm just like being a teacher… (sighs) I mean I feel like I do everything with care." All the participants shared and demonstrated an ethic of care in their work with students and this helped to reduce power struggles often found in classrooms between teachers and students.

Another major theme that emerged from our data was mentorship. Three of our four participants shared that having a mentor to guide them in their formative years as educators contributed to their practice and gave them courage to engage students in more collaborative pedagogies. For Bailey, Wesley, and Kathleen, mentorship consisted of working with a more established teacher in the field. Interestingly, Nicole served as Bailey's mentor, but Nicole was not mentored in this way during her early years as a teacher. Rather, Nicole found guidance from networking with veteran teachers through social media and by engaging in professional development centered on project-based learning. Mentorship provided teachers with confidence to think about their teaching practices differently than many of their colleagues.

Finally, teachers in these case studies were found to seek and implement innovative practices on a regular basis. For instance, all four teachers were part of both state and national mathematics teacher organizations. This allowed them access to innovative approaches in problem-centered learning, project-based learning, and discovery learning. It also provided curricular space for them to incorporate larger social issues into their curriculum. Participating teachers demonstrated a willingness to implement new ideas they discovered that would best-serve their students. Upon reflecting on these, teachers would amend their efforts to best suit their students.

Implications

Much like trying to determine what thread begins or completes an intricate woven tapestry, which one completes the picture, or which one could be removed without changing what makes it inherently and qualitatively unique, some events and experiences, even in retrospect, cannot be fully disentangled and understood, much less reproduced. The authentic teaching and learning practices present in these teachers' classes are woven together in ways that are difficult to pull apart and certainly cannot be viewed as a formula to be followed. This research reveals that these types of teaching approaches can be accomplished in a variety of classroom settings. For participating teachers, authentic teaching practices were those that engaged students in substantive conversations, connected learning to students' lives, and valued students as human beings. For all teachers, this meant dedicating time in class to build positive relationships with students through grouping and structuring mathematical tasks and projects to connect to their students' lives. In particular, Nicole went as far as setting aside time in her class for students to share something positive and something negative that happened to them throughout the week. This allowed her to better understand what her students were experiencing outside of her mathematics class in order to group them in a way that could help them socially and emotionally.

All four participants established classroom communities based on care and meaningful relationships and focused the learning of mathematics around problem solving tasks that were relevant to the lives of students. These classrooms focused on learning and deep understanding rather than on skill acquisition. These constructs can subjectively manifest themselves in many ways in different classrooms and cultures. It is important to note that the teachers involved in these case studies work within the constraints of a 45-minute class period at traditional schools, with state mandated testing, and with culturally and socio-economically diverse students. These teachers have chosen to participate with their students in the learning of mathematics, have chosen to work in and around the traditional barriers to teach differently, and have imagined and embraced the possibility that mathematics is not fixed and static. Each day they engage their students in authentic opportunities to learn and understand mathematics – both its beauty and usefulness in their lives.

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ENGAGING SCIENCE INSTRUCTION USING STORIES

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Abstract

This paper describes a phenomenological case study investigating the integration of narratives with science activities by pre-service teachers (PSTs) to teach science concepts at a literacy festival for students in grades K-8. A three-question open-ended anonymous survey was distributed to participating PSTs to explore, describe, and interpret how they made sense of their experience. The data were analyzed by identifying themes that emerged from participants' responses. Results aligned with findings of previous researchers suggesting positive outcomes for student learning when integrating narratives into science education. Additional conclusions revolved around the need for diversity education in teacher preparation programs.

Keywords: science, narratives, literacy, pre-service teachers

Introduction

Science is often seen by students to be rigid, severe, and impersonal (Lemke, 1990). In addition, students from lower-income communities and diverse backgrounds are underrepresented in Science, Technology, Engineering, and Mathematic (STEM) fields (The National Academies of Sciences, Engineering, and Medicine, 2018). This research aims to investigate the impact narratives have when linked to science activities presented to K-8 students from Title 1 schools at an outdoor literacy festival. We use the term *narratives* to describe a variety of texts that include both fiction and non-fiction short stories and book excerpts. These narratives were paired with related science concepts from the K-8 curriculum.

Using selected science concept and narrative combinations, PSTs constructed 15-20 minute outdoor mini-lessons. Some examples of the science concepts and narrative combinations that were used by the PSTs included: states of matter and snowflake geometry with *Snowflake Bentley* by J. Martin (1998); camouflage with *Where in the Wild?* by D. Schwartz and Y. Schy (2007); and pH indicators (red cabbage juice) with an excerpt from *Harry Potter and the Chamber of Secrets* by J. K. Rowling (2000). In addition, several stories from Konicek-Moran's *Everyday Science Mysteries* series (2013) presented questions or discrepant events for students to explore. The selected narratives supported the targeted science concepts without revealing to students in advance what they were going to learn during the activities. The activities were chosen based on the time required, safety of materials used, and the ease with which they could be presented to children outdoors. Finally, only verbal questions were used to assess student learning.

Objectives of the Study

While PSTs have many opportunities to use storybooks to read aloud to students during their field experiences, the literacy festival provided a different perspective because a science activity was related to the selected reading. The study involved PSTs learning how to integrate reading and science through student exploration rather than simply accepting information from the reading. In addition, questions were developed to encourage diverse K-8 students to make connections among science, reading, and their own lives.

Theoretical Framework and Related Literature

The importance of using read-aloud text to support student inquiry of science concepts was explored by Pappas, Varelas, Barry, and Rife (2004). Connecting science activities with narratives provided the K-8 students an opportunity to explore and discuss different scientific concepts. Learning science requires more than knowing isolated facts, hence using stories adds mystery and encourages careful and persistent observations, similar to the work of scientists (Martin & Miller, 1990). The goal was to use inquiry strategies to help K-8 students from Title 1 schools become aware of the connections between scientific knowledge and their personal experiences (Settlage & Southerland, 2012).

The literacy festival setting provided an opportunity for PSTs to discover the knowledge that students from diverse backgrounds bring to discussions of science concepts. The mini-lessons, which included read-alouds linked with science activities, supported development of scientific language in K-8 students (Pappas et al., 2004). The activities in the mini-lessons were introduced through questions directly in the reading (if available) or developed by the PSTs. The K-8 students responded with their original ideas prior to engaging in the science activities with the intention of promoting conceptual understanding. Students must become dissatisfied with their original ideas before they can be replaced with scientifically acceptable explanations (Konicek-Moran & Keeley, 2015).

Methodology

Stemming from a constructivist perspective, where learners draw from previous experience and current knowledge to ascertain information and new truths (Dewey, 1938; Piaget, 1957; Vygotsky, 1978; Bruner, 1961), we logically employed a qualitative research methodology. To add reliability and consistency to the study, we utilized a phenomenological case study approach. This allowed us to better understand lived experiences of our participants as they took part in a unique experience and make sense of the essence of a specific phenomenon (Merriam, 2009). For this particular study, a literacy festival hosted by the College of Education at a regional mid-sized state university was used as the selected case. More than 2,000 K-8 students from Title 1 schools throughout the region attended the five-hour literacy festival where they met authors, participated in book signings, and engaged in hands-on workshops.

In preparation for the literacy festival, we worked with 47 College of Education PSTs enrolled in two science methods courses to select narratives that paralleled a science lesson appropriate for students in kindergarten through eighth grade. On the day of the literacy festival, groups of students from Title 1 schools rotated through stations where the PSTs used narratives to engage literacy festival student participants in 13 different science lessons. Following the literacy festival, we distributed an anonymous survey to the 47 PSTs to explore, describe, and interpret how they made sense of their experiences. Data was collected in the form of three open-ended questions that allowed us to investigate this specific phenomenon within its real-life context:

- How was teaching a science activity using a story different than just teaching science on its own?
- In what ways did the story you chose engage students in the science topic?
- What were some observations you made about the engagement of students from Title 1 schools as you used stories to teach them science at the Literacy Festival?

All responses were voluntary and given anonymously through the university's online learning management systems. A total of 27 of the PSTs responded to the questions, leading to a 57% return rate. The typological data analysis strategy (Hatch, 2002) was utilized to organize the data in this study and to make judgments about the meaning of the data. The data were analyzed by identifying themes that emerged from participants' responses to the three questions.

Results and Discussion

As a result of the analysis, we identified several themes and sub-themes: student engagement, background knowledge, and relatable content. We include participant voices in this section as rich testimony to individual epiphanies and reflections. A simple text analysis of the responses was also completed for each question and is represented in the form of a word cloud that highlights the frequency of the words used to describe the experience. The more often a specific word appeared in the responses, the bigger and bolder it appears in the word cloud.

In response to the first question "How was teaching a science activity using a story different than just teaching science on its own?" two main themes emerged in the participants' responses. The first theme was that narratives helped get students engaged and kept their attention throughout the lesson. Participant 18 stated, "The story really helps reel in students. It captures their attention and helps them connect what they are doing to their lives." This response supports the idea that narratives improve students' engagement in science-based lessons. Responses from this question also showed that a majority of the PSTs believed that the narratives provided background knowledge and connections to the science content. As participant 2 explained in the following quote, the narratives aided students in forming foundational knowledge. "The students had a foundation rather than jumping right into the lesson." Both themes of student engagement and providing background knowledge were expressed in the following quote by participant 9, "The story helped provide a base for the lesson and hold the students' attention and focus the lesson." With words like *helped*, *concepts*, *attention*, *interest*, *connected*, and *background* being emphasized in the word cloud in Figure 1, the themes of narratives providing a background knowledge and engaging students in science are easy to visualize.

Figure 1. A word cloud representing the frequency of words used in PSTs' responses to the question "How was teaching a science activity using a story different than just teaching science on its own?"

When the PSTs responded to the second question, "In what ways did the story you chose engage students in the science topic?" we found that a majority of the participants believed that the content of the narratives helped students relate to the science lesson being taught. Participant 24 stated, "The story I chose got students thinking about things they can do at home and how they can see science with things in their house." The theme of relatable content was further supported by participant 13 who stated, "Students were able to connect the activity to the real world." Having students make connections between the science lesson and their own real world experiences seemed to aid in engaging them in the topic and holding their attention. This theme was again supported by participant 27 who explained, "The story engaged the students because within the book, there were things that the student could relate to." The word cloud in Figure 2 helps illustrated the theme of relatable content with words like *relate* and *real-world* being used frequently by the PSTs.

Figure 2. A word cloud representing the frequency of words used in PSTs' responses to the question "In what ways did the story you chose engage students in the science topic?"

In response to the third question, "What were some observations you made about the engagement of students from Title 1 schools as you used stories to teach them science at the Literacy Festival?" two main themes emerged from the PSTs' responses. One theme that emerged was that many of the PSTs observed that the stories sparked students' interests and encouraged them to ask questions. Participant 8 described their observations by stating, "The students exhibited an interest in participating, asking questions and curiosity as my partner and I carried on with our story...I observed that the students felt more prepared for the activity conducted afterwards, as well." This theme can be clearly seen in Figure 3 with the high frequency of the phrases *interested*, *excited*, *asked questions*, and *participated*.

Figure 3. A word cloud representing the frequency of words used in PSTs' responses to the question "What were some observations you made about the engagement of students from Title 1 schools as you used stories to teach them science at the Literacy Festival?"

A second theme, which is not as well represented in Figure 3, was that of engaging with English Language Learners. While not as frequently used as other words when responding to question three, PSTs used words like *English*, *speak*, and *Spanish* to describe their observations when working with students from Title 1 schools. Participant 10 responded to the question by stating, "Many of the students weren't able to speak English fully, so you had to make accommodations to communicate with these students." This theme of working with English Language Learners came across in many of the PSTs' replies and could be in response to the large Hispanic population in the area's Title 1 schools and/or indicate a need for additional teacher training in working with diverse student populations.

Implications

Throughout this study, we explored and described the lived experiences of a group of PSTs who used narratives to teach science lessons at a literacy festival. Our findings align with Morgan and Ansberry's (2007) argument that narratives can aid science educators in holding a student's attention and have the ability to spark an emotional and intellectual response. We also found that narrative can be used as a bridge for students to make connections between science topics and their own lives. Hammond (2014) also found that lessons that include narratives can aid students in making connections between the curriculum being taught and things they find relevant. These findings help to make the case for an increased use of narrative when teaching science to all students. We acknowledge that these short mini-lessons are insufficient for deep conceptual understanding, but we expect they will serve as a springboard for future science learning for the K-8 students. Additionally, PSTs gained competence in integrating science and reading in their future classrooms.

The PSTs' observations when working with students from Title 1 schools indicated the need to practice better engaging these students from a young age in STEM subjects. Our findings help support the idea that teacher preparation programs should include experiences designed to address any implicit assumptions or beliefs that teachers may have in regards to working with students from diverse backgrounds (Vomvoridi-Ivanovic & Chval, 2014). This type of training could aid pre-service teachers as they plan lessons for their future students by addressing any hidden assumptions they may have.

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DEVELOPING STUDENTS' ARGUMENTATION THROUGH DATA-DRIVEN INSTRUCTIONAL PRACTICE

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Abstract

In this paper, I will discuss the use of data-driven instructional practice in developing my students' argumentation skills. My students utilized the C-E-R (**claim, evidence, and reasoning**) framework as a formative assessment in some units in 7th-grade science through collaborative instructional intervention. Their performance in multiple CER assessments allowed me to reflect on my practice and develop informed instructional decisions in assisting them to complete argumentation tasks successfully. My students completed the CER in three phases: individually completing the CER, peer feedback, and revision of CER. They collected pieces of information such as data from experiments conducted during class and recorded notes from various references (textbooks, web resources, and multimedia) in their science journals. We studied the topics such as energy, types, and forms of energy, energy transformation, characteristics of living things, cells, and movement of materials in cells. Analysis of their scores indicated that the students increased their performance in scientific argumentation when working with their peers with the most improvement when collaborating in small groups. Instructional strategies involving collaboration with other students in analyzing data and information, conceptualizing, validating and supporting a claim, and developing the skills and confidence in a scientific discourse through the CER framework and opportunities for examining models help students develop argumentation skills. Further, data on students' performance should drive instructional decisions to improve students' skills on discourse and argumentation and, in the long run, making real-life decisions based on evidence.

Keywords: CER, formative assessment, intervention, collaboration, data-driven instruction

Introduction

The goals of science education shifted to developing the fundamental skills applicable throughout the students' lives. Students' ability to make sense of their observations by supporting their claim with evidence and scientific explanation is a vital component in science instruction. One of my goals as a science teacher was to develop my students' argumentation skills through formative assessments using the CER framework.

Objectives/ Purpose

In this paper, I will discuss how I used data-driven instructional practice in developing students' argumentation skills. My students completed CER (claim, evidence, and reasoning) formative assessments using collaborative instructional intervention.

Related Literature

National Science Education Standards implies scientific literacy as "the capacity to pose and evaluate arguments based on evidence and to apply conclusions from arguments appropriately" (p. 22, 1996). Also, the Next Generation Science Standards (NGSS) aims to provide high quality K-12 science education that develops students' critical thinking, data analysis and problem-solving skills (2013). These standards function as the core of any science curriculum to meet the state assessment requirements and prepare a scientifically literate and globally competitive society.

Research on CER and argumentation techniques in the classrooms could lend to students' practice and understanding of the nature of science through scientific thinking distinct from everyday thinking (Archila, Molina & Truscott de Mejia, 2018; Keeley, 2015) while examining common data and discussing from different perspectives (Duschl & Osborne, 2002). The opportunities for argumentation in instruction develop students' more in-depth understanding of the content knowledge and increased the level of communication of their ideas in verbal or written forms (Alegado & Lewis, 2018; Larrain, Howe & Freire, 2018; Keeley, 2015). The use of the CER framework provides evidence of students' level of understanding of the content and prior knowledge, opportunities for differentiation, assessment of learning (Alegado & Lewis, 2018; Keeley, 2015; Novak, McNeil & Krajclk, 2009).

Peer collaboration would maximize learning when students assist each other and learn together. Peer discussions before completing the exploratory activities benefit both the low and high achievers because engagement in peer discussions provide opportunities for students in communicating their thinking while learning from others' ideas (Rivard & Straw, 2000). The Data-Driven Decision Making in Education (DDDM) posits the cyclic process of gathering and analyzing data, developing actions based on the data and assessing the effectiveness of decisions in all levels of educational systems (Marsh, John & Hamilton, 2006). When students are periodically assessed, and their performance data is analyzed, students' mastery of concepts and skills build up over time. However, it could be challenging for teachers to collect and analyze data to implement interventions with fidelity due to an additional time and energy required (Bianco, 2010).

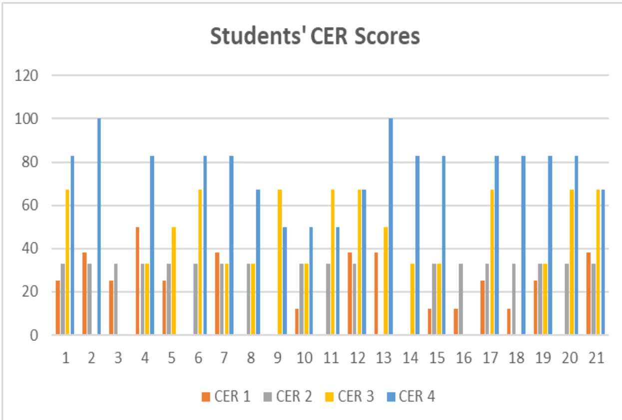

Fig. 1 Students' scores in four CER assessments

Practice

The CER framework has three (3) components: claim, evidence, and reasoning. In this framework, students apply scientific literacy skills through developing a claim based on data gathered from their experiments, and information collected from various resources. The claim is the component that answers the question or problem in one sentence. The second component is the presentation of evidence that supports the claim. This component may include data or observations (qualitative or quantitative) from investigations and information from resources such as book, magazines, videos, or various websites. The last component is reasoning, which builds coherence between the evidence and the claim using the scientific concepts that the students learned. In this part of the framework, students apply their learning by making sense of the claim using the evidence that they presented. I analyzed my students' CER scores and used the data to drive instructional decisions that could improve their performance in argumentation.

Classroom Examples

I taught three units in the 7th-grade curriculum and used four (4) CER assessments as a component of unit assessments for twenty-one students. I chose this class out of my five teaching loads to be the subjects in this article. Throughout the year, all my students utilized their science journal in keeping their observations and notes. The lessons followed the 5E cycle model: engagement, exploration, elaboration, enrichment, and evaluation. Moreover, scaffolding as a tool provided some students with extra support and assistance to complete their argumentation (such as the use of sentence starters for ELL students). Although my students have completed argumentation tasks in other content areas (such as English and Language Arts), they had little or no knowledge and skills in completing argumentation using CER in Science. To determine my students' baseline on argumentation in science, they completed their first CER (CER 1) without any help or support from me. Each of the students answered the CER question and I graded their responses following the adapted rubric from McNeill & Martin (2011). The students' baseline scores (CER 1) in Fig. 1 implied that students had low level skills in argumentation; thus, as a teacher I thought that my students needed some more scaffolding and support when completing CERs.

My students completed their CERs in three (3) stages: students answering the CER individually, peer feedback, and revision of CER individually based on peer feedback (Fig. 2). My initial intervention on peer feedback allowed my students to work with a partner after individually completing their CERs (CER 2 and 3). Their partner suggested some ways to improve their argumentation with the CER rubric that we were using as their guide. Working with a partner, students identified any missing components in their argumentation based on the rubric, then revised their work individually before submitting their final CER for grading. Results of their performance indicated a minimal increase (9 out of 21 in CER 2 and 7 out of 21 in CER 3 increased their scores from their baseline scores). This data implied that students still struggled on how to develop a claim, identify evidence, and provide reasoning despite of collaboration with a partner which could be supported by examining some students' responses. For example, in one student's reasoning in the 3rd CER assignment implied his confusion between the reasoning and evidence where he wrote for evidence, "They (living things) all prove to be living things because they contain cells" and for reasoning as "During the microscope experiment, we saw flies and crickets with cell most likely similar to other living cells". Another student's response did not answer the question in his claim that says, "It is not living thing if it doesn't have these: cells, grows and develop, respond to surrounding, reproduces and uses energy". This response could have been a part of reasoning and not his claim.

Working with a partner for peer feedback did not seem to help my students' development of argumentation skills. It indicated that most of them could not help each other because they might have lacked the skills to complete the task. I changed how the students received peer feedback by working in small groups involving two phases. The first phase was practicing scoring sample CER responses adopted from the web ("How to Write"). In this document, CER samples completed the question "What do plants need to grow?". The purpose of this activity was to provide opportunities for the students to examine three (3) CER models with varying scores based on the scales in the rubric. They worked collaboratively with their group in evaluating sample CERs with the same rubric used in our class. The students analyzed the samples, graded them and justified the grading for each of the

CER samples, and then we discussed the decisions as a class. We specifically emphasized the differences in each response and their corresponding grades with the use of the rubric as a guide.

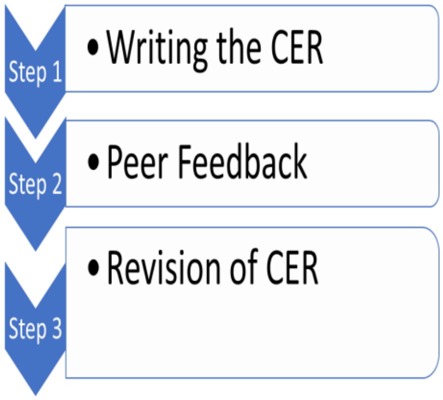

Fig. 2 The Stages of the CER Completion

The second phase involved peer evaluation through a gallery walk. In this stage, students completed CER 4 individually then presented their responses to their group. During the group work, students examined each other's CER, and shared notes to identify the group's claim and pieces of evidence to support their claim, and develop the reasoning based on their understanding as a group. They wrote their group CER on a poster for a gallery walk scheduled on the following day. Before the gallery walk, we discussed the expectations in providing constructive criticisms during group presentations. We discussed sentence starters that reflect a positive tone when giving feedback to their classmates that they might want to use. The sentence starters were "Can you explain to me…….?", "What evidence do you have…..?" or, I agree with …because….". During the gallery walk, one member from each group stayed with the group's poster to present while the rest of the group moved around the classroom (see Fig. 3). Post-it notes were provided with each poster so students could record both the score based on the rubric, and their feedback. Each group walked around together to examine, evaluate the CERs, and presented suggestions or recommendations for improvement. After the gallery walk, my students convened with their group, revisited their CER ,and discussed how they could improve their work through examining their peers' feedback, and suggestions. Following this activity, I returned their CER, and they revised their responses individually. The results were recorded as CER 4 scores. Data indicated that CER 4 had the most improvement in all the assessments with 14 out of 20 students increasing their scores from the previous CER.

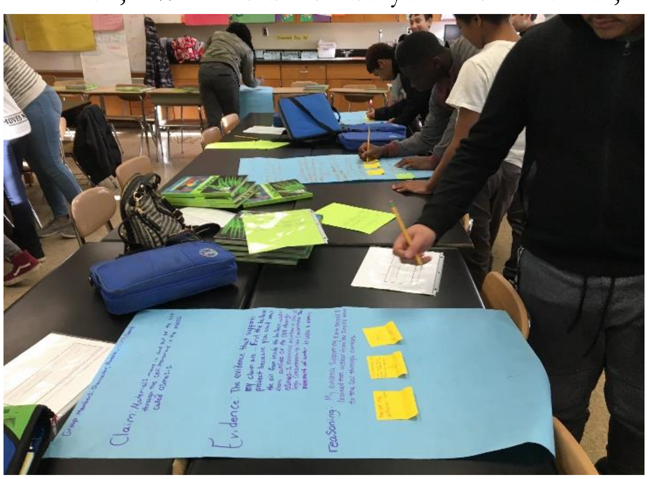

Fig. 3 A photo taken during the Gallery Walk

Working collaboratively with other students in constructing their CER allowed them to listen to others' thinking, understanding of the concepts, and analyzing data. In addition, their discussion with other peers while evaluating various CERs might have helped them study the rubric intentionally. Moreover, their peers' feedback allowed them to reflect on their argumentation because the feedback they received was specific and explicit, which helped them improve their CER and meet the expectations in the rubric. Some of the feedback included were "Add more evidence," "The information seems to be repeated throughout the poster," "The reasoning does not have much value toward the point in hand." The constructive feedback they provided showed that students were analyzing and critically examining other students' responses while providing insights for improvement. When they worked with other members of the group, the two students mentioned previously increased their scores and provided responses in the CER that meet the expectations based on the rubric. One of the student's evidence was "During the experiment that used balloons, there was a scent of oil leaking through and proved that the balloons have the capacity to contain within and seated" while his reasoning was "I can prove that osmosis took a large part of the experiment because the scent was able to pass through the balloons molecules and that was possible because the balloon had a high concentration area." The other student's claim was "Materials move in and out of the cell through the cell membrane."

Implications

Students' understanding of the nature of science and the skills to apply their scientific knowledge requires answering questions supported by evidence and reasoning – making sense of learning (Keeley, 2015; Archila, Molina & Truscott de Mejia, 2018). The instructional activities presented in this article have common components such as collaboration, critical feedback and reflection, and modeling. As used with my students described in this article, the CER framework could lend to opportunities of students' engagement in scientific discourse by providing a claim, supporting their claim with evidence and providing reasoning using scientific concepts while working collaboratively. Moreover, students' more in-depth understanding of the concepts is exposed while developing the skills of argumentation in scientific discourse using CER (Alegado & Lewis, 2018; Keeley, 2015; Larrain, Howe & Freire, 2018). Support strategies for students (especially with special needs and English language learners) could include sentence starters and science journals. The use of science journals for notes and observations (with emphasis on the organization of science notebooks) in keeping their notes intact is also helpful. Finally, our role as a teacher to analyze data to make informed instructional decisions is essential to maximize student learning.

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