1-1-2015

Engaging A Middle School Teacher And Students In Formal-Informal Science Education: Context Of Science Standards-Based Curriculum And Urban Science Center

Shamarion Gladys Grace
Wayne State University,

Recommended Citation
Grace, Shamarion Gladys, "Engaging A Middle School Teacher And Students In Formal-Informal Science Education: Context Of Science Standards-Based Curriculum And Urban Science Center" (2015). *Wayne State University Dissertations*. 1359.
https://digitalcommons.wayne.edu/oa_dissertations/1359

ENGAGING A MIDDLE SCHOOL TEACHER AND STUDENTS IN FORMAL-INFORMAL SCIENCE EDUCATION: CONTEXTS OF SCIENCE STANDARDS-BASED CURRICULUM AND AN URBAN SCIENCE CENTER

by

SHAMARION GLADYS GRACE

DISSERTATION

Submitted to the Graduate School

of Wayne State University

Detroit, Michigan

in partial fulfillment of the requirements

for the degree of

DOCTOR OF EDUCATION

2015

MAJOR: CURRICULUM AND

INSTRUCTION

Approved by:

Advisor Date

DEDICATION

This dissertation is dedicated to my late parents, Sallie Leona and Clarence Nelson Brumley. For your love, support, and guidance, I am eternally grateful! To my husband, Darryl Grace, thank you for your never-ending love, patience, and support. To my children, Thaddeus, Ashley, and Darryl II, may God continue to bless you and guide you in realizing that dreams do come true with diligence, hard work, and much prayer.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank God for giving me the stamina, wisdom, and courage to continue through the years to write this dissertation. Next, I want to thank my family and friends for encouraging me to complete this daunting task. Many thanks to my husband, Darryl Grace, who continued to nudge me by asking, “Are you done yet?” The love, patience, and sacrifice of my family and my faith in God have helped me continue this journey to completion.

I would like to especially thank my primary advisor and committee chair, Dr. Jazlin Ebenezer, for your patience, understanding, and constant guidance throughout this process. Your encouragement and willingness to see me through to the end are very much appreciated. Through the many drafts and rewrites, you have shown me and modeled for me the importance of scholarly work and true excellence. I will forever be grateful for your time and dedication to my success. I look forward to continuing my scholarly path with you in the future.

I would like to thank Dr. Susan Gabel for being a part of my journey. Your comments and suggestions have helped me to improve the quality of my work. Your time and dedication are appreciated.

Also, I would like to thank Dr. Lynda Wood. I consider you my mentor because I used your dissertation as my measure of success and benchmark for excellence. You will always be my intellectual friend, and I look forward to continuing our scholarly journey together.

Many thanks to Dr. Joseph Krajcik and his research team for allowing me to use the Investigating and Questioning Our World Through Science and Technology (IQWST) curriculum and assessments in this study. I want to thank the staff at the informal science center for allowing me to conduct research in their facility. Also, I would like to thank the staff at the school that allowed me to be a part of their environment for the duration of my research.

I would like to thank “Cathy” (pseudonym for the teacher). Your willingness to allow me to work with you and your students in your classroom on this complex research project will have a positive impact on science education. I hope you will continue to incorporate informal learning opportunities in your curriculum so that your students will benefit from these experiences and opportunities to grow academically.

I would like to thank the students who participated in this study. Your participation was necessary and valued throughout this process. Your contribution will help future generations.

To my dear children, Thaddeus, Ashley, and Darryl II, who sacrificed and supported me throughout this journey, I am eternally grateful. You were patient and supportive because you had to share your mom with this dissertation. I pray that God will grant you the same success, and please know that I will always be here for you.

Finally, I would like to thank the special women who have been a part of my life and contributed to my successful journey. These women are Sallie Brumley (my mother), Gladys Traylor (my grandmother), Vertie Clark (my sister), and Julian Green (my mother-in-law). You all have helped me to believe that “I can do all things through Christ which strengthened me” (Philippians 4:13).

TABLE OF CONTENTS

Dedication ii

Acknowledgements iii

List of Tables xi

List of Figures xii

Chapter 1: Introduction 1

- Background 1
- Problem Statement 6
- Research Objectives and Questions 10
- Significance of the Study 11
- Overview of the Methodology 13
- Description of Terms 14
- Overview of the Study 16

Chapter 2 (Article 1): Characterizing a Third-Space Emergence at the Interplay of Formal-Informal Science Educators: Challenges as Opportunities for Personal Growth 18

- Abstract 18
- Introduction 19
- Literature Review 20
- Theoretical Frameworks 23
  - A Third Space for Personal Growth 24
  - A Hybrid Third Space for Knowledge Development 25
- Research Questions 28

Significance of the Study 29
Methodology 29
  Data Collection 33
  Data Analysis 33
  Validity and Reliability 34
Results and Discussion 35
  Opportunity One for Personal Growth: Beginning a Science Lesson without the Focus on Terminology 36
  Opportunity Two for Personal Growth: Downplay or “Dumb-Down” Science Exhibits 39
  Opportunity Three for Personal Growth: Exploration Distracts the Lesson Structure 41
  Opportunity Four for Personal Growth: Deciphering the Meaning of Models/Modeling 45
  Opportunity Five for Personal Growth: Learning Science Content First or Exploring Science Exhibits 48
Implications 50
Chapter 3 (Article Two): A Grade Seven Science Teacher’s Discursive Interactions in Developing Common Knowledge: Intertwining Concepts of Energy and Science Inquiry Processes 56
Abstract 56
Introduction 57
Literature Review 58

Theoretical Frameworks 62
  A Sociocultural Perspective of Learning and Science Classroom Discourse 62
  Related Science Classroom Discourse Studies 67
Research Questions 69
Significance of the Study 70
Methodology 70
  Research Design 70
  Research Site: The Science and Mathematics Academy 71
  Investigating and Questioning Our World Through Science and Technology (IQWST) Curriculum 72
    Energy Unit of the IQWST Curriculum 72
  Participants 73
  Data Collection 74
  Data Analysis 75
  Reliability and Validity 77
Results and Discussion 79
  Focusing on the Inquiry Process 79
  Understanding Kinetic Energy 81
  Formulating Scientific Explanations 85
  Translating Energy Transformation 90
Implications 95
  Cathy's Struggle with Dialogic Discourse 96

Professional Development with Intellectual Empathy and Follow-Up 100

Chapter 4 (Article Three): The Effect of Formal-Informal Instruction of Energy Concepts on Urban African-American Students' Science Application and Achievement 102

Abstract 102

Introduction 103

Significance of the Study 107

Theoretical Framework: School Science Learning Augmented with Informal Learning among Urban Minority Students 108

A Literature Review on Students' Understanding of Forms and Transformation of Energy 112

Methodology 113

Contexts of the Study 113

Characteristics of the Science and Mathematics Academy 114

Characteristics of the Science Learning Center 115

Energy-Related Science Center Exhibits 116

Flywheel Exhibit 117

Brownian Motion 117

Giant Pendulum 118

Simple Machines 119

Partnership between the Science and Mathematics Academy and Urban Science Center 120

The IQWST Curriculum 121

The Forms and Transformation of Energy Unit of the
IQWST Curriculum 122
Research Design and Procedures 123
Professional Development Experience of Both Teachers..............................124
Parallel Teaching in the Experimental and Control Classes..........................125
Teaching in the Experimental Class 125
Quantitative Data Sources and Analysis..127
The IQWST Unit Achievement Test (IUAT) 127
Analysis of Pre-Test and Post-Test IQWST Unit Scores 127
Qualitative Data Sources and Analysis..128
Video Creation and Presentation 128
Focus-Group Interview 131
Validity and Reliability..132
Results and Discussion 133
Students' Achievement 133
Students' Understanding of Energy: Scientific Explanations of
Science Exhibits...139
Students' Understanding of Energy: Model Development of the
Flywheel Exhibit 145
Implications..151
Standards-based Augmented Curriculum for Improved Achievement and
Science Learning...152
Analysis of Students' Presented Videos Reveals Scientific Explanations 153

Extended Time on Informal Learning Projects to Improve Scientific Explanations 153
Chapter 5: Conclusions of the Study 155
Introduction 155
Summary of Article One 155
Summary of Article Two 156
Summary of Article Three 158
Appendix A: IQWST Activity 2.2 161
Appendix B: IQWST Unit Achievement Test (IUAT) 162
Appendix C: A Complete List of Classroom Events with Days and Dates 169
Appendix D: Students' Flywheel Model 173
References 174
Abstract 188
Autobiographical Statement 192

LIST OF TABLES

Table 1: Emerging Purpose through Evolving, Open Discussion in Year Two....................32

Table 2: Transcript Excerpts Based on IQWST Workbook Lessons 75

Table 3: Types of Teacher-Posed Questions and Examples..76

Table 4: Partial Table of Classroom Events 125

Table 5: Mean Scores and Standard Deviations of the IUAT for Both Groups..................132

Table 6: One-Way ANOVA Descriptive Statistics of Scientific Explanations..................134

Table 7: One-Way ANOVA Tests of Between-Subject Effects of Scientific Explanations...134

Table 8: One-Way ANOVA Multiple Comparisons of Scientific Explanations................135

Table 9: One-Way ANOVA Descriptive Statistics of Teacher/Students' Time Spent at Exhibits...136

Table 10: One-Way ANOVA Tests of Between Subjects Effects of Teacher/Students' Time Spent at Exhibits 137

Table 11: One-Way ANOVA Multiple Comparisons of Teacher/Students' Time Spent At Exhibits...137

Table 12: Quality of Student Understanding of Energy Based on Video Evidence: Explanation of Energy—Making Claim-Evidence-Reasoning Connections 139

Table 13: Extracted Comment from Transcripts of Students' Videos on Scientific Explanations of Exhibits Connected to the Concept of Energy 141

LIST OF FIGURES

Figure 1: Flywheel Exhibit--Urban Science Center....116

Figure 2: Brownian Motion--Urban Science Center....117

Figure 3: Giant Pendulum--Urban Science Center....118

Figure 4: Simple Machines--Urban Science Center....119

CHAPTER 1

INTRODUCTION

Background

In the past decade, the American public has witnessed the proliferation of informal science centers. The public's enthusiastic response to the educational contributions made by informal science centers has prompted schools to launch ambitious collaborations with these centers to improve how science is taught. Thus, a need arose for science teachers and informal science educators to examine the factors that make such collaborations powerful science learning experiences for students (Katz, 2001; Martin, 2004). In particular, research on how informal science centers support science teaching and learning in school has gradually taken shape (Martin, 2004).

Informal learning happens throughout people's lives in a highly individualized manner based on their particular needs, interests, and past experiences (Dorsen, Carlson, & Goodyear, 2006). Much of what people come to know derives from real-world experiences within a variety of physical and social contexts and is motivated by an intrinsic desire to learn (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003). Science centers promote informal learning by providing real-world experiences in diverse physical and social contexts, and they cater to a myriad of human experiences while building a more interested and receptive audience devoted to lifelong learning. With the goal of inviting learners to go beyond their present knowledge and to construct a newer, larger vista of scientific thinking (Ramey-Gassert, 1997), informal science centers provide opportunities for learners to engage in inquiry-based, self-directed science discovery.

Experiences within informal science centers and within schools can interact to influence the ways learners develop scientific knowledge and understanding, cultivate positive attitudes toward science, and encourage positive behavioral changes. The collaborative efforts between schools and informal science centers, such as museums, may also contribute to science achievement because learning rarely occurs and develops from a single experience (Dierking et al., 2003). Cox-Peterson, Marsh, Kisiel, and Melber (2003) highlighted the goals that informal science centers share with formal science standards, including (a) increasing science knowledge, (b) increasing science activity and career access among student populations that have been traditionally underrepresented, (c) emphasizing science literacy, and (d) fostering understanding that comes from research in teaching and learning science. The motivation of students to learn science may result from the interaction of curriculum experiences and informal learning experiences (Hodson, 1993). Informal science learning environments are expected to provide teachers with unique insights into the cognitive, social, and affective aspects of learning—all of which have led science educators to emphasize the importance of learning in informal science centers as a complement to the science curriculum (Rennie, 2007).

Partnerships with informal science centers have been credited for making science learning more consequential. Informal science centers offer potential academic supplements that provide opportunities for learners to engage in self-directed scientific practices (Ramey-Gassert, 1997). The inquiry experiences that occur within informal science centers can interact with curriculum experiences to influence, among other things, the ways learners develop scientific knowledge and understanding—to go beyond their present knowledge and construct a newer, larger landscape of scientific thinking (Hodson, 1993). The expansion of science knowledge in the process of becoming “science literate” is a goal that informal science centers share with the creators of formal science standards (Cox-Peterson, Marsh, Kisiel, & Melber, 2003). Thus, formal and informal learning environments have the shared responsibility of providing students with meaningful experiences that deepen scientific knowledge (Rennie, 2007). For instance, Dorsen et al. (2006) and Rosser (1997) have pointed out that interacting with museum exhibits increases the type of learning that supports persistence and success in future course work within science, technology, engineering, and mathematics (STEM) disciplines. Informal STEM educational opportunities can augment school curricula and prepare young people for greater school achievement in science (Dierking et al., 2003). Greater coordination of informal and formal learning opportunities is essential in enhancing opportunities to participate in science activities among low-income minorities—a student population that historically has been underrepresented in the sciences (Bevan & Semper, 2006). Consequently, establishing collaborative relationships between urban science teachers and informal science educators has become an important goal in education.

Ramey-Gassert (1997) has pointed out that as connections between schools and informal settings are developed, it is helpful for informal science educators to be aware of reform documents, such as the *National Science Education Standards* (NSES) (NRC, 1996) and *A Framework for K-12 Science Education* (NRC, 2012). Much of the NSES focuses on scientific inquiry, which refers to the activities of students in which they develop knowledge and understanding of scientific ideas through inquiry. In inquiry science, students are given an opportunity to explore scientific concepts by observing, asking questions, coming up with possible solutions, and communicating their knowledge of what was learned. Students learn science related to their lives outside school and develop skills required to enter careers in science, engineering, and technology (NRC, 2012).

An inquiry-based curriculum, founded on the National Science Education Standards (NRC, 1996), may serve as a bridge between formal and informal education that has the potential to reach diverse students (Bybee, 2001). An excellent example of such a curriculum is *Investigating and Questioning Our World Through Science and Technology* (IQWST) because it incorporates the learning ideals of informal science centers that provide real-world experiences in diverse physical and social contexts. The compatibility of the IQWST curriculum for all learners specifically addresses inquiry processes that connect with technology and the sociocultural context of real lives (Davis & Krajcik, 2005). The building of science content and scientific practices through projects across content strands and across time makes IQWST unique in that it addresses requirements of the *National Science Education Standards* (NRC, 1996) and *A Framework for k-12 Science Education* (NRC, 2012). Concurrently, IQWST provides a curriculum framework that integrates interactive museum exhibits. Linking a standards-based inquiry curriculum, such as IQWST, with informal science learning opportunities provides extended experiences that build knowledge and understanding of science among students from diverse backgrounds.

The Science and Mathematics Academy (SMA) is an urban Public School Academy secondary school that focuses on science and math and features a student population that is majority African-American. SMA believes in learning communities that (a) seek, create, and use opportunities to benefit themselves; (b) encourage students to explore science, technology, engineering, and mathematics; (c) rigorously investigate curriculum aligned with state standards; and (d) engage students in constant inquiry. The IQWST curriculum supports the mission and values of SMA, and therefore the IQWST curriculum was selected as the science curriculum for this school. The IQWST curriculum is based on of project-based science that emphasizes students' engagement in student-directed scientific practices with technology and collaboration (Krajcik, Czerniak, & Berger, 2002; Ruopp, 1993; Schneider, Krajcik, & Blumenfeld, 2005; Tinker, 1996). Teachers at SMA were required to adhere to the State's standards-based curriculum; however, SMA was allowed to adjust the curriculum to meet the needs of it students. Hence, science teachers were able to implement the IQWST curriculum in their classroom.

Based on the IQWST curriculum, teachers were provided professional development that included support in the areas of science content, inquiry pedagogy, and contextualizing learning that focused on Big Ideas. Coherence and developing student understanding of concepts and explanations were emphasized along with methods of properly assessing students. During this time, the Center for Informal Learning and Schools had established a research agenda that included understanding how informal science institutions can support and improve K-12 schooling with the goal of improving (a) formal learning in informal settings as well as (b) informal learning in formal settings. Teachers also received professional development on the BIG Lesson Model. The BIG Lesson Model includes a study trip for teachers and students that involves a partnership between community resources and schools. Because the teachers at SMA were given autonomy to implement the IQWST curriculum in order to improve student achievement, the idea emerged of combining formal learning (i.e., the IQWST curriculum) with informal learning. Because SMA is located next to the Urban Science Center (USC), a natural environment conducive to this type of learning was in place.

The Urban Science Center is one of the largest hands-on science museums in the

United States. It produces hundreds of displays that explore space, life, and physical science that appeal to diverse audiences (DSC, 2009). In particular, this study focused on a teacher who worked collaboratively with an informal science educator to plan and implement learning experiences for students who integrated the IQWST curriculum with USC exhibits.

Problem Statement

Many successful school programs draw on real-world relevance and connections with informal learning to help students find personal meaning in cognitive activity (Ramey-Gassert, 1997). Teachers are well situated to meet the challenges and capitalize on the opportunities to address students' interests in science by connecting informal learning with school science (Anderson, Lucas, & Ginns, 2003). However, many teachers seldom use informal science learning environments because either they are unaware of how to incorporate informal learning materials into their science curricula or because they are unfamiliar with informal science resources and exhibits (Ramey-Gassert, 1997). Likewise, informal science learning centers have been criticized for promoting fun and enjoyment rather than science education, obscuring the value of the scientific process, providing poor explanations, and ignoring ethical dimensions of science and technology decisions (Rennie, 2007). In fact, many exhibits are designed for the museum's exhibit collection and not for the school curriculum. If informal science centers portray science merely as a connection between scientific thought and conclusions and do not address the connections among science, technology, and society, then there are flaws in this educational system.

To address these types of flaws in informal science centers, the science community must initiate partnerships between informal institutions and formal institutions so that such partnerships can foster the interactions among science, technology, and society in ways that address students’ perspectives about the nature of science and how it is situated in the socio-cultural context of real lives (Pedretti & Forbes, 2000). More research is needed to explore the connection between informal museum exhibits and how they can integrate with a formal science curriculum that addresses inquiry processes and connects with technology and the socio-cultural context of real-world living.

With standards and assessments driving accountability in schools, there is an increasing recognition that support is needed from informal science centers to help schools and teachers strengthen or expand the ability of schools to meet their goals for students. This recognition suggests a need to pursue the idea of a collaborative learning community consisting of informal science educators and science teachers. It is important for informal science centers to address the school-based needs of their school partners and audiences. However, at the same time, it would be beneficial for informal science educators to learn more about theories of science learning that inform classroom decisions. Collaborative efforts toward curriculum integration call both for formal science educators and informal science educators to step into each other’s professional spaces. Because the professional practices of formal and informal educators often conflict, the first part of this study explores an in-between “third space”—that is, a space that does not necessarily achieve consensus (Wang, 2004, 2006)—as opposed to a hybrid third space that expects both school educators (Hofstein & Rosenfeld, 1996) and informal science educators (Bevan & Semper, 2006) to shift their thinking.

The second part of this study focuses on the discourse between a seventh-grade teacher and her students as she attempted to foster the development of common knowledge in science. Teaching models that have adopted the notion that knowledge is co-constructed within a sociocultural context (Driver, Asoko, Leach, Scott, & Mortimer, 1994) are consistent with the notion of mediation of oral language referred to as “dialogic discourse.” Dialogic discourse aligns with the idea that knowledge is constructed through a social process that fosters the development of common knowledge (Edwards & Mercer, 1987). Although most science educators promote dialogic discourse, in practice, many employ discourse strategies that maintain control of the course content, interaction, and discussion in order to achieve a desired outcome (Edwards & Furlong, 1978; Mishler, 1975). Teacher-student verbal interactions deserve to be called “dialogic” because teachers use language to provide a cumulative, continuing, contextual frame that enable students to engage with new information that they encounter (Alexander, 2000, 2004). As a result, it is important to observe how teachers conduct whole-class discussions and assess how they develop conceptual understanding of science-related knowledge in order to establish common knowledge.

The third part of this study investigates how the IQWST curriculum augmented with science center exhibits influenced how seventh-grade students learned about the concept of energy. Children of racial and ethnic minorities with high-poverty backgrounds living in urban cities lack opportunities to learn high-quality science (Tan & Barton, 2012). The work of (a) social justice researchers, (b) conceptual change researchers with a focus on teacher care and intellectual empathy (Ebenezer et al., 2010; Wood, Ebenezer, & Boone, 2013) and (c) project-based science education researchers (Geier, Blumenfeld, Marx, Krajcik, Fishman, Soloway, & Clay-Chambers, 2008) offer promise in exploring ways to increase urban youth learning and achievement. Geier et al. confirm that historically underserved urban students have realized standardized achievement test gains when teachers used standards-based, inquiry science curriculum that is highly specified, developed, and aligned with professional development for teachers and supported by the administration.

Katz (2001), in his study of a teacher and an informal science educator meeting consistently to plan and align exhibits that connected with science standards taught in the classroom, states that it might be worthwhile for informal science learning centers to provide experiences that align more closely with school science standards as a way of improving science learning and achievement. In line with Katz's study, Dierking, Falk, Rennie, Anderson, and Ellenbogen (2003) observe that when they are connected to classroom teaching, informal STEM educational opportunities (e.g., exhibits that focus on STEM activities and interactions) can prepare young people to reach greater achievements in science. The Centre for Advancement of Informal Science Education (2010) asserts that learning in informal environments, such as science centers, has resulted in positive outcomes for students in conceptual understanding, achievement, and disposition. Falk and Needham (2011) report that students learned science content; extended their learning to other contexts; and increased their interest, curiosity, and attentiveness to science because of their multiple visits to a science center. Hung, Lee, and Lim (2012) propose that time should be allocated for students to learn in informal contexts and that teachers should play the role of "brokers" to help students articulate, reflect on, and think about their learning experiences in informal contexts, thereby helping students to re-contextualize learning strategies in formal learning. Currently, no studies have been conducted that trace the connections made by classroom teachers and informal science educators as they attempt to integrate museum exhibits into science curriculum.

The researcher of this study, as an administrator in her own school district in another nearby urban city, attended the professional development featuring the IQWST curriculum materials. She was interested in augmenting her school district's science curricula with the support of the local museum exhibits in order to reach urban African-American students. Because of these common interests, the researcher connected with the science teacher ("Cathy") (a) to determine whether there was an increase in achievement scores when the IQWST curriculum was augmented with science exhibits and (b) to understand the nature of students' learning at the intersection of the IQWST curriculum and the USC interactive science exhibits. Based on the joint interest of the teacher and the researcher, a complex, classroom-science center study was developed at SMA to observe students' science achievement and learning that occur at the intersection of formal (IQWST) and informal (interactive museum exhibits) educational environments.

Thus, the goals of this study were to (a) characterize the emergence of a third space through the conversations of formal and informal science educators as they attempt to implement a standards-based curriculum with the support of science center exhibits; (b) interpret the discursive moves during classroom discourse on the topic of energy as Cathy prepared her students to observe exhibits on energy at a science center; and (c) to investigate whether a standards-driven, project-based IQWST curriculum unit on forms and transformation of energy augmented with science center exhibits had a significant influence on urban African-American seventh-grade students' achievement and learning. Based on these goals, the following research objectives and questions are outlined in the next section.

Research Objectives and Questions

Following are the research objectives and research questions that guided this study:

Objective 1: To characterize the nature of an emerging "third space" at the interplay of formal-informal science educators.

1. What is the character of an emerging third space created through the interplay of a community of educators when they attempt to implement the standards-based IQWST curriculum with the support of resources from the Urban Science Center?

Objective 2: To interpret the discursive moves that a seventh-grade teacher makes as she teaches students about the topic of energy.

2. What discursive interactions does a middle school science teacher make as she attempts to develop common knowledge related to the concept of energy and science processes?
3. How does the discourse reflect a sociocultural perspective on learning?

Objective 3: To observe students' science achievement and learning that occur at the intersection of the formal (IQWST) and informal (interactive museum exhibits) educational environments.

4. Are there significant gains in students' achievement scores from pre-test to post-test as a result of the intersection of the IQWST unit and the interactive museum exhibits?
5. Are there statistically significant gains in students' achievement scores from pre-test to post-test as a result of including interactive museum exhibits in an IQWST unit on forms and transformation of energy? What conceptual understandings do sub-groups of the same African-American students reveal based on the USC exhibits that demonstrate forms and transformation of energy?

Significance of the Study

This study is significant for the following reasons:

The characterization of a third space that emerges based on the conversations between formal and informal science educators provides insight into the distance and proximity of the interplay between educators. Because science learning takes place both in formal and informal settings, this study helps identify the position of each on the nature of learning in a third space. This study also provides a platform for future research on the intersection of formal and informal institutions that seek to improve school science learning.

It is important to understand how teachers conduct whole-class discussions and develop students' conceptual understanding on the topic of energy in order to establish common knowledge over time. Because the teacher in this study implemented a standards-based science curriculum from a sociocultural learning perspective, it is important to know whether classroom discourse parallels the intention of the curriculum. This study also provides a platform for future research on developing common knowledge through classroom discourse. This research can help teachers and administrators become aware of how the process of developing common knowledge plays out in the reality of an urban classroom with African-American students.

This study contributes to the knowledge base of the IQWST program, the focus of which is on urban student learning and achievement. In the tradition of the IQWST program, this study was conducted in an urban school consisting primarily of an African-American population from a low economic urban setting. As a result, this study situated in IQWST curriculum indicates how to develop students' conceptual understanding of science concepts in an urban setting. This study also illuminates how teachers may be able to help urban students who (a) come to school lacking prior knowledge about science or (b) who are not fortunate enough to experience learning outside the context of school to link such knowledge with school science.

The outcomes of this study align with the work of the researchers studying the influence of standards-based science inquiry on students' learning and achievement. The interest of other investigators likely will be sparked by the published results of this study, resulting in a subsequent amplification of productivity in this highly significant area of research. This study lays the theoretical and methodological foundation for future researchers to study the influence of formal and informal teaching on students' science learning and achievement.

Overview of the Methodology

This study primarily focused on understanding how science teachers communicated and collaborated with informal science educators at the USC during the second year of a long-term SMA-USC project. The year-two participants of this study included a science teacher ("Cathy") at SMA, an informal science educator ("Roger") at USC, an urban university science teacher educator/researcher ("Dan"), and the researcher/school district administrator ("Sharon") of this study. The conversations among the community of educators in the planning and implementation sessions were collected via a type of audio-recorder called Integrated Circuit (IC), video-recording, and field notes. Nine planning sessions were conducted, and the documents generated by the community of educators were gathered.

A case study methodology (Stake, 1995; Yin, 2003) was used in order to gain a deeper understanding of how Cathy developed common knowledge about the concept of energy and science procedures using the standards-based IQWST curriculum. Sociocultural tools were used to understand the interpretive analysis (Creswell, 2003) that was conducted on the classroom discourse that occurred between the teacher and students during a four-month period. The classroom discourse between the teacher and students was IC recorded and transcribed verbatim. A sampling of students' IQWST workbooks was collected as evidence that student work corresponded to the forms and transformation of energy lessons taught by Cathy. Sharon identified teacher-student classroom discourse transcripts corresponding to the workbook lessons from the IQWST physics unit.

A mixed-methods approach, such as the one employed by Clary and Wandersee (2007), was used for concurrent triangulation and corroboration of findings within a single investigation (Cresswell, Clark, Gutmann, & Hanson, 2003). The study consisted of a quasi-experimental, pre-test and post-test control-group design, and classes were randomly assigned to a treatment (Campbell & Stanley, 1963). Two groups of students were compared based on their pre-intervention test scores. The intervention consisted of implementing the IQWST curriculum unit entitled Forms and Transformation of Energy with Science Center exhibits. The post-intervention test scores of two groups were compared after the curriculum had been implemented. The IQWST Unit Achievement Test (IUAT) was used to determine achievement scores of students. Qualitative observations were made of one learning community of 18 students in one of the two experimental classes. Of the students in the learning community, a small sub-group was followed to observe how students connected what they learned in school to an interactive science exhibit at the USC. As part of her pedagogy, Cathy actively engaged her students as they indicated their understanding of forms and transformation of energy in their workbooks, models, and videos.

Description of Terms

Common knowledge is based upon shared understanding as participants pursue common goals.

Dialogic discourse is the mediation of oral language where there is a dialectical relationship between knowledge that is constructed by reflecting on an activity and knowledge that is negotiated.

Formal learning is learning in a structured setting guided by a formal curriculum and a trained teacher. Formal learning took place in Cathy's classroom and SMA.

Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating results (NRC, 1996).

Informal learning occurs outside a dedicated learning environment. It arises from the activities and interests of individuals and groups, but it may not be recognized as learning. Informal learning may involve short, structured courses organized in response to identified interests and needs but delivered in flexible and informal ways and within informal community settings.

Informal science education refers to any science learning that occurs outside the school walls (Gassert, 1997).

Out-of-school learning involves the accomplishment of an intellectual or physical task by a group that is interacting using real elements, which allows learning to take on greater meaning (Gassert, 1997).

Project-based science (PBS) curricula such as IQWST have project- and inquiry-based aspects that leverage the strengths of urban students from ethnic and racial groups underrepresented in science careers, potentially impacting positively these students' science learning and achievement.

Science achievement focuses on the topic of forms and transformation of energy.

Science center exhibit is an object or collection of objects that are on public display at a science center.

Scientific knowledge refers to facts, concepts, principles, laws, theories, and models that can be cultivated in many ways.

Scientific understanding requires that individuals integrate complex structures of many types of knowledge, including the ideas of science, relationships between ideas, reasons for these relationships, ways to use these ideas to explain and predict other natural phenomena, and ways to apply them to many events (NRC, 1996).

Sociocultural perspective relates to both social and cultural matters that have an effect on individual thinking and collective thinking. The IQWST curriculum was informed by a sociocultural perspective.

Standards curriculum is based on national or state educational requirements that students are expected to learn and that teachers are expected to teach. The standards-based curriculum in this study is IQWST.

Third space focuses on the personal growth of individuals (Wang's (2004, 2006), whereas a "hybrid third space" refers more to knowledge development (Moje et al., 2004). Wang's (2004) third space does not consume the first space and the second space but is rather an ongoing process of generating new possibilities as a result of mutual movement between the two spaces.

Overview of the Study

Chapter one argues for the integration of formal/informal science learning. In order to improve student learning in science using a formal/informal intervention, teachers and informal educators need to plan and collaborate; investigate classroom discourse practices; and measure students' achievement, learning, and application of the concepts being studied. Chapter two presents the first article that discusses characterizing the emergence of a third space at the interplay of formal-informal science educators—a third space that characterizes challenges as opportunities for personal growth. Chapter three presents the second article that discusses a grade-seven science teacher's discursive moves in developing common knowledge by intertwining concepts of energy and science inquiry processes. Chapter four presents the third article that discusses the effect of formal-informal instruction about energy concepts on African-American students' science application and achievement. Chapter five concludes the dissertation with a summary of research findings, issues reflecting evidence, and implications.

All three articles/chapters present and discuss the need for a study that reflects the present status of research in a particular area of research, an extensive literature review, and theoretical frameworks to guide the study. The framework shared by all three articles is the intersection of formal and informal science education/learning. Each article frames one or more research questions and describes the significance of answering these questions. Methodology is described and justified in each article. Results are presented logically and coherently, and implications are drawn based on evidence presented in each article.

CHAPTER 2 (Article One)

CHARACTERIZING A THIRD-SPACE EMERGENCE AT THE INTERPLAY OF FORMAL-INFORMAL SCIENCE EDUCATORS: CHALLENGES AS OPPORTUNITIES FOR PERSONAL GROWTH

Abstract

The purpose of this study was to characterize the conversations of formal and informal science educators as they attempted to implement a standards-based curriculum with the support of science center exhibits. Accomplishing this goal required the discovery and exploration of a "third space" meant for personal growth—a space that provides insights into the proximity of formal and informal science educators' interplay. A case study featuring audio-recorded, semi-structured interviews and field notes provided the methodological framework for this study. The results and discussion revolve around five challenges that characterize the emergence of a third space: (a) to begin a science lesson without the focus on terminology, (b) to down-play "dumb-down" science exhibits, (c) to explore distracts lesson structure, (d) to decipher the meaning of model/modeling, and (e) to learn science content first or explore science exhibits. However, these challenges have been considered as opportunities for personal growth. The results of this study suggest that a third space allows for participant reflection and transformation in formal-informal collaboration and communication.

Key Words: formal learning, informal learning, third-space emergence

Introduction

Mediation of learning between schools and science learning centers has been evolving and taken many forms (Bevan & Semper, 2006; Hofstein & Rosenfeld, 1996; Stocklmayer, Rennie, & Gilbert, 2010). Researchers have emphasized the benefits of formal-informal science learning for several reasons. Informal science learning may facilitate the development of reasoning abilities that are pre-requisites to learning and understanding science processes and concepts (Gerber, Cavallo, & Marek, 2001). Students who spend more time with museum objects and exhibits develop a deeper, more complex understanding of science than students who have little or no exposure to the museum setting (Martinello & Kromer, 1990). In addition, studies have indicated that students who create their own museum projects from start to finish and put them on display at their school tend to learn more and have more enthusiasm for learning when they are subsequently faced with comprehensive and intellectually demanding tasks (D'Acquisto, 2006). These studies and others (e.g., Falk & Dierking, 2000; Rennie, 2007; Stocklmayer et al., 2010) have indicated that science education augmented by museum resources is considered valuable because the nature of learning is viewed the same by both sectors as personal, contextual, and socio-cultural. These studies also pointed out the connection between classroom experiences and experiences with local science centers. This connection fosters student production through problem solving, construction, collaboration, and creativity.

While school science augmented by informal learning has been a focus of research during the past three decades (Stocklmayer et al., 2010), documentation of the mediation of learning between formal and informal educators is ostensibly missing from the science education literature. Kisiel (2014) investigated the experiences of (a) teachers who engaged in informal science education institutions and (b) informal educators in an effort to clarify the limitations and opportunities for encounters between the two communities. Kisiel's study revealed possible avenues for strengthening activities and creating a more effective merger of learning and teaching resources among formal science educators and informal science educators. In response, the purpose of this case study was to systematically document, analyze, and interpret the conversations that occurred within a small group of formal and informal science educators in a midwestern city when they attempted to augment a standards-based science curriculum that incorporated interactive museum exhibits. Understanding this interaction and mediation is important because opportunities for personal growth that lead to transformed practices are embedded within challenges when members of formal and informal sectors work together to enhance school science learning.

Literature Review

Hybridity theory refers to the intersection of two "spaces." The first space consists of the formal school science culture, and when it is combined with a second space consisting of the informal science center culture, it creates a third space, or hybrid space that manifests characteristics of both spaces (Calabrese Barton, Tan, & Rivet, 2008). Hofstein and Rosenfeld (1996) have suggested that schools should effectively use out-of-school contexts to provide all students with opportunities for hybridized learning experiences. Little is known about how informal learning experiences may support school curriculum, but Hofstein and Rosenfeld (1996) have called for research that effectively hybridizes formal and informal learning experiences as a way of improving science education. Schools tap into opportunities that are available through science centers primarily through field trips and guided tours (e.g., Cox-Peterson, Marsh, Kisiel, & Melber, 2003; Griffin & Symington, 1997; Falk & Dierking, 2000). Teachers also develop informal learning activities to augment science curriculum, and such supplementation has been considered a form of hybridity (Hofstein & Rosenfeld, 1996).

Griffin and Symington (1997) described the benefits of using a hybrid space when they investigated the strategies that teachers use when moving away from traditional classroom tasks, such as worksheets, to more active learning opportunities, such as those available through museum exhibits. These authors examined the link that teachers make between classroom topics and excursion topics after observing school groups as they participated in museum visits. They interviewed students and teachers before, during, and after these excursions. The authors discovered that the teachers, who were aware of the type of learning that "ought" to take place in a museum, overlaid traditional task-based school strategies and practices onto museum activities. For instance, the teachers did not use the museum as an informal learning resource and did not adequately link museum exhibits that they visited with relevant school topics. Teachers attempted to juxtapose two different learning cultures but were unable to create an effective and appropriate hybrid space. Griffin and Symington provided two recommendations for museum educators: (1) develop a set of guidelines that enable teachers and students to tap into the benefits of museum visits in order to learn science in school and (2) collaborate with teachers to purposefully prepare them for museum visits and develop follow-up activities that link these museum visits to school curriculum. Both recommendations are directives to change teachers' understanding of informal learning resources and how to use them in classroom teaching. Griffin and Symington have recommended the creation of a hybrid space so that teachers will be successful in merging the two spaces.

Cox-Peterson, Marsh, Kisiel, and Melber (2003) reported that simple guided tours do not necessarily align with key science education standards, nor do they connect to informal learning priorities. However, these authors have acknowledged the potential role museums can play in science learning after observing student-docent interactions, conducting interviews, and documenting docents' perceptions of guided tours in a museum. In fact, they have suggested that museum educators and science educators ought to bridge three elements in order to prepare students for a meaningful visit to the museum: (a) the school curriculum, (b) exhibits/museum contents, and (c) student inquiries. One issue that has been problematic in this bridging process is informal science educators' lack of familiarity with the research literature on science learning, especially classroom science learning. Examples of this type of learning include the following: (1) the importance of students' prior knowledge and experience, (2) the role of evidence and explanation, (3) the role of formative assessment and meta-cognition, and (4) the context of teaching and theories of science learning that inform classroom decisions (Bevan & Semper, 2006; Jolly, Campbell, & Perlman, 2004).

Another issue relates to the need for administrators at informal science institutions to think seriously about their work with high-stakes accountability school systems in light of the ability of these science centers to provide enjoyable, interactive learning experiences (Falk & Dierking, 1996). Falk and Dierking suggested that informal educators merge with school culture by participating in the knowledge, discourse, and identity of schools. Thus, connecting with schools to support curriculum requires deep-seated shifts in the way informal science educators orient their professional practices. This shift can start with informal science educators re-conceptualizing their role within the broader educational landscape (Bevan & Semper, 2006).

Consistent with the recommendations made by formal-informal science education researchers, Falk and Dierking (2000) emphasized the importance of collaborative programs and efforts between schools and informal science centers that involve students in science learning. They also advocated curriculum modifications that weave museum experiences into the classroom learning objectives and day-to-day science activities to facilitate science education. Curricular integration requires much more than access to informal contexts that feature self-directed exploration or inquiry opportunities. Thus, collaborative efforts toward curriculum integration call both for formal science educators and informal science educators to step into each other's professional spaces. Researchers have called for informal science educators to be willing to align outreach activities to the requirements of the school-based science curriculum and to develop a deeper understanding of the science culture within academic environments. Likewise, researchers have called for formal science educators to do more than simply overlay school-based traditional structures onto informal resources. Because the professional practices of formal and informal educators often conflict, a "third space"—an in-between space that does not necessarily achieve consensus—might be an effective compromise (Wang, 2004, 2006), as opposed to a hybrid third space that expects both school educators (Hofstein & Rosenfeld, 1996) and informal science educators (Bevan & Semper, 2006) to shift their thinking.

Theoretical Frameworks

The goal of this study was to characterize the conversations carried out by formal and informal science educators when they implemented the standards-based IQWST curriculum with support from the Urban Science Center. Accomplishing such a goal requires the use of "a third space" (Wang, 2004, 2006) meant for personal growth, rather than a "hybrid third space" (Moje et al., 2004) meant for knowledge development. This study adopted Wang's notion of a “third space” because of its focus on personal growth. In order to clearly distinguish between the two views (i.e., a “third space” and a “hybrid third space”), a detailed discussion of the former concept is presented in the next section.

A Third Space for Personal Growth

Although Wang has discussed transformational aspects of a third space based on her life experience being in two different cultural worlds (i.e., China and the United States), the same ideas can be extrapolated to studies concerned with teachers, researchers, and students’ personal growth in the process of teaching and learning science. A third space “embraces contradictions and ambiguity… to address the complicated issue of identity across the conflicting doubles of culture… so that new subjectivities can be generated (Wang, 2004, p. 111).

Using the third space as a second layer is helpful when the focus is on personal growth rather than on knowledge development. Wang’s notion of a third space is more about subjective and inter-subjective negotiations. The notion of a third space allows disagreement without the need for reaching consensus, and something new can be generated from disagreement in the new forms of subjectivity. Her notion of the third space is that it is in between, but it is *dynamically* in between, which means that it does not converge but rather diverges into multiple new directions. Her third space also is a hybrid, which includes the formation of new forms but also leaves separate strands if necessary. In other words, Wang’s (2004) third space does not consume the first space and the second space but is rather an ongoing process of generating new possibilities as a result of mutual movement between the two spaces. According to Wang, making out the differences between two different entities rather than merging the two is empowering. In Wang’s sense, the formal and informal educators coming together to pursue some work in the study at hand does not represent a fusion or synthesis or conversion, nor does it represent conceptual change or unified completion towards teleological pursuance as manifested in various strands of science education studies that embrace a hybrid third space.

A Hybrid Third Space for Knowledge Development

A hybrid third space is born when two opposing philosophical traditions merge to fill a space with ideals not possessed by either of the two (Gutierrez, 1993). Elaborating on this concept, Gutierrez, Rhymes, and Larson (1995) stated that the space created by the intersection of two learning sectors reorients social discourse patterns that reveal what counts as knowledge and development. The social discourse about knowledge development that emerged in a hybrid third space for learning may be viewed from three perspectives (Moje, Cienchanowski, Kramer, Ellis, Carrillo, & Colazo, 2004).

The first perspective considers the hybrid third space as a bridge between academic and traditionally marginalized cultural knowledge and discourses (Gutierrez, Baquedano-Lopez, & Tejeda, 1999). For example, a space is created to hear voices of subcultural groups in order to provide them opportunities to be successful in formal school learning. A bridge is built between (a) marginalized, everyday cultural knowledge and (b) practice and conventional content learning so that this bridge helps the marginalized knowledge and practices to cross over cultural boundaries and enter into a new bounded space. Building bridges is considered a necessary aspect of creating a third space, which allows learners to see connections and contradictions between their worlds and the worlds of others (Moje et al., 2004). This sort of bridging of cultural knowledge and conventional knowledge in classrooms has resulted in increased academic engagement and learning in the formal sense.

The second perspective defines the hybrid third space as a navigational space—that is, a way of crossing boundaries and succeeding in different discourse communities (New London Group, 1996). For example, students are taught navigational skills based on their everyday knowledge, which then leads to developing conventional academic knowledge and literacy skills. Engaging students in exploring multiple funds of knowledge and discourses related to a particular domain can support their own abilities and help them to navigate different contexts (Hammond, 2001).

The third perspective focuses on cultural, social, and epistemological change by integrating everyday knowledge with domain knowledge (Moje et al., 2004). This perspective recognizes the complexity of people's everyday knowledge and provides a platform for negotiation in order to arrive at an "in-between ness" (Tan & Barton, 2012, p. 28) that allows the construction of alternative histories, discourses, and positions (Bhabha, 1994; Moje et al., 2004; Soja, 1996). In addition, according to Tan and Barton (2012), "Competing knowledge and discourses challenge and reshape both academic and everyday knowledge when people, ideas, and practices of different communities meet, collide, and merge" (p. 29). This hybrid third space is formed by deconstructing boundaries between one space (everyday funds of knowledge) and a second space (science cultural knowledge) and bringing together competing discourses to improve science learning (Moje et al., 2004). Thus, the hybrid third space manifests a variety of shared scripts, voices, and contexts that allow the coexistence of individuals, privileged content and discourses, and identities through negotiation (Gutierrez et al., 1999).

The hybrid third space formed between learning contexts offered by the foregoing three perspectives provides insight into the ways in which science learning involves the negotiation of multiple texts, discourses, and knowledge available between learning communities. In science education, the hybrid third space is vicarious in conceptual change inquiry (Duit & Treagust, 2003); innovative technologies-embedded scientific inquiry (Linn, 2003; McFarlane & Sakellariou, 2002; Zhang, 2013); science, technology, society and environment education (Pedretti & Nazir, 2011); and social justice pedagogy (Tan & Barton, 2012). A hallmark of these hybrid third spaces is (a) incorporating learners' everyday conceptions and experiences into curriculum and pedagogy that develop scientific knowledge and explanations through a process of negotiation (Ebenezer, Chacko, Kaya, Koya, & Ebenezer, 2010); (b) embedding innovative technologies that promote scientific inquiry about environmental issues for the purposes of understanding scientists' practices via exploration of socio-scientific issues (e.g., Ebenezer, Kaya, & Ebenezer, 2011; Kimura, 2008; Means, 1998); (c) creating science, technology, society, and environment education studies that connect schools to communities in ways that empower decision making and action taking (Bouillion & Gomez, 2001; Braund & Reiss, 2005); and (d) engaging in social justice pedagogy that advocates and provides opportunities for students to compete for equity in quality learning (Calabrese Barton, 2003; Calabrese, Barton, & Tan, 2009).

In summary, the hybrid third space manifested in science education studies is about knowledge construction and navigating between different knowledge systems—i.e., personal knowledge and science culture knowledge. In fact, using students' funds of knowledge to develop science content knowledge and socio-scientific cultural knowledge is valuable. Knowledge construction and development, the view of the hybrid third space embraced by science education studies, is important for achieving success in school and in the field of science. Based on the ease with which the borders of these spaces can be crossed, students' consensual knowledge is expected to emerge as a result of navigations in these hybrid third spaces. However, the emergence of a third space that Wang (2006) has identified is a result of simultaneous movement between the first space and the second space via a bi-directional bridge. This bridge is formed by the creators of opposing professional lives because of their different priorities and commitments. Tensions contributed by school educators in their attempts to implement IQWST curriculum and educators of the Urban Science Center must be nurtured in order to foster transformative thinking because binding the two opposing practices can never happen. Each entity can extend only to the point whereby a willingness is maintained to mutually influence and transform each other in creating meaningful learning experiences for school science learners.

Research Question

Responding to the call for collaboration and communication between formal and informal learning sectors and the need for rigorous documentation of the successes, impacts, and challenges encountered in establishing relationships (Falk & Dierking, 2000; Stocklmayer, Rennie, & Gilbert, 2010), the study at hand, a part of a larger investigation, documents the conversations within a four-member community of educators as they attempted to implement the standards-based Investigating and Questioning Our World Through Science and Technology curriculum with the support of the Urban Science Center (USC— seudonym) exhibits. While earlier studies on school science center work have focused on the outcomes of learning and made general observations, none has documented the actual conversations between the educators of these two sectors during their collaborative work. In this study, the community of educators was comprised of a school district curriculum director (first author/researcher), a science teacher educator from a local university, a middle school science teacher at a public charter school called Science and Mathematics Academy (SMA—pseudonym), and an informal science educator at the Urban Science Center (USC)—all from a midwestern metropolitan city and referred to by pseudonyms. Based on the goal of incorporating the Investigating and Questioning Our World Through Science and Technology (IQWST) curriculum through the support of resources from the USC, this study sought to characterize the nature of an emerging "third space." Thus, the following research question guided this study: What is the character of an emerging third space created through the interplay of a community of educators when they attempt to implement the standards-based IQWST curriculum with support of resources from the Urban Science Center?

Significance of the Study

This study is significant for the following reasons:

First, the characterization of a third space that emerges based on the conversations between formal and informal science educators provides insights into the distance and proximity of the educators' interplay.

Secondly, because formal and informal agendas both involve science learning, this study helps identify the position of each on the nature of learning in a third space.

Finally, this study also provides a platform for future research conducted on the intersection of formal and informal institutions to improve school science learning.

Methodology

At the onset (i.e., the first year) of the Science and Mathematics Academy (SMA) and Urban Science Center (USC) partnership project, all subject-area teachers were involved. The primary focus of this partnership project was training teachers to be comfortable incorporating exhibits into their curriculum. An integrated curriculum approach was used, and teachers from each subject area planned an experience for students. However, the study at hand primarily focused on understanding how a science teacher communicated and collaborated with an informal science educator at USC during the second year of a long-term SMA-USC project. The year-two participants of this study included a seventh-grade science teacher at SMA, an informal science educator at USC, an urban university science teacher educator/researcher, and the researcher/school district administrator of this study. All names of individuals and organizations referred to in this study, such as the Urban Science Center and the Science and Mathematics Academy, are pseudonyms.

The teacher, “Cathy,” has worked at SMA for approximately three years as a sixth-grade science teacher. At the time the study was conducted, she taught seventh grade. Cathy holds a Bachelor of Science in Elementary Education and an Associate of Arts in Liberal Arts. Cathy attended a training session focusing on how to implement the IQWST seventh-grade physics unit curriculum. Thus, her primary responsibility was to teach the IQWST curriculum to seventh-grade students and evaluate program effectiveness based on students’ performance. Her goal was to implement the IQWST curriculum with support from the USC science exhibits.

The informal educator, “Roger,” holds a Master of Arts in Education with an emphasis in physics, a secondary certification, a Master of Business Education in Marketing, and a Bachelor of Science in Mechanical Engineering. He is the director of science, technology, engineering, and mathematics (STEM) education and works to advance STEM education objectives for the USC. He was the liaison to the SMA for curriculum development and support. He is also responsible for content development for new exhibits and galleries and assumed responsibility for the informal component of this study. He had no professional development training in the IQWST curriculum. His first exposure to the IQWST curriculum was when Cathy desired to connect this particular curriculum to the museum exhibits.

“Dan” is an assistant professor and researcher in science education within the college of education at a nearby urban university. He holds a Ph.D. and has three to five years of teaching experience at the university level. His academic interests include science teacher education, teacher-student interactions in science classrooms, and urban environmental science curriculum design. Dan helped to create the IQWST curriculum, particularly the physics unit.

The researcher, “Sharon,” is the acting executive director of the office of curriculum and instruction at a large urban school district. She is currently a doctoral candidate at an urban university, and she is majoring in curriculum and instruction with a minor in education leadership. At the time the data were collected, the researcher served as the K-12 science coordinator and later director of curriculum and instruction. The researcher is a former secondary science teacher and has experience partnering with formal and informal institutions in her district. The school in which she collected data was located in a different urban city. During data collection, this target school focused on providing professional development for science teachers in IQWST and establishing partnerships with the local science center in order to connect each subject with USC exhibits.

Table 1 outlines how the purpose of each session emerged as the community of educators continued to engage in discussions about planning for their joint activities.

Table 1

Emerging Purpose through Evolving, Open Discussion in Year Two

Session and Date	Emerging Purpose
Session 1 12-2-09	Connecting the lessons in the IQWST curriculum with the USC exhibits (See Excerpt #1, results section)
Session 2 12-14-09	Planning for the research project and student experience at the science center
Session 3 1-5-10	Finalizing plans for the students' visit to the science center
Session 4 2-2-10	Focusing on student learning in formal and informal environments (See Excerpt #2, results section)
Session 5 2-5-10	Scheduling the docent activities
Session 6 2-11-10	Connecting the formal IQWST curriculum with the informal USC exhibits, capturing student learning, sustaining the idea, and planning for teachers to become involved (See Excerpt #3, results section). Implementing the IQWST curriculum and USC exhibits at this point
Session 7 2-23-10	Using videotapes and journals for student learning and outcomes Focusing on the scientific practice of model/modeling as identified in the IQWST Curriculum (see Excerpt #4, results section)
Session 8 3-2-10	Using the space at the science center for student learning
Session 9 3-23-10	Discussing what was lacking in their collaboration and depicting the direction Cathy and Roger will take in the future by reflecting on their goals (See Excerpt #5, results section)

A case study methodology (Stake, 1995) was selected in order to identify the opportunities that characterize a third space emergence at the intersection of formal (SMA) and informal (USC) educators as they attempted to connect the IQWST curriculum with the science center exhibits. The planning sessions took place during a period of four months with meetings occurring twice a month with the exception of February, during which five meetings were held. More meetings were held in February in order to solidify plans for implementation. The planning sessions consisted of face-to-face meetings with the aforementioned participants in Cathy's classroom at the SMA. The meeting structure was informal and consisted of discussions facilitated by Sharon and Cathy. Sharon and Cathy established the agenda of the meeting sessions prior to each meeting. Cathy, Roger, and Sharon were consistent participants, and Dan participated occasionally in these sessions. There was equal participation and engagement from all of the participants throughout the sessions, and Sharon was responsible for ensuring the meetings occurred. The goal of the planning sessions was to integrate the IQWST curriculum physics unit with the USC exhibits in ways that increase students' ability to learn science concepts. The discussions were organic and lasted for one hour.

Teachers at the SMA were bound by state standards related to the curriculum; however, some autonomy was provided to Cathy to adjust the curriculum. These dialogues and planning sessions were critical in sustaining the empowering learning spaces that were characteristic of this learning community. The subject of these dialogues included goals, logistics, implementation of the IQWST unit, and science center policies.

Data Collection

To answer the research question, the conversations by the community of educators in the planning and implementation sessions were collected via a type of audio-recorder called Integrated Circuit (IC) video recording. Nine planning sessions were conducted (see Table 1). The IC recordings were subsequently transcribed verbatim.

Data Analysis

The transcripts were read several times in order to identify the various challenges that the community of educators encountered when they attempted to connect school science to informal science center science. These challenges were color coded in the transcripts. Excerpts belonging to each color were grouped together, and a label was attached to each group. For example, “science terminology for the lesson focus” was the label assigned to the first challenge.

In this study, the challenges that the educators encountered (see the “Results” section) characterized the emergence of a third space and were considered important for personal growth. The notion of the third space allows disagreement without the need for reaching consensus, and something new can be generated from disagreement in the new forms of subjectivity. But consensual knowledge is expected to emerge as a result of navigations in the hybrid third space. This is a major difference between the hybrid third space and the third space. Because the focus of this study was concerned with teachers’ and researchers’ discussions about students’ personal growth (i.e., subjective formation in the process of science teaching and learning) rather than navigating between different knowledge systems, using the third space was helpful. In other words, the third space does not consume the first and the second spaces but rather consists of an ongoing process of generating new possibilities as a result of mutual movement between the first and the second space. Wang’s notion of the third space is in between, but not in the sense of reaching a final point through in-between negotiation. Rather, it is dynamically in between, which does not converge but diverges into multiple new directions; it is also hybrid, which means that it includes new forms but also leaves separate strands if necessary.

Validity and Reliability

Validity of this study was established by adopting the principles of “trustworthiness”—i.e., credibility, confirmability, dependability, and transferability (Lincoln & Guba, 1985). The credibility of this study was established by the researcher’s prolonged engagement (two years) with the participants in the field and systematic collection of in-depth data during the second year. Through this process, rapport and mutual trust were developed between the researcher and the participants. Two years in the field also provided the researcher with an opportunity to better understand the research settings of the SMA and the USC. Confirmability was achieved by systematically IC recording the planning and implementation sessions and chronicling them using accurate dates. To ensure that the findings were clearly linked to the data, the transcript lines in the dialogue excerpts were highlighted at the initial stages of analysis. Dependability was addressed by having two researchers with methodological expertise check the research plan and implementation. In addition, the same two researchers repeatedly read the transcripts to identify the opportunities that characterized the emergence of a third space at the intersection of formal educators and informal educators. An external audit consisting of two researchers was utilized to evaluate the accuracy of the coding and to determine whether the findings, interpretations, and conclusions reflected the data. Both external researchers agreed that the research was dependable. Validity was sufficient to establish reliability because Lincoln and Guba (1985) have stated that reliability and validity in qualitative research are congruent.

Results and Discussion

The conversations within the community of educators in an attempt to plan and implement the IQWST curriculum with the support of the USC exhibits revolved around five opportunities for personal growth that characterize the emergence of a third space. The opportunities for personal growth stemmed from the following issues: (1) to begin science lesson without the focus on terminology; (2) to down-play “dumb-down” science exhibits; (3) to explore distracts lesson structure; (4) to decipher the meaning of model/modeling; and (5) to learn science content first or explore science exhibits. In the descriptions that follow, each of these opportunities for personal growth is contextualized and supported by an excerpt from the transcript of the community of educators' conversations. These evidentiary excerpts were then analyzed and interpreted to characterize the emergence of a third space established by their creators, i.e., the formal and informal educators. In the descriptions that follow, lessons learned are appropriately linked to relevant literature.

Opportunity One for Personal Growth: Beginning a Science Lesson without the Focus on Terminology

The first conversation occurred at the USC within the community of educators. At this point, Cathy already had completed her training on how to implement the IQWST curriculum (see "Methodology" section). Excerpt 1 demonstrates the first opportunity for personal growth as the community of educators attempted to develop a framework that enabled them to make connections between the IQWST curriculum and the science center exhibits. A conflict arose because of the differing views of the teacher (Cathy) and the informal educator (Roger) about developing a framework to connect IQWST curriculum with the USC exhibits.

Excerpt 1:

1.1 Roger Not having seen your curriculum, it won't come right to my head as to exhibit a, b, or c that would be a good fit. This is where I will struggle with trying to connect our museum exhibits to your curriculum. I wish that we could have some preparation time, where, for example, you give me a copy of your curriculum and we could connect the exhibits. "Oh yeah, maybe that exhibit, this exhibit"—I would see that being a part of the natural process.

1.2 Cathy Okay, maybe our dialogue would be concerned with understanding some of the science terms that my students would be using. There is a lot of terminology. For example, the use of the term “gravitational energy” and just understanding how I develop this piece and what it looks like versus knowing just what the question is.

1.3 Roger This is your framework! You are kind of walking me through that framework and what I am doing at that time.

1.4 Sharon If I might make a recommendation, a template was developed, and there is no reason why you guys can’t come together and develop one template that works for both of you as you lay out your lesson. You guys can follow that, and you can be in tune with each other as the students go through the whole process—with you, Cathy, being aware of the classroom practices and your students, and you, Roger, knowing the facility and what it takes.

{planning session #1, date (12-2-09), transcript lines #1-19, 27-32}

This passage suggests that Roger is unfamiliar with the IQWST curriculum and exposes his struggles about how to make connections with the science center exhibits (1.1). Cathy focuses on developing science terminology that students will encounter in a particular unit in the curriculum rather than focusing on the questions to guide their work (1.2). The introduction to understanding the curriculum with reference to the terminology being used makes Roger wonder whether terminology drives the framework for connecting IQWST curriculum and the science exhibits, and his work is determined by what Cathy does (1.3). To bring Roger and Cathy together in terms of how they might connect the curriculum and the exhibits, Sharon introduces the template that previously has been developed (1.4). The content of the template includes information about the connection between the exhibits and the learning sets as they relate to the concepts of physics, i.e., “the forms of energy and energy conversions.” A learning set in the IQWST curriculum contains the essential question, the lesson topics, and the number of class periods required to teach the lesson topics.

According to Anderson and Nagy (1993), introducing and defining vocabulary and then building lessons around that vocabulary are common practices in school science. Cathy’s belief about using science terminology to focus her lesson and to provide a framework in order to connect the IQWST curriculum with the science exhibits becomes an opportunity for personal growth. Almost at the end of the study, Kathy reflects with Sharon about her experience related to integrating museum exhibits with the IQWST curriculum. Then she ponders: *What should come first—the science terminology or the visit to the museum to see the exhibits—in order to derive a driving question for the lessons as IQWST intends?* This issue will be addressed later on in this article.

Neither the IQWST curriculum nor informal learning advocates use lessons focused on science terminology to guide learning. Here, two distinct learning cultures collide at the intersection of a third space in which each other’s perspectives and suggestions may be viewed. Klein, Corse, Grigsby, Hardin, and Ward (2001) have suggested that looking at formal and informal educators’ collaborative work requires the recognition and acknowledgement of distinct cultures. For this sort of mediation, Kisiel (2006) has suggested developing a shared language and an understanding (or at least awareness) of each partner’s resources. Wang (2004), however, has reminded us that the language of different cultures may never be completely shared.

The long history of scientific terminology-focused lessons throughout the world may never be completely changed. However, teachers need to be nurtured through inter-subjective negotiations that foster transformative thinking with defensible pedagogical practices in which opportunities arise in order to show different directions.

Opportunity Two for Personal Growth: Downplay or "Dumb-Down" Science Exhibits

Excerpt 2 reflects the conversation within the community of educators as it shifts focus to the specific content of the lesson that students would be learning in formal and informal environments. Being a science teacher educator/researcher, "Dan," who also is a member of the community, asks a series of questions about learning within the context of the science center. Cathy and Roger both respond by providing their perspectives about how they view student learning both in formal and informal learning environments. The conflict illustrated here arose because of the constraints of the informal setting.

Excerpt 2:

2.1 Dan	What is formal and informal learning, and how do kids learn best from the exhibits? Is it them trying to make sense of the exhibits or having something explained to them about the exhibits?
2.2 Cathy	Not necessarily the teacher teaching them how to use the exhibits but having the students figure out the exhibits.
2.3 Roger	Whether formal or informal, a teacher can facilitate the use of exhibits and still allow the students to construct their own understanding. And it doesn't mean that you are up there delivering a lecture and tell everything. They can still learn in an informal setting but having you [Cathy] there as the coach. Our science center here from an exhibit development standpoint tends to simplify it to the point... can I say, "dumb it down"? It's dumbed down. It's a philosophical issue from an educator's standpoint. I'm of the camp that I want

> them to be meaningful content for good learning—you know, meaningful experiences and knowledge that can be gained. The problem with that, philosophically on the other side of the fence from our exhibit content folks, is that people don't read signs. And anybody with children knows when they are in the science center, you're just trying to keep them corralled and from breaking something. And with that comes a dumbing down of the content to a point where our signage... new stuff that's coming out... you'll notice there are very few words. There is very little depth to what you're reading. You can read a book, but the idea here is that we want to make exhibits immersive and fun. And hopefully some learning connections can be made from it. That's almost an expectation as opposed to something that's more like the coaching that I referred to earlier.
>
> **{planning session #2, date (2-2-2010), transcript lines #46-67, 27-32}**

Based on Dan's questions about the nature of learning with science exhibits (2.1), particularly referring to the focus on the teacher or the learner, Cathy immediately responds with a comment about student ownership of learning (2.2). Listening to Dan and Cathy, Roger expresses that in both formal and informal learning, the teacher can facilitate the use of exhibits. Roger points out that he does not mean that teaching is simply a matter of telling students about the exhibits or allowing the students to make sense of the exhibits without proper guidance. In fact, Roger suggests that Cathy can be the "coach" (2.3). However, Roger reflects upon what he said about coaching in terms of the museum constraints. He alludes to the simplification of the museum exhibits as opposed to developing deeper knowledge gains because, as he observes, normally people visiting museums do not read signs. He states that museums have the tendency to “dumb down” the content of the exhibits and provide very little reading material. Roger’s argument is that the content can be read from a book, but the ideas presented by the exhibits need to be “immersive and fun.” In other words, Roger struggles with how to provide learning connections through teacher coaching that he himself suggests (2.3) within the constraints of the normal practices of the museum. Roger also points out that instead of observing what the visitors learn, docents are guarding the exhibits from misuse. This also causes “dumbed-down” learning.

This whole conversation about “dumbing-down” the exhibits provided an opportunity for personal growth as Roger was able to re-think the purpose of the museum exhibits. It is not that he believes in “dumbed-down” learning with museum exhibits. Rather, he is pondering how to bring about changes when there are constraints.

With respect to Roger’s reference to “dumbed-down” experiences of the exhibits rather than contributing to rigorous learning, science education researchers make several points. Pedretti (2002) has suggested that science centers should undergo a paradigm shift and move from “objects in a glass case” (p. 2) to an emphasis on involvement, activity, and ideas. This paradigm shift, Pedretti has argued, will increase student learning and engagement with the exhibits. As museums move toward critical exhibitions—that is, exhibits that speak to the processes of science, the nature of science, and science and technology in their socio-cultural contexts, such as the type Pedretti envisions—visitors will experience a more authentic notion of the development of scientific knowledge.

Opportunity Three for Personal Growth: Exploration Distracts the Lesson Structure

The opportunity for personal growth reflected in Excerpt 3 is based on Cathy’s uneasiness about the freedom to explore the exhibits because it will distract the structure of her lesson. The conflict arose because of the teacher's and the informal educator's differing belief systems about learning with respect to freedom and structure.

Excerpt 3:

3.1 Cathy Yeah, we are probably going to skip next week because you said you guys are really busy.

3.2 Roger You know, it's funny. We said we were busy next week, but in the same vein, we sent out the e-mail saying, "Come on over because there is a lot going on that might be meaningful. So feel free to come over..."

3.3 Cathy To come over! I just don't think I would come over and be this structured. They are everywhere, touching everything as they are going by, and it was really hard. So, I think if they were really busy, then it would be hard for me to maintain that structure and that focus that I am trying to get. Come and do some of the fun things, participate, and walk around—that is not an issue, but to be this unstructured might not work.

3.4 Roger After their free day, students will be ready to do more serious learning.

3.5 Sharon After the free day, maybe just focus on one exhibit as a model. So they [students] don't go over to the museum seeing more that they have already seen. But, we are going over to look at it with a different view. I know it takes time, it really does, but just taking one exhibit as a model and taking them through the whole scientific process of utilizing that one exhibit. It is not quantity. It is quality. It is not all about how many you get through but the quality of what you do when you go through. And they could visit that same exhibit two or three times and still get something else out of it, and that increases the number of times they go over there. Plus that increases what we want to do, which is to have students construct knowledge.

3.6 Roger We could show the potential of the museum models through an exhibit with proper planning and suitable time and resources. If all of those stars align, then this is what it could be.

3.7 Sharon Examining one model increases what we want to do, which is to have students construct knowledge. Writing is usually descriptive and/or narrative and centered around authentic tasks, such as collaborating, researching, analyzing, and interpreting information. It is a central place where language, data, and experience work together to form the meaning for the student, and it is a place where students can clarify their ideas, respond to their experiences, and construct knowledge connected to what they are learning in the classroom. The IQWST curriculum provides the framework to help students construct their knowledge about science using museum exhibits.

{planning session #6, date 2-11-10, transcript lines # 82-115}

Roger appears to believe that they will be very busy because they have organized a special event for the general public. Because of this event, Cathy suggests that they "skip" that week and start their activities the following week (3.1). Roger believes that Cathy should bring her students despite the event because the event will be "meaningful" to them (3.2). Cathy does not think that this public event will be meaningful to her students because of her need to implement the IQWST curriculum in a structured manner (3.3). She states this in light of her previous experience of taking students to the science center simply to show them around. Cathy is concerned about her students being distracted at the science center during busy times and suggests that it would be difficult for her to maintain the structure that is needed to complete their journals and videotaping of the exhibits. While Cathy is adamant about the structure of her curriculum, Roger is convinced that the students should take part in the planned activities they have for the public so that students will do more “serious learning” later (3.4).

Although Cathy and Roger express their diversities intrinsic to their own individual learning spaces, the differences provide an opportunity for personal growth with the emergence of a third space. The strengths of both institutions in designing learning experiences are that they are social in nature, they focus on the development of the learner as an agent, and they focus on student engagement with the content (Bevan & Semper, 2006); however, the processes by which these experiences might be achieved in these two spaces are different. This is where the notion of a third space is at play because the differences between two spaces do not necessarily need to merge; however, two distinctive spaces can change because of the interaction between the two.

Sharon’s input leads to a new possibility within a third space that contributes to the personal growth of Cathy and Roger. Sharon proposes that after the free event, the focus should be on one model that can be used to help students make meaning in order to help them understand what they are learning. She points to a new direction with a specific focus on the scientific inquiry processes that inhabit the two cultures (3.5). Roger does not dismiss the alternative view that Sharon proposes when he points to the potential of learning with models, “provided the stars align [i.e., proper planning, suitable time, and resources]” (3.6). Sharon, in response to Roger, presents her alternative view by focusing on the student construction of knowledge. Particularly, Sharon expounds on the specific knowledge that is to be constructed and highlights important scientific processes and discourse that the IQWST curriculum emphasizes (3.7). In Excerpt 3, we see evidence of the emergence of a third space that allows disagreement without the need to reach consensus. The disagreement between Cathy and Roger, as well as differences between the two entities, lead Sharon to point to the vision of the IQWST curriculum, which is an opportunity for personal growth.

Opportunity Four for Personal Growth: Deciphering the Meaning of Models/Modeling

As the community of educators continued to identify ways in which to use models/modeling in students' journals and videotapes, differing viewpoints surfaced. Excerpt 4 focuses on the scientific practice of modeling as reflected by the IQWST curriculum. A conflict did not arise, but the meaning of "models" and "modeling" was clarified.

Excerpt 4:

4.1 Sharon The use of models and student learning and using the exhibits as a method of investigation—collecting some type of data—and developing a model. What are your thoughts about that?

4.2 Cathy I guess mine would be that my kids need more modeling, and that's going to go back to the journaling. I'm going to model with them on Thursday. I had the concept that I could give them a piece of paper and it would have questions on there, and they could figure it all out and do what I asked them to do. And I was so wrong. I have to go back and do some re-teaching of what the purpose of the journal was and teach them how to make the connections I want them to make. Showing them by using the key terms of "myself" in the journal and maybe even setting a goal for them to have so many terms that I've introduced and making sure that they're doing that—I don't think they're getting it on their own.

4.3 Roger I don’t think any exhibits have truly been designed to be a classroom learning tool or model. That’s probably an area that we could um… move in the future—maybe if we’re using IQWST as our curriculum.

4.4 Cathy There weren’t a lot of exhibits that straight out modeled. I can think of the one that was the elastic—the rubber band stretching. The other ones... they’re going to have to pull it out. But the one that was a model was the, um… I think it’s called the stretching machine. It actually stretched a rubber band, and we were watching the graph that it broke a rubber band, and it had a graph and we were able to see the drop and the amount catching on it. The other ones aren’t really, truly models. They’re going to have to go in and do some explanation and reasoning, like I explain this because I know this. I don’t know if you can think of any off the top of your head that were straight-up models, so to speak.

4.5 Dan I think in terms of models, and right now, I’m saying how IQWST thinks about models. There are two uses of models. Either students are collecting data. They’re doing inquiries so that they’re finding evidence for principles of the model. The rule is that energy goes from high to low places. That’s an energy transfer. So they’re doing experiments to find energy transfer and to make the model. And then there’s the opposite use of models, which is now—students have the model. This is how energy transfers through materials. Now, they go back to exhibits and explain what’s happening in the exhibit based on having a model as their framework. So, those are two different uses of models.

> IQWST tries to work with both—constructing the models and using the models. And I said that to you when I was over there with you last Tuesday looking at the Museum exhibits; they lend themselves more to the using models aspect than collecting evidence.
>
> {**planning session #7, date 2-23-10, transcript lines #245-303**}

The opportunity for personal growth at the emergence of a third space displayed in this excerpt is because of the qualitatively different ways of understanding models/modeling by the community of educators. Sharon's view of models/modeling is consistent with the view of Harrison and Treagust (1998) in that modeling is scientific thinking and that models are both the methods and the products of science (4.1). This view advocates the use of science exhibits as models and modeling as a form of improving student learning. Cathy's initial interpretation of models/modeling is something that she needed to demonstrate for her students to follow—for example, what to put in their journals (4.2). Roger suggests that exhibits were not intended to be used as classroom learning tools and models (4.3). Roger's thinking is supported by Yoon, Elinich, Wang, Steinmeier, and Schooneveld's (2012) idea that interactive activities displayed through science center exhibits have been shown to increase important science skills; however, higher-order inquiry skills, such as modeling, critical thinking, and theorizing, are less frequently demonstrated. After listening to the conversation, Cathy attempts to describe the aspects of the science exhibits that she perceives as models (4.4).

Dan explains that IQWST incorporates both construction of models and the use of models by students (4.5) and that the IQWST curriculum focuses on modeling because of its centrality in the practice of science, which emphasizes constructing, critiquing, testing, and revising models (Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008). Dan was able to help the community of educators shift into a third space in which they were not fixed in their own understanding about modeling, but rather they fluidly moved to a more complete understanding of how models/modeling is interpreted in the IQWST curriculum. Wang's (2004) third space includes the formation of new forms but also leaves separate strands if necessary. In other words, a third space does not consume the first space and the second space but is rather an ongoing process of generating new possibilities as a result of mutual movement between two spaces.

Opportunity Five for Personal Growth: Learning Science Content First or Exploring Science Exhibits

Cathy was midway through the implementation of the IQWST curriculum and teaching a unit on physics. Sharon took the opportunity to reflect with Cathy and Roger. Excerpt 5 reflects their discussion about the direction they should take in the future. The teacher has an opportunity to reflect to resolve her original understanding about teaching science.

Excerpt 5:

5.1 Sharon Now that you're a little past midway through the unit, reflecting back on your goals, what were your goals in regards to integrating museum exhibits into the IQWST curriculum? Do you feel that what you've done has gotten you to your goals? Thinking about that will help you to craft your goals for the next unit.

5.2 Cathy I want to make them understand…. I want them to make outside connections to what I have taught them in the class and to see something that I have taught them in action... be able to explain how what they have seen… by the content knowledge, using the terminology, the words, and the things that I've taught them. Has it been working so far? I think so. I think that they are getting it. I think I'll be able to see it more with the final product—the audio or the videotape. Um… yes, for me it has been somewhat to the degree of what I expected this far. And so… I would like them to step away from wanting to go over to the science center and being all over the place. … I wish we would have done it backwards—had them go see the exhibits first, before I taught them to kind of generate the questions. Now I think it's not so appealing because they know how it works. And they're like, "Oh, well, you explained this to me. Why do I have to play with the exhibit? Why do I have to think about it?"

5.3 Roger The process of inquiry as opposed to a more traditional format!

5.4 Sharon And you're starting to do that because you're talking about biology as your next unit. You could change your approach where they experience the exhibits first, if it's possible, logistically?

5.5 Cathy My ultimate goal was to have them use the museum exhibits to explain what they learned in the class and apply from the exhibits what they were taught. The only thing that I would say that would work a little better—and you touched on that—is having that space there to reflect—as opposed to having them try and do it all over the place. That would be beneficial.

{implementation session #8, date 3-2-10, transcript lines #75-109; implementation session #9, 3-23-10, transcript lines #105-138}

Midway through the project, Sharon asked Cathy to reflect on her new teaching experience (5.1). Cathy wants her students to be able to explain the science exhibits based on what they have learned in class using science content, terminology, and the concepts that she has taught them (5.2). Cathy wants her students to be focused and intentional about their learning when they visit the science center instead of being all over the place (5.2). Up until the point of the discussion, Cathy had taken her students to the science center to observe the exhibits only after conducting her classroom instruction about the pertinent science concepts. At this point in her discussion with the community of educators, she offers an alternative approach to making use of the science center exhibits for her classroom instruction. This approach consists of first taking the students to the science center so that they will generate research questions to guide their exploration of the science concepts involved in the exhibits (5.2). Roger affirms Cathy's inquiry approach to teaching (5.3).

Cathy feels that what they have done so far works; however, she believes that students need an opportunity to reflect as they learn about the exhibits (5.5). It is important to point out Wang's (2006) emphasis on the importance of reflection in understanding that a third space does not remain static, but rather the space that is created constantly changes as borders are crossed between two entities. Cathy now wants her students to engage in lesson activities driven by a question that might arise after going to the museum first. This thinking is now in line with the IQWST curriculum and Roger's desire to bring the students first to the museum for exploration and then attend to the science details. By participating in the construction of a third space, Cathy has had the opportunity to reflect and be transformed.

Implications

The purpose of this study was to characterize the emergence of a third space during the interplay of formal and informal educators as they attempted to collaboratively integrate the IQWST curriculum and USC exhibits. The goal of this formal-informal integration was to provide meaningful learning opportunities for students. However, the community of educators soon realized that formal-informal integration cannot be considered a seamless process because of the core belief systems, structures, and practices that guide each independent space—i.e., the formal, school-oriented IQWST curriculum and the informal, free-reigned USC. Thus, this study envisioned challenges as opportunities for personal growth because the emergence of a third space occurs when individuals work at the "boundaries" or at the margins of two different worlds and fluidly move between them (Wang, 2006). Based on the characterization of a third space emergence in this study, the results of this study have implications for formal-informal partnerships and, in particular, for those science education researchers who desire a productive collaboration between the two entities.

The interplay between Roger and Cathy, as they discuss developing a framework for working with students at the USC, exposed differences in belief systems. Cathy refers to developing scientific terminology and building lessons around these terms, even opposing the IQWST philosophy of learning. Cathy also wants to keep the structure of her curriculum intact when she takes the students to visit the USC. Roger questions her framework for their collaborative efforts. He believes that if students take part in the free, fun event and semiotic activities, then Cathy's students will be more willing to engage in deeper learning of the concrete and symbolic meanings embedded in the IQWST curriculum. He is convinced that students should take part in public events so that they will do more "serious learning" later. Cathy realizes this only at the end of the IQWST implementation, when she states that she should have started with the science exhibits to develop driving questions for science activities and inquiries instead of introducing scientific technical terms and developing lessons around them. Thus, the emergence of a third space offered opportunities for personal growth for both Cathy and Roger. Although Cathy and Roger cannot fully move into the center of another space, they can safely reside at the borders of that space and take advantage of what it has to offer. In line with Roger's belief, and Cathy's claim at the end of the excerpt, Wang (2004) has suggested that powerful teachers are able to reach the hearts and souls of learners in order to interact with the symbolic structure of a domain.

According to Wang (2004), a third space opens up and re-opens more possibilities. New boundaries are drawn and re-drawn on the border of each space. These qualities are obvious during the emergence of a third space. For example, Cathy was willing to rethink her position concerning which ought to come first—the exhibits or the curriculum. This implies that teachers should resist collapsing into their own spaces and entertain the multiplicity of the self. Opening up to multiplicity helps to recreate the teacher-self. Thus, sites for creating the singular-self are multiple. Such an interaction between interconnection and independence sets teachers and their practices in constant movement between one and the multiple.

In light of Wang's (2006) ideas, this study clearly reveals that the emergence of a third space is beyond unity or separation. Formal-informal collaboration, like the researchers of this study, envisions a posture that allows formal and informal educators to be freed from the confines of their own bounded views. For example, Roger expressed that in both formal and informal learning, teachers can facilitate the use of the exhibits. However, the museum is constrained to simplify the content of the exhibits to facilitate student understanding. Roger believes that coordination and planning between both entities is required in order for Cathy to facilitate the use of the simplified content of the exhibits at the USC. The rare emergence of a third space carves out the new potential of going beyond the limit of one's boundary and situating oneself between the two boundaries to continuously explore new ways of thinking about how informal science centers can augment science learning by providing experiences on their premises that are more educationally rigorous. This study revealed that educators who situate themselves in the in-between realm of formal-informal learning benefit from struggling to provide creative ways of science learning and by perpetually moving back and forth across the boundary.

Cathy and Roger's reflection and awareness generated by the emergence of a third space provide a new vision for USC in providing for school science learning. When informal educators are brought into awareness about their practices, then symbolic, taken-for-granted science can be destabilized and channeled in new directions. The distinction between the semiotic and the symbolic still does not disappear, but both are set into a dynamic interplay so that a third space emerges from their interaction and transformation. The notion of a third space points to the necessity of affirming both distance and engagement with respect to curriculum design and pedagogy (Wang, 2006). According to Wang, without engaging in the original two spaces, a third space will not emerge, and nothing new can be generated. Being immersed in any one space uncritically merely leads to the reproduction of the existent.

A third space in which the constituents of the "double" (i.e., more than one person) interact with and transform each other gives rise to a new subjectivity and new areas of negotiation (Wang, 2006, p. 121). The multiple landscapes that unfold at the intersection of two cultures, such as formal (SMA) and informal (USC) education, reveal the language of each space. Unlike communities of educators creating an identity in a third space, a space of the multiple and one's own space at the same time will lead to interdependence and independence simultaneously. The space that is created constantly changes, and as borders are crossed between two entities, they can never reach each other in full embraces.

In summary, the results of this study emphasize the importance of dynamic movements across boundaries as well as the significance of these boundaries. To work through a conflicting double culture—i.e., formal and informal—a third space is necessary in which members of both cultures experience a new understanding and a mutual transformation. It is a transformative space in which consensus or resolution is not necessary or encouraged but rather where different layers of self and culture shift, intersect, and change. The comfort with one space and the struggle with the conflicts between the two spaces are shifted to a third space in which movement and fluidity rather than fixation is privileged. Participants are longer trapped within, or between spaces; rather, a new realm is created in which "either-or" dichotomies and "in-between" clashes are challenged to make possible mutual transformations and create different cultures. When these transformations occur, collaboration between partners promotes the interplay between the relational and the individual—an interplay that represents the hallmark of transformational learning.

An engaged and provocative pedagogy implies the ability to live with paradoxes and relational ambivalence—a perspective that is affirmed by curriculum scholars in the so-called post-modern age (Doll & Truit, 2012; Pinar, Reynolds, Slattery, & Taubman, 2006). The characterization of a third space emerges based on the conversations between formal and informal educators as each provides insights into the distance and engagement of their interplay. Because both formal and informal agendas involve science learning, communication, and collaboration, communities of science educators can facilitate their understanding at the emergence and intersection of a third space. An engaged and provocative pedagogy in a third space valorizes both distance and engagement, differences and communication, questioning and nurturance, self and stranger, individuality and relationship, and polyphony and conversation.

CHAPTER 3 (Article Two)

A GRADE SEVEN SCIENCE TEACHER'S DISCURSIVE INTERACTIONS IN DEVELOPING COMMON KNOWLEDGE: INTERTWINING CONCEPTS OF ENERGY AND SCIENCE INQUIRY PROCESSES

Abstract

The purpose of this research study was to explore the discourse between a middle school science teacher and her students as the teacher developed students' conceptual understandings during a unit on energy and energy transformation. In order to develop common knowledge, the teacher used a standards-based curriculum and accompanying student workbook that promoted mediation of oral knowledge referred to as "dialogic discourse." The intention of the teacher was to develop students' understanding of the concepts of (a) energy and (b) science inquiry processes before she took the students to observe energy-related exhibits at the urban science center. The whole-class discussions between the teacher and her students were audio-recorded and transcribed verbatim. Four instructional events were selected for discourse analysis: (a) focusing on the inquiry process, (b) understanding kinetic energy, (c) formulating scientific explanations, and (d) translating energy transformation. Analysis of the discourse excerpts representing these instructional events revealed four teacher behaviors: (a) teacher-posed questions, (b) teacher-explanations, (c) teacher responses, and (d) teacher references to past learning. Of these teacher behaviors, teacher-posed questions dominated the discourse between the teacher and students. These teacher-posed questions consisted of the following forms: fill-in-the-blank, affirmation, second-order, descriptive, and explanatory. Based on the findings in this study, two implications emerged: (a) the teacher's struggle with dialogic discourse, a communicative approach that fosters common knowledge through a social process, and (b) the need for professional development that fosters dialogic discourse.

Key Words: dialogic discourse, sociocultural perspective, common knowledge

Introduction

Understanding the discourse between teachers and students that foster the development of common knowledge in science is particularly crucial at a time when science curricula and pedagogical practices are being shaped by national policies (NRC, 2012) that have been informed by a sociocultural perspective (Vygotsky, 1978) of science learning (Duschl, Schweingruber, & Shouse, 2007; Singer, Marx, Krajcik, & Chambers, 2000). Language is at the core of a Vygotskian sociocultural perspective, and this perspective has an effect on individual thinking as well as collective thinking and learning. According to Vygotsky, language is both a cultural tool and a psychological tool that transforms students' thinking. It is a cultural tool because it is used to develop and share knowledge among members within a community, and it is a psychological tool because it provides structure and content to the process of producing individual thoughts. Prawat (1993) has claimed that there is a dialectical relationship between knowledge that is constructed by reflecting on an activity and knowledge that is negotiated. This mediation of oral language is referred to as "dialogic discourse," and it is consistent with teaching models that have adopted the notion that knowledge is co-constructed within a sociocultural context (Driver, Asoko, Leach, Scott, & Mortimer, 1994). In this process of knowledge construction, students are encouraged to question, evaluate, and challenge the ideas of others (Berland & McNeil, 2010). The statements of others are not simply accepted but undergo scrutiny through critical analysis, and in this process, students justify their own views as well as support or refute the ideas of their peers (Mercer, 2009). Dialogic discourse aligns with the idea that knowledge is constructed through a social process that fosters the development of common knowledge (Edwards & Mercer, 1987).

Literature Review

Although most science educators promote dialogic discourse, in practice, many employ discourse strategies that maintain control of the course content, interactions, and discussions in order to achieve a desired end (Edwards & Furlong, 1978; Mishler, 1975). Barnes (1976) has observed that teachers do not provide students with opportunities "to ask their own questions, to formulate hypotheses, or to make intelligent responses other than those predetermined by the teacher's own implicit associations of thought and frames of reference" (p. 30). Even in contemporary times, Mercer and Howe (2012) have noted that in whole-class settings, especially in secondary education, teacher-student interaction is dominated by "teacher talk"—a type of interaction in which teachers use closed questions simply to seek brief responses in order to ensure that at least some students repeat the right answers. This type of teacher-student interaction is commonly known as initiation-reply-evaluation (IRE) (Mehan, 1979, p. 37), initiation-response-feedback (IRF) (Sinclair & Coulthard, 1975, p. 21), and triadic dialogue (Lemke 1990, p. 8). Griffin and Mehan (1981) have summarized a typical round of triadic dialogue as follows:

> The first part, spoken by the teacher, is a question about an academic topic and an indication of who should answer it. The second part is a child's reply to the question. The third part is the teacher's expression of approval or rejection of the response to the elicitation. (p. 193)

This triadic dialogue, Lemke (1990) has argued, can be beneficial for maintaining control over the direction of discussion and the lesson content. However, Lemke also has pointed out that the overuse of triadic approaches has been criticized because they do not provide students with opportunities to link their everyday ideas to the course content being discussed. Although some curriculum documents (Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008) recommend using and describe how to use “give and take” discussion methods as a preferred form of classroom discourse, Lemke has stated that the reality is that teachers typically resort to a more traditional form of discussion. Krajcik, Reiser, Fortus, and Sutherland (2008) have pointed out that a question-and-answer format puts teachers at the center of the classroom experience while relegating students’ questions (and consequently their learning) to the background of the classroom experience. Leshesvuori, Viiri, Rasku-Puttonen, Moate, and Helaakoski (2013) have cautioned that the overuse of triadic approaches can create a learning environment that limits student participation, minimizes contributions, and inhibits critical reasoning.

While teacher questions often are aimed at prompting students to provide expected answers, teacher questions can indeed provide students with opportunities to present more explicit explanations, to analyze their experiences more systematically, and to use language as an instrument to break down and restructure their experiences (Barnes, 1976). Teacher questions such as *How did you know that?* And *Why?* Can guide students’ learning. For example, such questions enable students to use language as a tool for reasoning. These types of question further encourage students to express key ideas and elaborate on those ideas in their own words (Wolf, Crosson, & Resnick, 2006). In order to increase student engagement and improve learning outcomes, the discourse between teachers and students should develop students' reasoning skills and increase academic performance (Cazden, 2001). Science teachers should help their students make sense of classroom discourse in ways that connect their existing knowledge and ways of thinking with academic content (Leach & Scott, 1995). Expert involvement also can have a crucial and beneficial influence in positively guiding students' learning (Mercer & Howe, 2012). In summary, sociocultural research on learning clearly has helped overcome the notion that teacher-initiated interactions should be discouraged. In fact, research does not suggest or imply that teachers should avoid checking students' understanding, providing them with accurate information, or correcting their misunderstandings. However, in order to obtain the best outcomes, teachers should strategically balance authoritative talk with dialogue (Mortimer & Scott, 2003). Teacher-student talk is referred to as "dialogic discourse" because teachers use language to provide a cumulative, continuing, contextual frame that enables students to engage with new information they encounter (Alexander, 2000, 2004). As a result, it is important to observe how teachers conduct whole-class discussions and assess how they develop conceptual understanding of science-related knowledge in order to establish common knowledge.

The study at hand focuses on a middle school science teacher, "Cathy," who has received professional development in a standards-based science curriculum that promotes dialogic discourse involving argumentation. In her seventh-grade science classroom, Cathy used a workbook and scientific activities to teach students about concepts related to energy. She also used the workbook to help students identify claims and reasons for their arguments through teacher-student classroom discourse. It is important to qualitatively analyze classroom discourse transcripts in order to understand the processes and mechanisms the teacher used to create and develop common knowledge as she attempted to implement standards-based science curriculum within a sociocultural framework. This qualitative analysis provides insight into whether classroom discourse aligns with the goals of a standards-based curriculum.

This study focuses on whole-class teaching because this was the prevalent method that the teacher used when teaching a unit on energy. Eshach (2010) has noted that although whole-class teaching is the most common instructional approach, it has been insufficiently studied. Lehesvuori et al. (2013) have recommended that in order to capture the essence of classroom communications between teachers and students, more micro-scale, moment-by-moment exploration is needed of classrooms in which teachers attempt to implement standards-based curriculum. Mercer (2008) has claimed that in order to understand how classroom education succeeds or fails as a method of developing students' knowledge, it is important to understand the temporal relationship between (a) the organization of teaching and learning as a series of lessons and activities and (b) how teaching and learning are enacted through dialogue. In other words, because learning is a process that occurs across time, and because learning is mediated through dialogue, dialogue ought to be studied across time to understand how learning occurs and why certain learning outcomes result. Thus, it is important to understand how the teacher in this study develops and establishes common knowledge about energy across time through a fine-grained analysis of transcripts. Although Polman (2004) has addressed how dialogue develops between teachers and students through fine-grained analysis of transcripts, he also has suggested that the way teacher-led, whole-class discussions constitute specific structural entities has not been fully understood.

Theoretical Frameworks

Although no existing structures were used to systematically analyze teacher-student discourse in this study (such as the triadic approaches), a combination of analytical principles, or "lenses," is used to interpret the discourse as the teacher develops common knowledge related to energy and science inquiry processes by intertwining both.

A Sociocultural Perspective of Learning and Science Classroom Discourse

This section characterizes the Vygotskian sociocultural perspective of learning. The zone of proximal development (ZPD) is a term Vygotsky used to describe the way students' intellectual capacities increase across time through the dialogic support, or "scaffolding," of an adult (Vygotsky, 1978). To address the need for a dynamic, dialogic process in which inter-subjectivity is pursued in the course of classroom discussion, Mercer (2000) has introduced the concept of an intermental development zone (IDZ). This concept refers to the way teachers and learners can stay in tune with each other's changing states of knowledge and understanding during the course of an educational activity with the goal of fostering interactive cognitive development and learning (Mercer, 2008). For example, IDZ explains how learners progress under guidance in interactive activities that are reflected in the task-related talk both of teachers and students. Drawing on shared experiential resources, teachers can use dialogue to set up and maintain an IDZ to support learning, enabling students to adopt a shared perspective on a task and pursue common goals. As participants in a continuing conversation interact to develop an IDZ, common knowledge, upon which shared understanding depends, is constantly developed. Future conversations then travel on contextual tracks that have been constructed out of common knowledge (Mercer, 2008).

A critical analysis of the few existing studies on science classroom discourse from a sociocultural perspective of learning revealed the character of dialogue between teachers and students in five interrelated ways: (a) “productive disciplinary engagement” (Eshach, 2010; Scott & Ametller, 2007; Scott, Mortimer, & Aguiar, 2006, p. 607), (b) solving open-ended problems (McNeill &Pimentel, 2009), (c) wonderment questions (Aguiar, Mortimer, & Scott, 2010), (d) critical discourse (Verma, Puvirajah, & Webb, 2014), and (e) dialogue that connects past and present learning experiences (Mercer, Dawes, & Staarman, 2009).

Conceptual change literature suggests that lessons should explore or elicit students’ conceptions and address these conceptions in ways that will cause students to shift their thinking to adopt scientific explanations (e.g., Duit & Treagust, 1998; Ebenezer et al., 2010). Scott et al. (2006) have termed this process of shaping students’ responses “productive disciplinary engagement” because classroom discourse between teachers and students during conceptual change inquiry lessons will reflect a combination of “authoritative and dialogic interactions” (p. 606). The authors also have cautioned that the use of teacher language in conceptual change lessons will reveal tension between “authoritative and dialogic interactions” (p. 606), particularly when authoritative language is used to reach scientific explanations. The use of authoritative or dialogic classroom language depends on the interactions between teachers and students through negotiating and adjusting the explanatory structure to the students’ understandings and interests. This adaptation, or shifting, between authoritative and dialogic approaches is required to support meaningful learning that involves connections between students’ evolving ideas and scientific knowledge (Scott & Ametller, 2007). Therefore, Scott et al. (2006), based on their 2003 study, provided “analytical frameworks with criteria used in identifying authoritative and dialogic communicative approaches" (p. 608). According to these authors, support of dialogic inquiry in a classroom where knowledge is dialogically co-constructed characterizes the IRF, IRE, and IRFRF patterns of interaction, and discourse assumes various forms depending on the teaching purpose and goals of the activities. These authors have drawn attention to the tension between authoritative and dialogic approaches using the framework based on a sociocultural perspective of teaching and learning developed by Mortimer and Scott (2003). Scott et al. (2006) have concluded that this framework can assist teachers in reflecting upon and developing their teaching practices in professional development sessions.

Within the same conceptual change inquiry lesson sequences, students might be set for argumentative discourse (Driver, Newton, & Osborne, 1994; Erduran, Simon, & Osborne, 2004). Lesson sequences that use scientific inquiry standards also advocate argumentation (NRC, 1996). One such curriculum design is the Investigating and Questioning Our World Through Science and Technology (IQWST) curriculum (Krajcik, McNeill, & Reiser, 2008). The IQWST curriculum is designed to provide teachers with tools/materials to help students learn science by engaging students in inquiry processes. These processes allow students to take an active role in their own learning and reflect on the ways in which knowledge is constructed within various scientific communities (Fogelman, McNeill, & Krajcik, 2011). Krajcik and Sutherland (2010) have proposed argumentation as an essential component of scientific discourse and of fostering inquiry in the classroom. Argumentative discourse, based on solving open-ended or ill-structured socio-scientific problems (Zeidler, Sadler, Simmons, & Howes, 2005) can also take on the character of argumentation—i.e., claim, evidence, reasoning, and explanation (McNeill & Pimentel, 2009). These authors have suggested that it is the role of the teacher through dialogic interactions to promote argumentation that employs a traditional argument structure. It is critical for teachers to provide students with opportunities to talk about science, to practice supporting their ideas with evidence, and to make arguments indicating why evidence supports one conclusion more than another (Krajcik & Sutherland, 2010).

Inquiry lessons, whether conceptual change, science, or ill-structured, provide opportunities for students to ask “wonderment questions” (Aguiar et al., 2010, p. 175), which are questions that focus on predictions, explanations, and causes. These wonderment questions are asked when students try to relate new knowledge and existing knowledge in their effort to understand science content. Wonderment questions might arise because of (a) comprehension, (b) prediction, (c) anomaly detection, (d) application, and (e) strategy planning (Chin & Brown, 2002). Based on an analysis of selected science lessons in which students posed many wonderment questions, Aquiar at al. (2010) concluded that such questions influence the teaching of explanatory structures and the development of ongoing classroom discourse. The IQWST curriculum extends student learning experiences beyond the classroom by posing driving questions in much the same way that wonderment questions situate science within issues that are of interest to students and the scientific community. Providing examples of questions and probes that help teachers foster connections between students’ questions and the driving question helps teachers as well as students to establish meaningful discourse (Singer et al., 2000).

In any science lesson, opportunities exist to connect previous lessons to the current lesson, particularly in the form of reviews. To illustrate these opportunities, Mercer et al. (2009) showed how teachers can use dialogue to (a) explore students’ understanding of topics; (b) establish a learning trajectory for students by relating past activities to the present and future; (c) build links between the content of earlier discussions and current concerns; and (d) make explicit for students ways of using dialogue to share ideas, reason, and develop shared understanding. Meaningful learning that connects past learning to the present (Mercer et al., 2009)—or that connects students' ideas to scientific knowledge (Scott & Ametller, 2007)—requires time and the ability to make students aware of how language is used both as a cultural tool and as a cognitive (reasoning) tool. Thus, Mercer (2008) has cautioned that temporal analysis of talk should not be neglected in order to understand classroom experiences when classroom discourse is observed and analysis is carried out. In other words, researchers must examine teachers' multiple lessons within a lesson sequence or several lesson sequences across time. As lessons are reviewed, Mercer et al. (2009) has concluded that teachers need reassurance that dialogic teaching is an effective way to help students learn and understand science as well as enhance their own participation in classroom discourse. Acknowledging how discourse in teacher-led, whole-group science class discussions can develop and progress over time, Lehesvuori et al. (2013) showed through a review of several classroom discourse studies in science and their own empirical work that different communicative approaches can be involved. For this reason, Lehesvuori et al. have argued for a conceptual framework to represent communication as a temporal and discursive process that recognizes both the historical and dynamic qualities of time and the variety of communicative approaches available to teachers. The authors provide a specific, cumulative communication structure with which to analyze classroom discourse. Using this structure, the authors found that communication structures and communicative approaches support broader conceptualizations of time and help teachers use reason to determine when, why, and how to apply a dialogic approach. In essence, teachers engage in the development of concrete examples of explicit communication structures and the opportunity to compose their own teaching sequences.

Related Science Classroom Discourse Studies

Analyzing discursive interactions during classroom discourse between high school students and their teachers in Brazil, Scott et al. (2006) observed that minimal shifting occurs between communicative approaches and that there was minimal dialogic teaching. Scott et al. reasoned that the problematic issues related to communicative approaches in science classrooms arise because teachers perceive their job to be providing information from a scientific perspective. Scott et al. (2006) suggested that teachers need to have insights into the everyday language conventions that students are likely to bring to their learning environment. They also pointed out that authoritative and dialogic discourse tools are particularly helpful in developing students' conceptual understanding of science concepts.

In their work on types of teacher questions and the development of argument structure during a lesson on ecology taught in a New England high school science classroom, McNeill and Pimentel (2009) indicated that more open-ended questions increased percentages of student talk, the use of evidence and reasoning to support claims, and dialogic interactions among students. McNeill and Pimentel have used a combination of Toulmin's (2003) argument pattern, a scheme for dialogic interactions, and Blosser's (1973) classification scheme for analyzing teacher questions to examine patterns of classroom discourse and the role of the teacher in promoting argumentation. Furthermore, McNeil and Pimentel argued that when questions with multiple answers are explored, interaction shifts from monologic to dialogic. The same authors emphasized that first establishing common knowledge within a monologic format and then introducing dialogic activities is key in an inquiry unit in order to prepare students to engage in dialogue and argumentation strategies. In this type of interaction, McNeil and Pimentel have pointed out that the emphasis should be placed on (a) teaching students social and discursive skills that lead to productive dialogue and (b) identifying effective discussion starters in the curriculum that help students make connections beyond the classroom. Because dialogic interactions among teachers and students rely on evidence and reasoning to support claims, McNeill and Pimentel have emphasized the importance of providing teacher support for students who struggle with this type of argumentation in science.

Aguiar et al. (2010) used Brazilian high school classroom episodes from different teaching sequences involving innovative teaching approaches to examine students' wonderment questions based on discourse between the teacher and students. These authors found that interactive discourse between the teacher and students influenced the teacher's explanatory structures and ongoing classroom discourse. Subsequently, these authors have argued that there is a need for professional development that shows teachers how to deal with students' questions and how to take into account the role and purposes of all individuals during student-led argumentation and debates.

Mercer (2008) used data from a primary school in the United Kingdom to examine how the passage of time is embodied in classroom talk. He used transcribed discourse from a series of events and dialogue between a teacher and students as well as among students to discuss the processes and the challenges associated with conducting a temporal analysis. A temporal analysis describes the process by which classroom discourse is used to represent past shared experience and carry ideas forward from one occasion to another to achieve learning outcomes. Using temporal considerations of a dialogic approach, Lehesvuori et al.

(2013) described a study in which high school students in central Finland experienced science lessons on the topic of energy in which the teaching sequences used by the teacher involved different communication structures that facilitated parallel visualization. A sociocultural discourse analysis was used with the teaching sequences and encompassed both historical and dynamic aspects at the episodic level of teacher-student exchanges.

Engaging students in dialogic interactions requires teachers to be skilled in this type of instruction. It also requires teachers to possess insight and expertise in engaging students in dialogic discourse while at the same time making the link between communicative approaches and patterns of discourse (Alexander, 2004; Scott & Ametller, 2007). The relationship between time, talk, and learning is important and requires curriculum and pedagogy that engage students in dialogic interactions (Leach & Scott, 2002; Mercer, 2008; Scott & Ametller, 2007). Teaching decisions to "open up" or "close down" instruction in either a dialogic or authoritative way must take into consideration the content being taught and the degree of difference between everyday views and scientific views (Scott & Ametller, 2007).

The insights of earlier studies on classroom discourse can be translated to the implementation of Krajcik et al.'s (2008) standards-based curriculum that incorporates dialogue into classrooms. The researchers mentioned above have provided analytical tools to characterize discursive interactions. Thus, this study analyzes and interprets the discursive interactions that transpire as the teacher in this study develops common knowledge on the topic of energy.

Research Questions

The following research questions guided this study:

1. What discursive interactions does a middle school science teacher make as she attempts to develop common knowledge related to the concept of energy and science processes?
2. How does the discourse reflect a sociocultural perspective on learning?

Significance of the Study

This study is significant for three primary reasons. First, understanding how this teacher conducted whole-class discussions and how she developed students' conceptual understanding on the topic of energy in order to establish common knowledge over time will provide insights into the nature of classroom discourse. Secondly, because the teacher implemented a standards-based science curriculum from a sociocultural perspective of learning, it is important to know whether classroom discourse parallels the curriculum's intentions. Finally, this study also provides a platform for future research conducted on ways of developing common knowledge through classroom discourse. This platform allows teachers and administrators to become aware of why and how such discourse plays out in the reality of an urban classroom in ways that can transform teaching and learning in more meaningful ways.

Methodology

Research Design

This was an interpretive discourse study that adopted notions advocated by Mortimer and Scott (2000) as well as Hoon and Hart (2006). Mortimer and Scott's (2000) framework has helped to explain how teachers use discourse to mediate students' conceptual understanding of science concepts from a macro perspective. Hoon and Hart (2006) have emphasized the importance of situating classroom discourse within a sociocultural perspective of learning in order to develop scientific knowledge, support student meaning making, and maintain a narrative.

Research Site: The Science and Mathematics Academy

The Science and Mathematics Academy (SMA), built in 2009, is situated in the heart of a large urban city in a midwestern state. SMA is a Public School Academy secondary school that focuses on science and math with students in grades seven and eight. There are no academic or behavioral criteria for student admission to the school. The total school population is 387, with 331 students living in an urban city and 56 students living in the surrounding areas. Of the 387 students, 227 students are on free or reduced lunch. At the time the study was conducted, 161 students were in the seventh grade, which is the focus grade of this study; of these, 155 were African-American, 3 were Caucasian, 2 were Hispanic, and 1 was Arab-American. There were 94 boys and 67 girls in seventh grade.

SMA was founded on the philosophy of "Big Picture Learning Design," which is a dynamic approach to learning, doing, and thinking. This philosophy is designed to help change the lives of students, the lives of educators, and entire communities. All components of the design are based on three foundational principles: (a) learning must be based on the interests and goals of each student; (b) the curriculum must be relevant to people and places that exist in the real world; and (c) students' abilities must be authentically measured by the quality of their work. SMA embraces the values of community, opportunities, rigor, and engagement (C.O.R.E.). SMA believes in nurturing powerful relationships that sustain robust learning communities; seeking, creating, and using opportunities to benefit themselves and the community; encouraging students to explore science, technology, engineering, and mathematics; rigorously investigating curricula that are aligned with state standards;

and engaging students in constant inquiry. These beliefs reflect all four C.O.R.E. values. The classroom learning environment is built around the team concept, which means each advisory team of teachers represents each of the core subject areas—English/Language Arts, Science, Mathematics, and Social Studies—and is responsible for teaching the same group of students. Teachers at the SMA are bound by curriculum based on state standards; however, some autonomy is given to the teachers to adjust their curriculum. Thus, the teacher who participated in this study was able to implement the IQWST curriculum in her classroom.

Investigating and Questioning Our World Through Science and Technology (IQWST) Curriculum

At the time of this study, SMA adopted the Investigating and Questioning Our World Through Science and Technology (IQWST) curriculum and the associated project-based learning approach that promotes inquiry and reflection. The IQWST curriculum is built on the premises of project-based science, which promotes student engagement in student-directed scientific practices supported by technology and collaboration (Kracjik, Czerniak, & Berger, 2002; Schneider, Krajcik, & Blumenfeld, 2005). As part of this curriculum, students also investigate real-world, standards-based problems that are interesting, relevant, valuable, and worthwhile to them over a sustained period of time (Toolin, 2004). The IQWST curriculum provides engaging learning experiences that involve students in complex, real-world projects through which they develop and translate knowledge and skills learned in each content area.

Energy unit of the IQWST curriculum. The major learning goals in the seventh-grade physics unit are to help students to understand that (a) there are different types of energy, and that (b) energy can be transformed from one type to another. Through shared learning goals across units, inquiry processes are repeatedly revisited. The driving question in the unit is the following: “Why do some things stop while others keep going?” To answer this question, the investigations enable students to experience scientific phenomena and processes by encouraging them to examine new information; ask new questions; plan experiments; and collect, analyze, and share data. The unit is divided into three learning sets. The first learning set attempts to answer the following question: “What determines how fast or high an object will go?” The first learning set is then divided into four lessons in which the students investigate the factors that determine an object’s kinetic energy and the connection between elevation and energy. The second learning set attempts to answer the following question: “Why do some things stop?” This learning set is divided into three lessons in which students investigate thermal energy and sound energy. The third learning set attempts to answer the following question: “Why do some things keep going?” It consists of four lessons that introduce chemical, electrical, and light energy as well as how they can be converted into one another and into other types of energy. The main investigation includes falling objects, a pendulum, a bouncing ball, playground instruments, and springs. Energy conversion diagrams are introduced as a way to represent energy transformations. In total, the IQWST seventh-grade physics unit consists of 11 lessons.

Participants

The participants in this study consisted of a seventh-grade science teacher and her students. At the time of the study, the teacher had approximately three years of teaching experience. The teacher holds a Bachelor of Science in Elementary Education and an Associate of Arts in Liberal Arts. Along with her colleagues, the teacher participated in a five-day summer institute conducted by University of Michigan professors and graduate students as well as a lead teacher. The professional development program included support strategies for teachers in the areas of science content, inquiry pedagogy, and contextualized learning focusing on Big Ideas using the IQWST curriculum. The institute emphasized coherence (development of science ideas), deep and meaningful student understanding, concepts and explanations, and assessment of students. A major goal for teachers in the summer institute was to understand how to use IQWST pedagogies within the framework of an educative curriculum. The session also focused on how to implement the IQWST seventh-grade physics unit curriculum. The teacher's primary responsibility was to teach the IQWST curriculum to seventh-grade students and evaluate program effectiveness based on students' performance.

In all, the teacher taught 68 students, ages 13-14, in four sections of seventh-grade science class. For the purpose of this study, one section consisting of 18 students was used. Ninety six percent of the students were African-American. All participants in this study are referred to by pseudonyms.

Data Collection

The classroom and science center visit portion of a two-year study took place from January 2010 to May 2010 during 30 periods consisting of 55 minutes each. The researcher personally observed all of the classroom sessions and related events and recorded field notes. At the same time, the researcher used integrated circuit (IC) system and videotapes to record the large-group classroom discussion during which the teacher developed the concepts of energy with students using the IQWST workbook activities that focused on the concepts underpinning the science center energy exhibits. These IC recordings of discourse were transcribed verbatim. A sampling of student IQWST workbooks that contained activities were collected as evidence of the work completed in the classroom. The IQWST workbooks provided evidence of student work correlated to the forms and transformation of energy lessons taught by the teacher.

Data Analysis

An interpretive discourse analysis following the notions of Hoon and Hart (2006) as well as Mortimer and Scott (2000) was used to analyze teacher-student classroom discourse transcripts that corresponded to the workbook lessons from the IQWST physics unit (see Table 2). No *a priori* codes from the discourse analysis literature were imposed on the data.

Table 2

Transcript Excerpts based on IQWST Workbook Lessons

Transcript Excerpt	IQWST Workbook Lesson
Excerpt #1: Focusing on the Inquiry Process	Workbook Activity 2.1 (Objects in Motion**)**.
Excerpt #2: Understanding Kinetic Energy	Workbook Activity 2.2 (Kinetic Energy Investigation)
Excerpt #3: Formulating Scientific Explanations	Completion of Activity 2.2 (Conclusion)
Excerpt #4: Translating Energy Transformation	Workbook Activity 8.4 (Chart on Energy Transformation)

In preparation for data analysis, each excerpt was numbered one, two, three, four (see Table 2). Then each line within each excerpt was numbered. For example, lines in Excerpt 1 were numbered 1.1, 1.2, 1.3 etc. Lines in Excerpt 2 were numbered 2.1, 2.2, 2.3, etc.

The data analysis process was conducted in several steps. First, the researcher identified the details of who said what. Every turn of the conversation was summarized with the line number in parenthesis. For example, Cathy continues to probe her students through questioning in order to get her students to think about additional explanations for selecting the bus as their first choice in one particular exercise (Excerpt 1, 1.6).[1] This detailed commentary was indeed necessary to accurately characterize the nature of the dialogue.

Secondly, the detailed commentary of the discourse among the teacher and the students was subjected to inductive analysis to identify common characteristics. Four discourse characteristics were identified: (a) teacher-posed questions, (b) teacher-explanations, (c) teacher responses, and (d) teacher references to past learning. The data also revealed five types of teacher-posed questions: While teaching students the concept of reasoning within the scientific explanation triangle, the teacher uses fill-in-the-blank questions to prompt students to provide her with correct responses, affirmation questions to ensure that there is no doubt in their minds, three second-order questions that reinforce ownership of student understanding, descriptive questions to elicit information, and explanatory questions to probe students' scientific explanations (see Table 3). The researcher categorized the questions and tallied the frequencies within each excerpt. The question types were then interpreted using evidence from the excerpts and research literature.

Table 3

Types of Teacher-Posed Questions and Examples

Question Type	Examples from Excerpts
Fill-in-the-blank	"When something is moving… it has what

---

[1] See the "Results" section for a more contextualized understanding of the teacher's intention.

Question Type	Examples from Excerpts
	kind of energy?" (4.1)
Affirmation	"But you started with the same size, right?" (3.7)
Second-order	"If I am changing the speed, how many things should you change in the experiment?" (2.9)
Descriptive	"How does speed affect what somebody is doing?" (2.9)
Explanatory	"Why do you think most people picked the bus as number one?" (1.4)

The researcher identified the common characteristics in the transcripts of the discourse between the teacher and students, and these characteristics comprise the main points—i.e., the observations and findings. In preparing the presentation of the results, the observations and findings informed the commentary that follows the excerpts. Examples from the excerpts were used to support these observations and findings. The insights and explications were then connected to the literature on teacher-students' classroom discourse.

Reliability and Validity

Validity of this study was established by adopting Lincoln and Guba's (1985) principles of "trustworthiness"—i.e., credibility, confirmability, dependability, and transferability.

The credibility of this study was established by the researcher's participation and observation in the classroom during the implementation of the curriculum; therefore, the context was familiar and well known. Rapport and mutual trust were developed between the researcher and the participants long before this component of the study began. In fact, the researcher and teacher ("Cathy") had met two years before the study began and had already engaged in conversations about how the study should be conducted prior to data collection.

Confirmability was achieved by systematically using the IC system to record the classroom teaching and learning activities. To ensure that the findings were clearly linked to the data, the transcripts were read repeatedly, and the dialogue excerpts were color-coded at the initial stages of analysis. For example, one common characteristic that was evident while teaching students the concept of reasoning within the scientific explanation triangle was the fill-in-the-blank question strategy to prompt students to provide correct responses. Excerpt 3 in lines 3.3, 3.5, 3.9, 3.11, and 3.17, for instance, shows evidence of the fill-in-the-blank questions. Interpretations were subjected to a member check by sharing them with the teacher of the science lessons.

Dependability was addressed by having two researchers with methodological expertise check the research plan and implementation. An external audit consisting of two US-based researchers with Ph.D.s, (one in science education, one in English literature, and both with experience in discourse analysis) was conducted to evaluate the accuracy of the coding and to determine whether the findings, interpretations, and conclusions reflected the data. Both external researchers agreed that the research was dependable. Validity was sufficient to establish reliability because Lincoln and Guba (1985) have stated that reliability and validity in qualitative research are congruent.

Results and Discussion

Four instructional events were selected to critically analyze teacher-students' discourse in Cathy's classroom:

1. Focusing on the Inquiry Process
2. Understanding Kinetic Energy
3. Formulating Scientific Explanations
4. Translating Energy Transformation

Focusing on the Inquiry Process

The teacher (hereafter referred to as "Cathy") carries out a whole-group class discussion based on IQWST Worksheet Activity 2.1 (see Excerpt 1), which poses the following question: "What has energy?"

Excerpt 1:

1.1 Cathy: Bus, bicycle, leaves in the street and throwing a basketball… Circle "yes" for each thing that has energy. Tell me which thing you think has the most energy and why. Put them in order, one to four, and so write one to four, and explain your most energy and explain your least energy. You are ranking them in the order of most energy to least energy. And then you are telling me why.

1.2 Mark: You said we're ranking them…?

1.3 Cathy: One, two, three, and four… put them in numerical order of most energy to least amount of energy, and tell me your reasoning for number one and your reasoning for number four. Don't tell me your reasoning for two and three.

They're in the middle. You should have two explanations. You should have all of them labeled one through four.

1.4 Cathy: It seems we are all pretty much in agreement. Some were a little different. We'll talk about that in a moment. So, why do you think most people picked the bus as number one? Let's hear your explanation why bus is your number one for you.

1.5 Tracy: It moves the fastest.

1.6 Cathy: So, it moves the fastest. Does anybody have anything to say other than it was moving the fastest?

1.7 Amber: It takes a lot of energy to move the bus because it has a lot of mass.

1.8 Cathy: Okay, the bus has a lot of mass. I love that terminology. Good work!

{Classroom Discourse Audio & Video, 1-8-10}

Cathy follows the educative curriculum script as written by the IQWST developers. The script is intended for teachers to use as they teach the lessons. The exchange throughout the dialogue in Excerpt 1 clearly reveals the teacher as both the initiator and the primary knower. For example, there is teacher repetitive talk (1.1, 1.3). The teacher validates the response of students with an approval (1.6, 1.8). The approval even accompanies emotive expressions: "I love that terminology. Good work!" (1.8). Such approval-type interaction is known as initiation-reply-evaluation (IRE) (Mehan et al., 1966), initiation-response-feedback (IRF) (Sinclair & Coulthard, 1975), and triadic dialogue (Lemke, 1990). Whereas all three follow a similar format, triadic dialogue allows for comments in the third segment of the triad with the teacher either repeating, rephrasing, or expanding upon students' contributions (Lemke, 1990).

Cathy's discussion with her class reflects continued questioning (1.1, 1.4, 1.6, 1.8). She asks questions that elicit explanation (1.1, 1.4)—"What do you think?"—and challenges students by asking the question, "Does anybody have anything to say other than it was moving the fastest?" (1.6). These two questions, according to Michaels and O'Connor (2012), promote productive discussions. They also can serve other useful functions that guide students' learning and that guide their own use of language as a tool for reasoning (Mercer & Howe, 2012). Amber provides a suitable explanation for why the bus requires a lot of energy to move (1.7). The process by which new ways of explaining are developed by students can involve dialogic interactions between teachers and students (Scott et al., 2006).

Understanding Kinetic Energy

Cathy guides students through an investigative activity designed to identify the factors that influence kinetic energy. The purpose of the entire investigation lesson was for students to learn that objects in motion have kinetic energy and that the amount of kinetic energy an object has is dependent on the object's mass and speed. Another purpose that directly connects to the goal of "questioning and designing investigation," which is a critical attribute of the IQWST curriculum, is to develop students' ability to recognize variables and design a fair test to isolate the effect of a single variable. Excerpt 2 reveals how Cathy develops students' understanding of kinetic energy.

Excerpt 2:

2.1 Cathy: Please read the purpose for this activity…

2.2 Bridget: The purpose of this activity is to determine which factors affect the amount of kinetic energy a falling object has. You will design a scientific experiment by changing one variable at a time.

2.3 Cathy: We have two findings, the independent and dependent. You are going to use Play-Doh to measure how much energy something has. How can you use Play-Doh to measure how much energy something has? I have a little, tiny piece of Play-Doh. And I have a medium-sized piece of Play-Doh. I have two pieces. If I put them in my fingertips and press—which one is going to squish first?

2.4 Tasha: The smaller one…

2.5 Cathy: Why?

2.6 Tasha: It has less mass.

2.7 Cathy: If I take two cans, and this is what you're going to do… Corey, please read the instructions.

2.8 Corey: Use the table to record your data when investigating how the speed of the falling object can affect the change in thickness of the modeling clay.

2.9 Cathy: How does speed affect what somebody is doing? If I'm testing speed… and I'm going to use these two cans… To make it a fair test… this is the question… if I'm changing the speed, how many things should you change in the experiment? Listen to the question… how many things should you change in the experiment?

2.10 Avery: One

2.11 Cathy: Avery said it. If I'm changing the speed, should I change anything else in the experiment?

2.12 Corey: No

2.13 Cathy: You're going to take a ball of Play-Doh. You're going to measure it to about two centimeters. You're going to take one can. You're going to put a piece of newspaper on the floor, and you're going to take your Play-Doh. You're going to take your ball of Play-Doh and put it on here. You're going to take one can and you're going to drop it onto that Play-Doh. First off, you're going to measure that Play-Doh. You're going to take a ruler and tell me how high is this Play-Doh? Right now, it's about two centimeters. You're going to take the can and drop it. You're going to measure the Play-Doh again. What do you think is going to happen when I drop it?

2.14 Michael: It's going to get smashed.

2.15 Cathy: It's going to get squished. I dropped it. It squished. You're going to measure it again. You're going to take it and take it back to the same size. It was two centimeters before. If it was two centimeters before, how big are you going to make it again?

2.16 Michael: Two centimeters…

2.17 Cathy: Thank you! It's two centimeters again, and you're going to take the same can… instead, this time, you're going to not throw it hard enough so I have open cans of food in my room. You're going to throw it down at the Play-Doh. After you throw it, what do you think you're going to do? You're going to measure it again. From now until 10:30, you should be independently writing your predictions. You can actually write in your books your predictions. What do you think is going to happen with that Play-Doh when you drop it versus throwing it? What's going to happen and why? When you

> are finished with the predictions, go ahead and use the equipment. The great things about predictions are that you don't have to be right.
>
> **{Classroom Video, 1-8-10}**

Perhaps this is the first time students have been asked to conduct an investigation with variables. Excerpt 2 reveals that Cathy is again following the IRE pattern of interaction (Mehan, 1979), or triadic dialogue (Lemke, 1990), by constantly asking questions to guide her instruction on scientific investigation. There are 11 teacher-posed questions and no student questions. Cathy asks four types of questions: (a) fill-in-the-blank, requiring one word answer; (b) second-order; (c) descriptive; and (d) explanatory. Of these types of questions, there are three fill-in-the-blank questions, requiring brief oral responses from students (2.5, 2.9, 2.11, 2.13, 2.15); four second-order questions (2.9, 2.13, 2.17); four descriptive questions (2.3, 2.13, 2.17); and two explanatory questions (2.5, 2.17).

While attempting to adopt a new way of teaching, Cathy falls into the trap of repetitive talk as a method of ensuring that students clearly understand what she is trying to teach them. Rather than probing for students' deeper understanding, Cathy continues to give long-winded instructions about what her students need to complete (2.13, 2.17). For example, immediately after asking a question, she gives specific instructions to students about how to answer that question (see 2.3). Cathy demonstrates the procedure for the students before allowing students to conduct the investigation (2.13, 2.15). For example, Cathy explains to students how to design and conduct a fair scientific test that enables them to assess the influence of one variable on another variable while all other variables are held constant (2.9). As well, Cathy wants students to understand the importance of multiple trials to establish the validity of a constant answer (2.15).

Cathy uses explanatory questioning to guide students to respond in writing (2.17). Besides questions that elicit obvious answers (2.4, 2.5, 2.10, 2.12, 2.14, 2.16), she asks "Why?..." questions (2.5, 2.17) to elicit explanations and "What do you think?" (2.17), a second-order question (Ebenezer et al., 2010; Marton & Booth, 1997), to probe their predictions.

A mixture of questioning types constitutes "authoritative" teaching that may be identified as teacher modeling, and then Cathy allows her students to conduct the investigation as they construct meanings for themselves. This type of teaching simulates what Scott et al. (2006) have described as "productive disciplinary engagement" (p. 607) although there is much show and tell on Cathy's part. Although Cathy uses the IQWST workbook lessons that foster classroom discourse as an essential component of inquiry through experimentation and argumentation (Krajcik & Sutherland, 2010), only a few questions are explanatory.

Formulating Scientific Explanations

The students had completed Activity 2.2: Kinetic Energy Investigation. They had tabulated their data for analysis and writing their conclusions. The following example is one student's original work. Excerpt 3 below suggests how Cathy helps students formulate scientific explanations.

Excerpt 3:

3.1 Cathy: Let's look at this conclusion question. How does speed affect kinetic energy? Did you guys figure out that squish is equal to kinetic energy?

3.2 Darryl: Yes.

3.3 Cathy: You need to write that on the top of that page. On the top of your page, write, “Squish equals kinetic energy.” That’s what you’re measuring. So, somewhere up here, squish equals kinetic energy. As we’re doing this conclusion question, you realize that what you were measuring was the amount of energy something had. We just wrote the sentence. As the speed goes up… kinetic energy does what…?

3.4 Darryl: Increases.

3.5 Cathy: Okay. Your evidence is, “When I increased the speed of the can, the Play-Doh squished more. Reasoning is going to be the hard piece. It always is. Talking about reasoning again. I’m going to leave this up for a few minutes. You’ve got to watch this demo to get it. I squished a little. I squished a lot. Which one took more energy? Watch again… I squish a little. I squish a lot. Which one took more energy? The littler one took more energy. Your reasoning is… Darryl, how could you write that so it makes sense? How could you explain that so it makes sense to other people? Squish a little and squish a lot… how could you explain that as reasoning? You have two things. It takes a lot to squish a lot. It takes a little to squish a little. How could that be tied into reasoning?

3.6 Darryl: When you have the small clay and the big clay, it takes more to squish because the mass is smaller.

3.7 Cathy: But you started with the same size, right?

3.8 JaCarol: Yes.

3.9 Cathy: How could you tie that into reasoning of when you increased the speed of the Play-Doh, it squished more? The reasoning is exactly what I said when I did this. The more the play dough squished, the more what does it have?

3.10 Aaron: Mass.

3.11 Cathy: Not more mass. It's the same mass. The more… what…? the more it squished, the more… what…?

3.12 Chris: Kinetic energy…

3.13 Cathy: Chris, say it again, loud and proud… you were right.

3.14 Chris: Kinetic energy…

3.15 Cathy: The more kinetic energy it had. Claim, evidence, reasoning: The claim is yeah, the speed does matter when it comes to kinetic energy… moving energy. When you increase the speed of the can, it's squished more. The more the Play-Doh squished, the more kinetic energy it had. The more I squish it with my fingers, the more energy it takes. It doesn't take a lot to just put my thumbs right in there a little bit. But to squish it takes a lot more energy. How could you answer question number two by looking at question number one? Read question number two to me please, Mateo.

3.16 Mateo: How does mass affect the amount of kinetic energy?

3.17 Cathy: Write that in the same context. Now, the question is… instead of speed, it is mass. How does mass affect kinetic energy? Could you just change those words? How do we know that? It's the same reasoning?

{Classroom Video, 1-12-10}

After students collected their data and recorded the data in a table in their IQWST workbooks, Cathy continues to use IRE, IRF, and IRFRF patterns as she directs her students to formulate scientific explanations by triangulating claims, evidence, and reasoning based on the conclusion question (3.1) and the IQWST standards. In these IRE patterns, three major strategies are evident: teacher-posed questions, teacher responses, and teacher references to past learning. There are 19 teacher-posed questions, while there is only one student question. While teaching students the concept of reasoning within the scientific explanation triangle, Cathy uses five fill-in-the-blank questions (3.3, 3.5, 3.9, 3.11, 3.17), two affirmation questions (3.7, 3.17), three second-order questions (3.1, 3.5, 3.17), four descriptive questions (3.1, 3.9, 3.15, 3.17), and three explanatory questions (3.5).

The teacher's strategy of using fill-in-the-blank questions is what is known as "cued elicitation," according to Mercer and Edward (1987, p. 142). When students mistakenly give an answer (3.7, 3.9), she points out that it is not the constant variable (mass). The IRE triad is obvious in her evaluative feedback to the students. She keeps probing until she gets the correct answer or the answer she is looking for (e.g., 3.11). She even goes as far as providing students with the majority of the answer, only allowing for a one-word response (3.7-3.10). In other words, Cathy probes until she receives the correct response (3.11-3.14). Using cued elicitation to create "common knowledge" is a very common practice among teachers. Cathy consistently uses the whole-class method of discussion to develop conceptual understanding of science topics in order to build common knowledge that leads students to become involved with the new knowledge they encounter; however, Alexander (2004) has suggested that teacher-student talk deserves to be called "dialogic" when the teacher uses dialogue to provide a cumulative, continuing, contextual frame to check students' conceptual understanding. Cathy tries to check for understanding regarding the concept of trials. Cathy repeatedly (3.3, 3.5, 3.9, 3.15, 3.17) makes the cultural tools of science available to her students and supports their construction of the ideas through discourse about shared physical events.

Translating Energy Transformation

The lesson on energy transformation is conducted after Cathy takes her students to visit the energy exhibits at the science center. The purpose of this lesson is to explore the topic of conversions of chemical energy into other forms of energy. Cathy guides students to complete a chart that describes various forms of energy, energy conversions, and energy transfers. Students are expected to write an explanation for each conversion. During the discourse, Cathy refers to the giant engine at the science center that illustrates energy conversions, which the students observe. The giant engine is a model of a four-cylinder, four-stroke engine and demonstrates the relationships of the major parts of an engine and how they function together. There is an electric motor that keeps it going at a slow speed. Cathy makes a connection between the concept of energy transfer and conversion and the processes of the giant engine. Excerpt 4 characterizes teacher-student discourse on energy transfer.

Excerpt 4:

4.1 Cathy: At the science center, they have on the top floor the pistons that move up and down, right? That's what gasoline does with the spark plugs. It pushes your pistons up and down. When something is moving… it has what kind of energy?

4.2 Sheldon: Kinetic energy.

4.3 Cathy: Kinetic energy… So, when you start exercising, you are doing what?

4.4 Sheldon: Moving…

4.5 Cathy: Okay, as you start exercising more and more… what happens to your body, Kia?

4.6 Kia: Elastic energy.

4.7 Cathy: Some people in my first hour also had this in there… it's not in the textbook answer. Why would you put elastic energy in there, Kia? Jalen? Think back to that reading about the human body and elastic energy. Henry, what was that connection? Jalen, you said it now. Go ahead and say it now, Jalen.

4.8 Jalen: Your muscles and things in your body are stretching out.

4.9 Cathy: Okay. So your muscles and things in your body are stretching out. I would take either one of those. The third one was the quartz watch. This chemical energy—and this is a tricky one—the chemical energy that's in the battery turns into… what? What do batteries provide?

4.10 Jalen: Energy.

4.11 Anthony: Heat.

4.12 Cathy: Some batteries provide heat, but what type of energy? We haven't talked about this one yet, which is why it's tricky. What kind of energy do batteries provide?

4.13 Darryl: Electric.

4.14 Cathy: So they don't provide sound. They provide…?

4.15 Darryl: Electric.

4.16 Cathy: Electric energy. When you have a battery… if I were to take a plug and plug it into the wall and not use a battery, what kind of energy am I getting?

4.17 Mark: Electric energy.

4.18 Cathy: I'm getting electric energy. Just like the battery provides the same type of energy, electric energy, right?

4.19 Mark: Electrical energy.

4.20 Cathy: What does that electrical energy turn into?

4.21 Tracy: Thermal energy.

4.22 Cathy: It doesn't turn into thermal. So what is it?

4.23 Tracy: Kinetic energy.

4.24 Cathy: What happens on the watch when the electricity hits the dials on the watch?

4.25 Amber: It turns to kinetic energy.

4.26 Cathy: Okay. It turns into kinetic energy. If you said, sound, I would take sound energy. Because sometimes you can hear… like if you put your hand up and you can hear a tick, tick on that type of watch.

4.27 Bridget: Electrical.

4.28 Cathy: Good point! Yep. Electrical… elastic…

4.29 Robert: What's sound energy?

4.30 Cathy: Sound, fireworks… we've talked about fireworks a lot. What do you think is one type of energy that's in there? Jalen?

4.31 Jalen: Kinetic energy.

4.32 Cathy: There is kinetic energy.

4.33 Bridget: Thermal.

4.34 Cathy: There's definitely also thermal. What comes at the very end of the fireworks?

4.35 Tasha: Gravitational.

4.36 Cathy: Not gravitational.

4.37 Avery: Chemical.

4.38 Cathy: Not chemical… chemical is in the beginning. There's sound energy. And there's another type of energy that we haven't talked about. How do you know that a firework has been lit?

4.39 Aaron: Smell.

4.40 Cathy: It's not smell. It's not heat. What do you see?

4.41 Michael: Colors.

4.42 Darryl: Light energy…

4.43 Cathy: There is also light energy.

{Video of Classroom Discourse, 3-22-10}

The exchange between Cathy and her students as revealed in Excerpt 4 is a classic example of IRE (4.38-4.43). For example, Cathy is looking for another form of energy in the students' responses and provides clues when the students do not respond as expected. Four major points are evident in the dialogue represented in Excerpt 4: teacher-posed questions, teacher-explanations, teacher responses, and teacher references to past learning.

There are 18 teacher-posed questions, while there is only one student question. Cathy asks five types of questions: (a) 12 fill-in-the-blank questions (4.1, 4.3, 4.9, 4.12, 4.14, 4.16, 4.20, 4.22, 4.34), (b) two affirmation questions (4.1, 4.18), (c) one second-order question (4.30), (d) two descriptive questions (4.24, 4.40), and (e) one explanatory question (4.7). For example, Cathy reminds her students about an exhibit with pistons and elicits their response about the type of energy that is involved when something is "moving," which requires a fill-in-the-blank response (4.1). Cathy affirms the correct answer from Mark as he moves away from the idea that the battery has chemical energy and focuses on the idea that batteries provide electrical energy (4.18). The second-order questions reveal the following: After talking about chemical energy, electrical energy, kinetic energy, and sound energy, Cathy wants to know whether Jalen will be able to identify the form of energy with respect to the watch (4.30). As a descriptive question, Cathy asks, “What happens on the watch when the electricity hits the dials on the watch?” But students respond with very few words. There is one explanatory or “Why?...” question (4.7). Cathy prompts Jalen to provide an explanation by thinking back to the reading about the human-body and elastic energy.

Other behaviors are obvious in Cathy’s classroom. Cathy provides positive responses when her students are correct (4.32, 4.34) and negative responses when they are incorrect, followed by additional prompts and questions to advance their thinking (4.38). For example, Cathy confirms Jalen’s and Bridget’s responses regarding the forms of energy, kinetic and thermal energy, respectively, while continuing to probe for the correct answer. During the discussion about the fireworks, Cathy is looking for another form of energy in the students’ responses because she says “no” to chemical energy although she acknowledges that there is chemical energy in the fireworks.

Cathy references past learning in the context of student experiences at the science center and in the classroom (4.1, 4.7, 4.12, 4.30, 4.38). For example, Cathy prolongs the conversation until the right answer comes forth based on a previous discussion. Later, Cathy does not give Robert a direct answer but uses fireworks as an example of sound energy that was discussed in a previous lesson. She provides a clue to students by asking the following question: “How do you know that a firework has been lit?” Research by Mercer, Dawes, and Staarman (2009) supports Cathy’s attempts to link prior learning to the present. These authors have suggested that this connection provides a way of understanding how participants draw on past text and/or practices to construct present texts and/or implicate future ones; however, Lehesvuori et al. (2013) have acknowledged that developing common knowledge through joint construction or in a meaningful manner takes time.

Cathy's classroom discourse is akin to Mercer and Howe's (2012) observation of whole-class settings in which teacher-student interactions are dominated by teacher talk and in which teachers use closed questions simply to seek brief responses in order to ensure that at least some students repeat the right answers. Teachers therefore need to apply less authoritative and more dialogic dialogue to help students construct their own knowledge--in this case, knowledge about the concept of energy. Thus, the predominant fill-in-the-blank-type questions should be sparse and be replaced with questions that encourage students to put main ideas into their own words and press students to elaborate on these ideas. For example, asking, "How did you know that?" or "Why do you think that?" develops students' understanding (Wolf, Crosson, & Resnick, 2006). The art of questioning is important in developing students' knowledge and understanding of scientific concepts.

Implications

The purpose of this study was to interpret a seventh-grade science teacher's discursive moves in developing common knowledge during classroom discourse on the topic of energy and during various scientific inquiry processes. The goal of the classroom discourse was to increase students' understanding of the concept of energy before observing science center exhibits about energy. However, developing common knowledge about the concept of energy is not an easy task for teachers, especially in whole-class teaching. This study revealed (a) Cathy's struggle to follow the lessons in the workbook using whole-class teaching to develop common knowledge about the concept of energy and (b) her ability to strategically balance authoritative talk with dialogue (Mortimer & Scott, 2000). Even though Cathy participated in professional development focused on how to implement the unit on energy and attempted to engage her students in dialogic discourse, this study revealed the need to provide additional training on how to develop student understanding and common knowledge using dialogic discourse. Based on the findings of this study, two related implications are worthy of discussion: (a) Cathy's struggle with dialogic discourse and (b) professional development with intellectual empathy that fosters dialogic teacher-student interactions and better student outcomes.

Cathy's Struggle with Dialogic Discourse

This is the first time that Cathy has attempted to teach a science topic after participating in professional development designed to help her teach the seventh-grade IQWST physics unit. The discussion that occurred during classroom interactions between Cathy and her students revealed IRF patterns of discourse, continued questioning, and a give-and-take of ideas. In Cathy's first attempt to follow the design of the IQWST curriculum, she led a whole-class discussion and exhibited the IRF pattern of discourse when teaching the concept of energy using IQWST workbook activity sheets as a guide. Furthermore, she developed her students' understanding of the concept of energy and scientific inquiry processes through the IQWST curriculum so that students could translate their conceptual understanding to the energy-related exhibits at the local science center. In other words, she attempted to achieve dual purposes: (a) to teach the IQWST curriculum on energy and inquiry and (b) to show her students the link between in-class learning and out-of-class learning. In this quest, Cathy fell into a discourse pattern that is primarily authoritative and monologic when she taught the concept of energy and the scientific inquiry process. To achieve her desired goal, Cathy, like most teachers, maintained control of the content, interactions, and discussion (Edwards & Furlong, 1978; Mishler, 1975). In this control process, Cathy assumed the role of the knower, initiator, and approver of knowledge (Shepard, 2010). This type of dialogue between Cathy and her students reflected the initiation-reply-evaluation pattern (Mehan,1979). The IRE pattern was evident in all four excerpts.

Cathy moved her lesson forward with continued questioning (1.1, 1.4, 1.6, 1.8, 2.3, 2.5, 2.9, 2.11, 3.1, 3.3, 3.7, 3.9, 3.11, and 4.1, 4.3, 4.5, 4.12, 4.14, 4.18, 4.20, 4.30, 4.34, 4.38, 4.40). Mercer (1992) argued for the necessity of constant questioning in order for teachers to monitor students' learning and make their teaching as effective as possible. Cathy's questions sought to elicit explanations (1.1, 1.4), and she asked questions that challenged more than one student to answer (1.6, 4.7). Such questions promote productive discussions (Michaels & O'Connor, 2012), develop explanations (Scott et al., 2006), and guide students' learning so that they can use their own language as a tool for reasoning (Mercer & Howe, 2012). As identified in Excerpt 2, Cathy demonstrated some productive disciplinary engagement (Scott et al., 2006) by switching back and forth between authoritative and dialogic interactions (2.3, 2.4, 2.5, 2.9, 2.11, 2.13). Cathy alternated her questions from one-response, pre-determined answers to questions such as "Why?" or "What do you think?" This strategy encouraged students to use language to express and elaborate key ideas in their own words (Wolf, Crosson, & Resnick, 2006).

The approach Cathy used, as revealed in Excerpt 3, set the stage for argumentative discourse (Driver et al., 1994) and the ability to solve open-ended problems through argumentation--e.g., claim, evidence, reasoning, and explanation (McNeill & Pimentel, 2009). Classroom discourse in the context of science inquiry depends on the use of data as evidence for explanation and argumentation (Krajcik & Sutherland, 2000). The preferred form of classroom discourse in the IQWST curriculum is a give-and-take exchange of ideas in which classroom discussion is centered on engagement and thoughtfulness (Krajcik et al., 2008). As Cathy attempted to implement the IQWST curriculum from a sociocultural perspective, she made several attempts to engage her students in classroom discourse using the give-and-take strategies outlined in the curriculum (3.5, 3.6, 3.15, 3.17). Cathy pursued lines of questioning by probing her students to discuss their reasoning. In this way, she set the stage for argumentative discourse; however, the questioning did not extend beyond one statement, and Cathy continued to engage with students within her comfort level, which consisted of the IRE pattern of discourse. Cathy continued to use closed questions that led to brief, accurate responses from selected students. In some instances, Cathy demonstrated discourse that led to scientific explanation (1.3, 1.4, 1.7, 3.5, 3.9). However, she heavily cued students to the point that she elicited one-word, correct answers from them. As noted, Cathy consistently reverted back to an IRE pattern of discourse (1.6, 2.13, 3.11, 4.14). Cathy’s behavior was not surprising because Lemke (1990) stated that teachers typically resort to the traditional form of discussion. Although Cathy was struggling to implement what she had learned about classroom discourse during the IQWST professional development and although she reverted back, her attempts to move toward dialogic interaction are noteworthy.

Although the IQWST curriculum provides an argumentative, dialogic framework using claim, evidence, and reasoning, Cathy’s implementation of the curriculum suggested that she is more comfortable with authoritative, monologic interaction in presenting and teaching scientific concepts. Sociocultural research indicates that teachers should balance authoritative discourse with more authentic dialogue (Mortimer & Scott, 2003) in order to establish common knowledge. In line with these authors, using authoritative discourse is not to be completely dismissed when attempting to reach consensus about scientific understanding during conceptual change inquiry teaching.

According to Kyriacou and Issitt (2008), good learning results when teachers use questions not only to seek right answers but also to elicit reasons and explanations. As seen in 3.5, asking students specifically to provide their evidence and reasoning encourages students to justify their responses and make their thinking visible to the teacher and to their peers in the classroom (McNeill & Krajcik, 2012). However, while Cathy focused on triangulating the scientific explanation with claim, evidence, and reason, the teacher-student interactions tended to be dominated by monologic exchanges between Cathy and her students in which she used “closed” questions to seek brief, accurate confirmation that select students knew the “right answers” (Mercer & Howe, 2012). The educative components of the IQWST curriculum include example questions and probes to help teachers understand ways of fostering connections between student wonderment questions and the driving question of the lesson (Singer, Marx, Krajcik, Clay, & Chambers, 2000). Teachers often elaborate and reformulate the contributions made to classroom dialogue by students (such as in response to a teacher’s questions) as a way of clarifying what has been said for the benefit of others and to make connections between the content of students’ utterances and the technical terminology of the curriculum (Mercer, 2008). However, if teacher questioning results in the overuse of triadic approaches, students will not be able to pose their own questions and link their ideas to the concepts being presented (Lemke, 1990).

Professional Development with Intellectual Empathy and Follow-Up

It is useful both for teachers and administrators to understand the various classroom discourse tools and how they should be used to develop common knowledge and conceptual understanding of difficult-to-learn science concepts, such as energy and inquiry. The tools provided in professional development should include training in how to achieve more in-depth understanding of the essence of classroom communications as they appear to the teacher and students as well as more micro-scale, moment-by-moment exploration (Lehesvuori et al., 2013). Because whole-class instruction is the most common instructional approach (Eshach, 2010), especially in urban classrooms, these tools should encompass strategies to help teachers navigate, mediate, and co-construct knowledge with their students. Professional developers and mentors themselves should use dialogic discourse when they attempt to move teachers toward such discourse. Teachers should also be taught when various discourse patterns can be appropriately used.

It is important to understand that learning mediated through dialogue happens over time and should be studied over time (Mercer, 2008) with the goal of conceptualizing the interactive cognitive development and learning of the teacher. Administrators and researchers who are observing the implementation of science lessons from a sociocultural perspective should be intellectually empathetic as teachers struggle to move towards dialogic discourse because it takes time to develop proper language use. As well as being empathetic with the time needed to develop dialogic discourse, teachers who are willing and truly trying to implement dialogic discourse need to be supported, monitored in their use of this type of communicative approach, and not left to their own discretion during implementation. Follow up from colleagues, administrators, and researchers regarding how teachers are progressing over a specific time period should be consistent and a part of job-embedded professional development in order to ensure that teachers are implementing dialogic discourse where appropriate.

CHAPTER 4 (Article Three)

THE EFFECT OF FORMAL-INFORMAL INSTRUCTION OF ENERGY CONCEPTS ON URBAN AFRICAN-AMERICAN STUDENTS' SCIENCE APPLICATION AND ACHIEVEMENT

Abstract

The purpose of this study was to investigate whether a standards-driven, project-based Investigating and Questioning our World Through Science and Technology (IQWST) curriculum unit on forms and transformation of energy augmented with science center exhibits had a significant effect on urban African-American seventh-grade students' achievement and learning. A mixed approach consisting of qualitative methods (classroom discussion, focus group interviews, and student video creation) and quantitative methods (a multiple-choice and open-ended question instrument) were used to collect data. The IQWST Unit Achievement Test (IUAT) indicated that students (N=37) in the experimental group who were taught with the IQWST curriculum unit augmented by the science center exhibits achieved scores ($p<0.001$) about the same as students in the control group (N=31) who were taught only with the IQWST curriculum unit. However, the experimental ($\Delta_{\text{post-pre}}= 4.78$) and control ($\Delta_{\text{post-pre}} = 4.04$) groups both revealed significant gains ($p<0.001$) from their pre-test scores to their post-test scores. The quantitative evidence is corroborated with qualitative findings based on students' understandings of energy: (a) scientific explanations of science exhibits and (b) model development of the Flywheel exhibit. The study's results confirm that the learning of underserved urban students can be enhanced with an augmented standards-based curriculum unit. These students also can realize significant achievement gains when professionally developed and administration-supported teachers use standards-driven science curriculum, whether augmented or not. However, the results suggest that the use of science center exhibits can provide a context in which to observe whether students are able to translate and apply knowledge constructed in the classroom. The implications of this study are three-fold: (a) implementing a standards-based augmented curriculum for improved achievement and science learning; (b) analysis of students' presented videos reveals scientific explanations; and (c) extended time on informal learning projects improves scientific explanations.

Key Words: formal and informal science learning, standards curriculum, project-based science, science center exhibit, science achievement

Introduction

Students from urban and minority backgrounds lose interest in science learning as early as middle school, and this trend has not changed, even in the recent past (Barmby, Kind, & Jones, 2008). As a result, a gap has emerged in science achievement between (a) urban and minority students and (b) their White and Asian counterparts (Viadero & Johnston, 2000). One explanation for this trend is that children of racial and ethnic minority groups with high-poverty backgrounds living in urban cities lack opportunities to learn high-quality science (Tan & Barton, 2012). However, (a) social justice researchers, (b) conceptual change researchers focusing on teacher care and intellectual empathy toward students' conceptions (Ebenezer et al., 2010; Wood, Ebenezer, & Boone, 2013), and (c) project-based science education researchers (Geier, Blumenfeld, Marx, Krajcik, Fishman, Soloway, & Clay-Chambers, 2008) offer the promise of improved learning and higher achievement among urban youth. Geier et al. observed that historically underserved urban students have realized standardized achievement test gains when teachers used standards-based, inquiry-based science curricula that are highly specified, developed, and aligned with professional development and supported by administration.

The Science and Mathematics Academy (SMA), a public charter school in a midwestern metropolitan area, aspired to provide standards-based science education to intellectually deprived African-American students with teacher support. In pursuit of this goal, SMA adopted the standards-based Investigating and Questioning Our World Through Science and Technology (IQWST) curriculum (Krajcik & Reiser, 2004) and provided the necessary professional development to its teachers. Concurrently, the school also established a partnership with the Urban Science Center (USC) to augment its core curricula, which included science. In line with the SMA's goal of providing standards-based science education, a seventh-grade science teacher, who had received professional development in the IQWST curriculum, attempted to augment the IQWST curriculum with the USC exhibits. Coincidentally, the researcher of this study, as an administrator in her own school district in another nearby urban city, attended the IQWST professional development on curriculum materials. She also had a great interest in augmenting her school district's science curricula with the support of the local museum exhibits in order to reach the urban African-American students in her district. Because of this common interest, the researcher wanted (a) to determine whether a gain in achievement scores resulted when the IQWST curriculum was augmented with science exhibits and (b) to understand the nature of students' learning at the intersection of the IQWST curriculum and the USC interactive science exhibits. The researcher's focus on student learning and achievement aligns with the political mandates of the state (1990, PA 25) and the nation (ARRA, 2009, for example, Race to the Top), which assess teachers and schools in terms of student achievement.

Based on the joint interest of the teacher and the researcher, a complex, classroom/science center study was developed. This study focused on the achievement of two experimental classes of seventh-grade African-American students in an IQWST curriculum unit on the forms and transformation of energy that was augmented by the USC interactive science exhibits. To test whether achievement gains resulted from augmenting the IQWST curriculum with science exhibits, a different teacher, who had received professional development in the IQWST curriculum at the same school, implemented only the curriculum (without using the USC interactive science exhibits) in two equivalent seventh-grade control classes. Data on science teaching and learning and students' understanding of forms and transformation of energy were gathered from one of the experimental classes. The researcher followed a small group of students as they (a) translated their understandings of forms and translation of energy and (b) explained the interactive science exhibit at the USC.

In an age of accountability, Katz (2001) has stated that it might be worthwhile for informal science learning centers to provide experiences that align more closely with school science standards that help to improve science learning and achievement. In line with Katz's study, Dierking, Falk, Rennie, Anderson, and Ellenbogen (2003) observed that informal science, technology, engineering, and mathematics (STEM) educational opportunities (such as exhibits that focus on STEM activities) and interactions, when connected to the content taught in the classroom, can prepare young people to reach higher achievement levels in science. The Centre for Advancement of Informal Science Education (2010) has asserted that learning in informal environments--e.g., science centers--has resulted in positive outcomes in students' conceptual understanding, higher achievement, and improved dispositions. Falk and Needham (2011) reported that students learned science content; applied their understanding to other contexts; and increased their interest, curiosity, and attentiveness to science because of their multiple visits to a science center. Hung, Lee, and Lim (2012) proposed that time should be allocated for students to learn in informal contexts and that teachers play the role of brokers to help students articulate, reflect on, and think about their learning experiences in informal contexts, thereby helping students to re-contextualize learning strategies and dispositions. Hung et al. reiterated that student learning occurs when students are provided multiple opportunities to observe exhibits in science centers that relate to topics they are learning about in the classroom. These authors further argued that learning both in formal and informal contexts provides students with opportunities to deepen their knowledge about scientific topics.

Aligned with the interest of the teacher at the SMA and the work of science educators in understanding the link between formal and informal learning (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003; Hung, Lee, & Lim, 2012; Katz, 2001), this study was conducted at the SMA to observe student science achievement and science learning that occur at the intersection of formal (IQWST) and informal (interactive museum exhibits) learning environments. Based on this overarching goal, three research questions were constructed:

1. Are there significant gains in students’ achievement scores from pre-test to post-test as a result of the intersection between the IQWST unit and the interactive museum exhibits?
2. Are there statistically significant gains in students’ achievement scores from pre-test to post-test as a result of including interactive museum exhibits as part of an IQWST unit on forms and transformation of energy? What conceptual understandings

do sub-groups of the same African-American students reveal based on the USC exhibits that demonstrate forms and transformation of energy?

Significance of the Study

This study contributes to the knowledge base of the IQWST program, the focus of which is urban student learning and achievement. In the tradition of the IQWST program, this study was conducted in an urban school comprised primarily of an African-American population within a low socioeconomic urban setting. Because of this context and a focus on the IQWST curriculum, this study demonstrates how to develop conceptual understanding of science concepts among urban students. This study also illuminates how teachers may help urban students who come to school lacking prior knowledge about subject matter or who are not fortunate enough to experience learning outside the context of school in ways that link such knowledge with school science.

The outcomes of this study align with the work of researchers who are studying the influence of standards-based science inquiry on learning and achievement. The interest and curiosity of other investigators likely will be piqued by the published results of this study, resulting in a subsequent amplification of productivity in this highly significant research area focused on linking formal and informal learning to science learning and achievement. This study provides a theoretical and methodological foundation for future researchers who wish to study the combination of formal and informal teaching and its influence on students' science learning and achievement.

Theoretical Framework: School Science Learning Augmented with Informal Learning among Urban Minority Students

As early as 1991, Haberman pointed out the influence that external constraints have had on teaching in urban classrooms, such as large class sizes, inadequate preparation time, lower levels of training, inadequate classroom space, and outdated materials. Ten years later, Songer, Lee, and Kam (2001) characterized urban classroom practices as consisting of teacher-controlled activities, such as giving information, administering tests, providing directions, awarding grades, monitoring seatwork, settling disputes, administering review tests, and assigning homework. The external constraints and subsequent teacher behaviors in urban classrooms have resulted in a pedagogy of poverty. In order to meet the intellectual needs of children living at or below poverty levels, Pozuelos, Gonzalez, and Leon (2010) have advocated inquiry-based learning in science classrooms.

A promising development for inquiry-based learning has been project-based science (PBS), a reform-based pedagogy that emphasizes students’ construction of a usable or meaningful understanding of the science concepts they are learning through inquiry (as opposed to memorizing decontextualized scientific facts). The IQWST curriculum, which features components that are similar to PBS learning environments, has shown the capacity (a) to improve urban students’ understanding of science content (Krajcik, McNeill, & Reiser, 2008; Linn, Bell, & Davis, 2004; Marx, Blumenfeld, Krajcik, Fishman, & Soloway, 2004; Rivet & Krajcik, 2004; Schneider, 2002) and (b) to promote the success of urban students (Schneider et al, 2005; Schneider, Krajcik, Marx, & Soloway, 2002; Stratford, Krajcik, & Soloway, 1998). The IQWST curriculum was developed in response to the need for reform in science education (National Research Council, 1996, 2000) regarding the integration of standards and inquiry-based practices in science classrooms via project-based science (Alozie, Moje, & Krajcik, 2009; Blumenfeld, Marx, & Harris, 2006; Krajcik et al., 1998; Polman, 2000). According to Kanter and Konstantopoulos (2010), PBS curricula, such as IQWST, have project- and inquiry-based aspects that leverage the strengths of urban students, especially urban students from ethnic and racial groups that have been underrepresented in science careers. These project- and inquiry-based components potentially create a positive influence and help these students achieve higher levels of science learning.

This research study also examined the mediation of learning between school classrooms and informal, community-based science learning centers (Bevan & Semper, 2006; Hofstein & Rosenfeld, 1996; Stocklmayer, Rennie, & Gilbert, 2010). Researchers have agreed that out-of-school learning activities, although developed only for those community contexts, also supplement formal learning in schools. Hofstein and Rosenfeld (1996) suggested that schools should effectively use out-of-school contexts and that certain conditions must be met in order to provide opportunities for a rich, blended learning experience for all students from diverse backgrounds.

Falk and Dierking (2000) were convinced that some measure of instruction is needed in order to effectively assess student learning while at the same time not compromising the social and choice opportunities afforded to students by informal learning environments. This assertion was based on their inquiry into whether guided tours were connected directly to inquiry and the National Science Education Standards (NRC, 1996), as well as their own contextual model of learning (Falk & Dierking, 2000). Their findings indicated that guided museum tours provide experiences that are satisfactory to students and teachers but mostly inconsistent with recommendations outlined in science education reform documents and informal science literature. The study also noted that if guided tours at science museums continue to implement didactic, instructor-centered models, then cognitive, affective, and social learning outcomes will be compromised and science learning opportunities may be missed.

Similar to Falk and Dierking's 2000 study and the studies of others (e.g., Hofstein & Rosenfeld, 1996; Griffin & Symington, 1997), as well as based on their own study, Cox-Peterson, Marsh, Kisiel, and Melber (2003) have pointed out out that simple guided tours enrich science learning, but they do not connect to science education standards or informal learning priorities. In fact, Griffin and Symington (1997) observed that teachers were unaware of the type of learning that ought to take place in the museum. Instead, these teachers overlaid task-based strategies that are often practiced in school on learning-oriented museum activities. For instance, the teachers did not consider using the museum as an informal learning resource. As well, the teachers did not adequately link museum exhibits that they visited with topics being studied in the classroom. Cox-Peterson et al. (2003) recommend that in order to prepare students for a meaningful visit to the museum, both museum staff and science educators must consider three elements: the school curriculum, exhibits/museum content, and student inquiry. This process requires much more than simply having access to informal contexts that provide self-directed inquiry opportunities and approaches through current exhibits.

If school curriculum and informal learning environment are appropriately blended, positive results other than achievement gains also accrue. The investigation by Gerber, Cavallo, and Marek (2001) into the relationship among informal learning environments, teaching procedures, and scientific reasoning ability indicated that students learning within enriched informal learning environments demonstrated significantly higher scientific reasoning abilities compared to students within impoverished informal learning environments. This positive result was attributed to authentic experiences that allowed direct contact with real objects that stimulated students' curiosity and interest in the topic (e.g., Falk, Koran, & Dierking, 1986; Meredith, Fortner, & Mullins, 1997; Pedretti, 1997). Lemelin and Benze (2004) claimed that focused planning between the classroom teacher and the informal science educator in a short-term collaborative project involving a school and a museum created a platform for bringing to the foreground some important dimensions of science learning. This project, however, did not provide in-depth connections or intentional alignment between the content being taught in the classroom and the exhibits being observed. Gonzalez, Moll, and Amanti (2005) found that students are able to add to their "funds of knowledge" by connecting classroom learning about science concepts with informal learning experiences at a science center. The Committee on Learning Science in Informal Environments, established in 2009 by the National Research Council to examine the potential of informal science settings, reported that these informal settings or learning environments can have a significant impact on science learning outcomes, particularly for individuals from non-dominant groups who have been historically underrepresented. Science learning experiences across informal environments may positively influence children's science learning in school, their attitudes toward science, and the likelihood that they will consider science–related occupations. Bransford et al. (2006) argued that learning in formal and informal environments can be successfully intertwined.

A Literature Review on Students' Understanding of Forms and Transformation of Energy

Lee and Liu (2009) emphasized the importance of developing students' understanding of forms and transformation of energy. When students were asked to select and describe pictures that show energy (Lee & Liu, 2009) or draw a concept (Liu, Ebenezer, & Fraser, 2002), their responses revealed that energy is human-related, activity-related, a product, a function, or a fluid-like substance (Watts, 1983). Other studies exploring the application of energy-related concepts, such as devices that convert one form of energy to another form, revealed that students' understanding of energy transformation was not transferable, even after instruction (Lee & Liu, 2009). Dorsen, Carlson, and Goodyear (2006) pointed out that the students in their study demonstrated learning about the forms of energy and the transformation of energy as they interacted with science exhibits. These authors found that interacting with museum exhibits increased students' learning in ways that support persistence and success in future course work in STEM disciplines.

Nordine, Krajcik, and Fortus (2010) explored the effectiveness of middle school energy instruction that was designed according to the principles of a learning-goals-driven design using project-based pedagogy (Krajcik et al., 2008). This type of instruction focuses on tracking energy transformations that occur in everyday contexts that students are likely to experience outside of school (Nordine et al., 2010) and enhance integrated understandings. With integrated understandings, students are more likely to effectively apply their knowledge in new situations and learn more efficiently (Bransford et al., 2000; Bransford & Schwartz, 1999; Linn & Eylon, 2000).

Goldring and Osborne (1994) found in their study that at least 50% of students had difficulty with the basic concept of energy, ideas related to energy, and the application of these ideas to everyday situations. Their findings suggested that although some students could manipulate complex formulas and work through involved exercises, they often did not understand fundamental principles. Students were not afforded the opportunity to think about the concepts that they are being taught but can recall statements dictated to them. These authors concluded that physics teachers should place more emphasis on developing the language of physics (i.e., energy) and its appropriate use as well as providing students with opportunities to discuss physics and the meaning of common terms. They provided examples of such opportunities, including concept mapping and discussions.

The choice of the concept of energy for the topic of this study was justified on the basis of the literature (Goldring & Obsborne, 1994; Lee & Liu, 2009; Nordine et al., 2010). This difficult-to-teach, standards-based curriculum, if augmented with science center exhibits, may have an effect on science achievement and learning. Thus, the results of this study on the topic of energy may be helpful in assisting teachers and researchers who are looking for intentional connections between formal science education and informal science education that influence and enhance African-American students' science learning, science application, and science achievement.

Methodology

Contexts of the Study

At the time of this study, The Center for Informal Learning and Schools had established a research agenda designed to explore how informal science institutions can support and improve K-12 schooling with the goal of increasing informal learning in informal settings, increasing informal learning in formal settings, and increasing the use of formalized learning in informal settings.

Teachers at the Science and Mathematics Academy were bound by state standards curriculum and usage of the curriculum; however, some autonomy was given to the teachers to adjust the curriculum. The freedom to engage in this dialogue about their goals and time to address various requirements--such as logistics, IQWST unit implementation, and science center policies--were critical in sustaining the empowering learning spaces that were characteristic of this learning community.

Characteristics of the Science and Mathematics Academy

The Science and Mathematics Academy (SMA), built in 2009, is an annex to the Urban Science Center (USC). The SMA is situated in the heart of a large urban city in a midwestern state. The SMA is a Public School Academy secondary school that focuses on science and math. Although students apply for admission to attend the SMA, there are no academic or behavioral criteria required to gain admittance to the school. At the time of the study, the total school population was 387. Approximately 85% (331) of the students lived in an urban city, and approximately 15% (56) lived in the surrounding areas. Two hundred and twenty seven students were on a free or reduced lunch program. There were 161 students in seventh grade: 155 black, 1 Arab-American, 3 Caucasian, and 2 Hispanic. There were 94 boys and 67 girls in the seventh grade.

SMA was founded on the philosophy of "Big Picture Learning Design," which is a dynamic approach to learning, doing, and thinking in order to help change the lives of students, educators, and entire communities. The components of this design are based on three foundational principles: (a) that learning must be based on the interests and goals of each student; (b) that students' curriculum must be relevant to the people and places that exist in the real world; and (c) that students' abilities must be authentically measured by the quality of their work. The SMA embraces the core values of community, opportunities, rigor, and engagement (C.O.R.E.). The SMA believes in (a) nurturing powerful relationships that sustain robust learning communities; (b) seeking, creating, and using opportunities to benefit the community; (c) encouraging students to explore science, technology, engineering, and mathematics; (d) rigorously investigating curricula that are aligned with state standards; and (e) engaging students in constant inquiry, thus upholding all four C.O.R.E. values. The classroom learning environment is built around the team concept. An advisory team representing each of the core subject areas--English/Language Arts, Science, Mathematics, and Social Studies--is responsible for the same group of students.

Characteristics of the Science Learning Center

The vision statement of the Urban Science Center (USC) is as follows: "We are the premier museum in the United States of America focused on engineering" (DSC, 2009, p. 1). Its mission is as follows: "To inspire visitors to pursue and support careers in engineering, technology, and science" (DSC, 2009, p. 1). The USC creates captivating, durable, engaging exhibits and displays for museum and corporate clients. The USC is one of the largest hands-on science museums in the United States. The USC has produced hundreds of displays that diverse audiences, including preschoolers who visit the Urban Science Center's Kids Town Gallery, the budding young engineers who are inspired by the U.S. Steel Fun Factory exhibits, and the adult visitors who marvel at the Saturn V Rocket and recall the Apollo mission that took us to the moon. The USC combines a range of talent and expertise to develop unique solutions to display challenges. The USC features more than 200 hands-on exhibits that explore space, life, and physical science. The physical science section offers experiences on how the manufacturing process turns ideas into reality with the aid of computer design, prototypes, simulations, conveyors, robots, statistics, and more in the United States Steel Fun Factory. The community resource is used as a classroom that goes beyond the concept of a traditional field trip. This experience includes investigations, tours, and presentations by museum docents. It also allows groups of students to work cooperatively on a project. “Museum Docent” is a title given to persons who serve as guides and educators for the institutions they serve, usually on a volunteer basis. They provide group learning experiences in the form of museum tours, demonstrations, or instruction in special activity areas. Docents were used in order to maximize productivity during the time the students were at the science center.

Energy-Related Science Center Exhibits

The teacher in this study took her students to the USC to provide them an overview of the exhibits that pertain to the physics unit on energy. The exhibits that the students observed were the Flywheel, Simple Machines, Brownian Motion, and the Giant Pendulum. Cathy wanted her students to connect these exhibits with the concepts related to forms and transformation of energy that were taught in class (see Appendix B). The USC visit was conducted as a whole group instead of individual groups. As the students observed the exhibits, Cathy instructed students about the assignments they needed to complete. Cathy made connections to what they learned in the classroom. For example, she stated, “Kinetic energy is energy of motion.” Those connections included gravitational energy and electrical energy. Note the authors of the IQWST curriculum use the term “gravitational energy” instead of “potential energy.”

Flywheel exhibit. At the USC, a large flywheel is encased in a cage with a seat attached on the outside of the cage and pedals to make the flywheel move (see Figure 2). The key concept displayed by the flywheel exhibit is the transfer of energy from one form to another, in this case from gravitational energy to kinetic energy (DSC, 2009).

Figure 1. Flywheel Exhibit--Urban Science Center (DSC, 2009).

Brownian motion. The Brownian Motion exhibit consists of four variable-speed rollers set in a square configuration with small metal ball bearings and a ring of aluminum pipe contained in the square (see Figure 3). The rollers impart energy to the ball bearings and send them moving across the table and colliding with the aluminum ring. These collisions are random, and as the speed of the rollers increases, so too does the number of collisions with the ring. The key concept in the Brownian Motion Exhibit is that as more energy is imparted to the ball bearings by increasing the roller speed, the number of collisions the balls make with the pipe ring increases, pushing the pipe ring around randomly. The ball bearings represent water molecules, while the pipe ring represents a larger particle, such as pollen. The roller speed represents the increase in energy to the system created by increased temperature (DSC, 2009).

Brownian Motion
Urban Science Center

Jaron, JaCarol, Kian.mp4

Figure 2. Brownian Motion--Urban Science Center (DSC, 2009).

Giant pendulum. The giant pendulum represents rotational motion, and the Earth is rotating under it. The inverted globe gives viewers an idea of how much the Earth has rotated since the pendulum began swinging. At the Earth's poles, the path of the pendulum will make one full rotation every 24 hours. At the equator, it will not revolve at all. This large Foucault pendulum consists of a granite ball hung from a central point in the ceiling two stories above. The pendulum is started each day just before opening of the science center. As the day progresses, the pendulum continues to swing in the direction it started (inertia) and the Earth turns underneath it. The key concept is that the rotation of the Earth can be demonstrated using the Foucault pendulum (DSC, 2009). The motion of a pendulum is an example of mechanical energy conservation. The bob of the pendulum has potential energy when it begins its swing in the upward position. As the bob loses height and potential energy, it increases speed and gains kinetic energy (The Physics Classroom, 1996-2015). Potential energy is stored energy and kinetic energy is energy of motion.

Figure 3. Giant Pendulum--Urban Science Center (DSC, 2009).

Simple machines. At the USC, there are four different simple machines: gear ratios, a giant lever, an inclined plane, and pulleys. A machine is any mechanical or electrical device that uses energy to perform or help perform a human task. Machines increase the force that is needed, add energy, and do work. Machines take input work (energy/force) and get more force or energy out than was put in (Idaho Public Television, 2015). The giant lever is an example of a first-class lever—i.e., the fulcrum is between the operator and the item that the operator is trying to lift. Since the length of the arm the operator is pulling on is much longer than the arm that the weight is hanging from, less force is required to lift the weight.

Gear ratios contain handles that turn a gear. The smallest diameter gear lifts the weight more easily, but it has to be turned farther to do it. A smaller force exerted over a greater distance is equal to a greater force exerted over a smaller distance. These gears are similar to the gears in a car's transmission. A lower gear makes the engine turn more times to move the car. This is similar to turning the smallest gear. Making the engine turn faster means the engine can use less force at higher speeds. A higher gear is used to make the wheels turn faster to save fuel.

The inclined plan is a simple machine. If something heavy needs to be lifted, an operator can lift it straight up or push it up a ramp. An operator can use less force on the ramp but push it a longer distance.

Each pulley is set up to lift a 15lb. weight. Lifting a 15lb. weight a given distance results in a specific amount of work. It can be accomplished by pulling a lot of rope through the system with a lower force. Pulling less rope through the system requires a greater force.

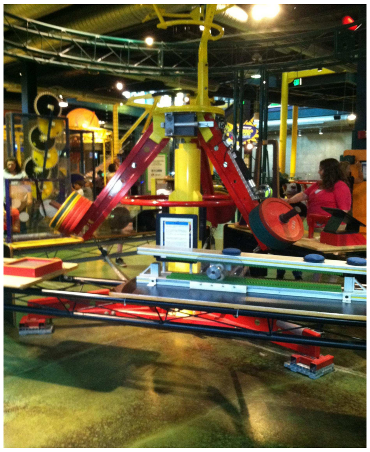


Figure 4. Simple Machines--Urban Science Center (DSC, 2009)

Partnership between the Science and Mathematics Academy and Urban Science Center

The partnership between the SMA and the USC provides an opportunity for teachers and students to combine teaching and classroom learning, respectively, with hands-on exhibits, theater shows, and museum programs on a regular basis. Pairing the museum with the school is a logical extension of the overall educational objectives of SMA. The vision of the SMA is to incorporate science center exhibits, behind-the-scenes logistics, programs, and theaters into the curriculum being taught at the school. This approach is different from other schools that experience USC activities only through field trips to the site or the traveling science program. However, these field trips and the traveling science program are limited in scope regarding the amount of time and interaction given to these schools. During the partnership between the SMA and the USC, USC personnel were willing to work closely with the teachers to provide them with information regarding the exhibits and training for the new exhibits and programs.

The IQWST Curriculum

At the time of this study, the SMA adopted the Investigating and Questioning Our World Through Science and Technology (IQWST) curriculum and the associated project-based learning approach that promotes inquiry and reflection. The IQWST curriculum is built on the premise of project-based science (PBS), which is similar to problem-based learning and other socio-constructivist, inquiry-based design models. In project-based science, students engage in extensive use of student-directed scientific practices supported by technology and collaboration (Kracjik, Czerniak, & Berger, 2002; Ruopp, 1993; Schneider, Krajcik, & Blumenfeld, 2005; Tinker,1996). Students also investigate real-world, standards-based problems that are of interest, relevance, value, and worth to them over a sustained period of time (Toolin, 2004). The curriculum provides engaging learning experiences that involve students in complex, real-world projects through which they develop and apply knowledge and skills learned in each content area.

Modeling is one of the scientific practices in the IQWST curriculum. The practice of scientific modeling consists of constructing, using, testing, evaluating, revising, and sharing models. The primary focus was using models to explain or predict phenomena. In this case, phenomena included various objects, events, and processes. The IQWST curriculum requires students to use models to build their understanding of all aspects of models. A scientific model is an abstract, simplified representation of a system or phenomena that makes its central features explicit and visible and can be used to generate explanations and predictions (Harrison & Treagust, 2000; Schwarz et al., 2009).

The Forms and Transformation of Energy Unit of the IQWST Curriculum

In line with NSF (2009), the major learning goals in the seventh-grade physics unit are to help students to understand that there are different forms of energy and that energy can be transformed from one form to another. Through shared learning goals across units, inquiry processes are repeatedly revisited. The driving question in the unit is the following: “Why do some things stop while others keep going?” To answer this question, the investigations enable students to experience scientific phenomena and processes by allowing them to examine new information; ask new questions; plan experiments; and collect, analyze, and share data. The unit is divided into three learning sets. The first learning set attempts to answer the following question: “What determines how fast or high an object will go?” The first learning set is then divided into four lessons in which students investigate factors that determine the amount of kinetic energy possessed by an object and the connection between elevation and energy. The second learning set attempts to answer the following question: “Why do some things stop?” This learning set is divided into three lessons in which students investigate thermal and sound energy. The third learning set attempts to answer the following question: “Why some things keep going?” This learning set consists of four lessons, which introduce chemical, electrical, and light energy as well as how they can be converted into one another and into other types of energy. The main investigation includes falling objects, a pendulum, a bouncing ball, playground instruments, and springs. Energy conversion diagrams are introduced as a way to represent energy transformations. In total, the IQWST seventh-grade physics unit consists of 11 lessons.

Research Design and Procedures

A mixed-methods approach, such as the one employed by Clary and Wandersee (2007), was used in order to achive concurrent triangulation and corroboration of findings within a single investigation (Cresswell, Clark, Gutmann, & Hanson, 2003). This study reflected a quantitative design (i.e., a quasi-experimental pre-test and post-test control group design in which classes were randomly assigned to a treatment) (Campbell & Stanley, 1963). The two groups of students were compared based on their pre-interventional test scores. The IQWST curriculum unit on Forms and Transformation of Energy with Science Center exhibits was the teaching intervention. The IQWST Unit Achievement Test (IUAT) was used to measure achievement scores of students (See Appendix A).

All 68 students, ages 13-14, from four seventh-grade classes at the SMA participated in the IUAT. Qualitative observations were made of one learning community of 18 students in one of the two experimental classes. Of the students in the learning community, a small sub-group was observed in order to identify the strategies that students used to connect what they learned in school to an interactive science exhibit at the USC.

The IQWST curriculum unit on forms and transformation of energy was implemented during a period of 16 weeks. Cathy took her students to the USC three times. As part of her pedagogy, Cathy actively engaged her students in depicting their understandings of forms and transformation of energy in their workbooks and by constructing models and videos.

The teacher of the experimental classes and the teacher of the control group classes were similar in terms of their teaching experience and educational backgrounds. For example, the teacher of the experimental classes (a female) has earned a bachelor’s degree in elementary education and an associate’s degree in liberal arts. The teacher of the control group classes (a male) has earned a bachelor’s degree in elementary education. At the time the study was conducted, both teachers had been teaching for approximately five years. The limitation of using two different teachers for the experimental classes and the control group classes was known at the beginning of the study. This limitation may have influenced student learning. In order to minimize this limitation on the results of this study and for verification purposes, the researcher observed the experimental and control classes and recorded written field notes to ensure that the teacher of the experimental classes and the control group classes followed the intended lesson plans in each class.

Professional Development Experience of Both Teachers

Like all teachers at the SMA, Cathy and the teacher of the control group classes received professional development training on the BIG Lesson Model and on IQWST curriculum implementation. The BIG Lesson Model is a professional development model for immersion learning that includes a study trip for teachers and a partnership between community resources and schools. All of the science teachers received professional development training on how to implement the IQWST curriculum. The professional development training included support in the areas of science content, inquiry pedagogy, and contextualizing learning focusing on Big Ideas using the IQWST curriculum. The five-day summer institute was conducted by University of Michigan (UM) professors, UM graduate students, and a lead teacher. Through this summer institute, teachers learned and practiced the components of the IQWST curriculum. The institute emphasized coherence (development of science ideas), deep and meaningful student understanding, concepts and explanations, and student assessment. A major goal for teachers during the summer institute was to understand IQWST pedagogies combined with the use of an educative curriculum.

Parallel Teaching in the Experimental and Control Classes

In both experimental and control group classes, teaching aspects were balanced around several issues. All five elements of the critical attributes of the IQWST curriculum (Krajcik, et al., 2008) were implemented by both classes. Prior to the implementation of the curriculum, the physics unit test on energy was administered to all students using a paper-and-pencil format during one class period. After the pre-test, teachers developed the knowledge structures in the physics unit based on the following question: “Why do some things stop while others keep going?” Both teachers implemented the project-based science lessons. At the beginning of the lesson, the teachers discussed the purpose of the lesson, reviewed the learning goals, and then proceeded to introduce the lesson by using an activity or video. Based on the introductory activity, the students generated questions that were recorded on the driving-question board. Activities were embedded throughout the lesson and intermingled with brief, direct instruction on the concept being taught in the lesson. The teachers provided opportunities for the students to enhance their knowledge by reading information sheets on the topic. The lessons concluded with students answering some of the questions generated on their driving-question board. Homework assignments were provided. The post-test was administered to students after the last day of the unit.

Teaching in the Experimental Class

The experimental class engaged in informal experiences, interacting with the museum exhibits at the USC. The teacher (Cathy) attempted to incorporate the USC exhibits into the IQWST lessons on the concept of energy. Cathy took her students to the USC approximately three times throughout the course of this study, which was 16 weeks long. The goal was for students to enhance their understanding of the concept of energy by experiencing both the formal IQWST curriculum and the informal USC exhibits. A partial table indicates the experimental class activities as well as the days and dates they were presented. All activities are taken from the following IQWST physics unit entitled "Why Do Some Things Stop and Others Keep Going?" These activities connect to the results section (see Table 4 and Appendix B).

Table 4

Partial Table of Classroom Events.

Teaching Days	Teaching Activities	Learning Activities
Day 4 Jan. 12	Wrapped up kinetic energy (KE) investigation (2.2); began KE predictions (2.3); discussed reading on impact crater; introduced claim, evidence, and reasoning; developed students' understanding that mass and speed have an impact on kinetic energy.	Identify two factors (mass and energy) that determine how much kinetic energy something has and analyze data based on data collected from previous lesson in which students had to drop cans into the modeling dough.
Day 20 Feb. 25 Museum Visit	Teacher took the students on another trip to the museum to observe the exhibits and make connections to energy transformations. Teacher directed the students to write in their journals.	a.) Students visited the USC and observed the Flywheel, Simple Machines, and the Pendulum. b.) After the exhibit visit, students debriefed with the teacher and began writing in their journals.
Day 30 March 24	Directed students on how to complete Activity 9.1 to continue their understanding of electrical energy. Focus group interviews took place during this time.	Students worked in pairs to complete Activity 9.1; noticed some students drew diagrams to demonstrate their understanding of electrical energy.

Cathy used students' models of science center exhibits and students' videos in order to probe into students' understanding of the concept of energy. The students were provided with chart paper to construct models that depicted their understanding of the concept of energy. The students were required to make videos that included the science exhibit, their model, and an explanation of their conceptual understanding of the concept of energy. In addition to these requirements, the teacher provided the students with a list of requirements that they needed to include in their video, a set of questions to be answered, and a scoring guide for their scientific explanations. In the video, the students were to explain the exhibit they observed by including a description of the type of energy involved, conversions of energy types available, and evidence collected to support their thinking regarding the types of energy involved.

Quantitative Data Sources and Analysis

The IQWST Unit Achievement Test (IUAT). The Pre- and Post-IQWST Unit Test (see Appendix A), designed by the IQWST curriculum authors, was used to identify a statistically significant difference that existed between the pre-test and post-test scores in terms of achievement in both the experimental classes and the control group classes. The instrument consisted of multiple-choice and open-ended questions. All items in the IUAT had in fits and outfits between 0.75 and 1.33. The reliability of the test, as measured by Cronbach's alpha and based on the national field trials, was 0.77 (Fortus, personal communication, 2014). There are 12 multiple-choice questions that have three or four possible answers, marked A, B, C and A, B, C, D, respectively.

Analysis of pre-test and post-test IQWST unit scores. An ANCOVA method of analysis was employed to compare experimental and control groups in terms of the students' post-test scores, including their pre-test scores as a covariate in the analysis. This kind of design was appropriate given the fact that the students were randomly assigned to the groups and the fact that the sample size provided enough statistical power. The demographic characteristics of the sample are recorded as percentages. Descriptive statistics, such as mean scores and standard deviations, are reported in Table 5. The goal was to determine whether there was a statistically significant increase in students' achievement on the unit post-test scores from the IQWST-interactive museum exhibits curriculum after controlling the effect of their levels measured by their pre-test scores.

Qualitative Data Sources and Analysis

Qualitative data collection for this study consisted of student-created videos and presentation of students' understanding of energy-related science concepts as well as a focus-group interview based on students' model of the Flywheel science exhibit on chart paper.

Video creation and presentation. As a culminating activity, the teacher required students in small groups to make a video of their understanding of the forms and transformation of energy and make a group presentation in class. Seven groups of two to three students in the 18-member learning community created a video of their understanding of forms and transformation of energy. These videos were part of a presentation students made to the class, and they were displayed on the school website. The requirements of the video were as follows:

1. Each group member must be on tape for 3-5 minutes.
2. Each group member must explain the science behind the energy of the museum exhibit displayed.

3. Each group member must make a connection (terminology or explanation using claim-evidence-reasoning format) from what they were taught in the classroom to the science center exhibit.
4. The video must be audible and free from background noise.
5. A transcript must accompany the final product.

A fully explained exhibit included a description of the energy forms involved, conversions of energy types (if available), and evidence that students collected to support their thinking regarding the forms of energy involved.

The videos were transcribed verbatim. The transcripts from the videos were then analyzed, coded, and categorized to reveal student understanding of the concept of energy. The transcripts of the recordings of the sessions were read and color coded. The transcripts were read repeatedly to identify students' understanding about forms and transformation of energy based on the USC exhibits.

Each video was critically analyzed, and scores were assigned using the video criteria rubric in order to identify students' understanding of forms and transformation of energy using science center exhibits levels: excelling, meeting, approaching, or beginning. The rubric contained a section for the video and a section for the content for each level. Inter-rater reliability of students' video scores was calculated by one of the researchers and one external expert independently using the rubric. During the analysis of the videos, when discrepancies arose across individual analyses, the researcher and expert reviewed the videos together, discussed discrepancies in analyses, and reached consensus on the students' ability to explain the exhibits and the connections with what they had learned in class about energy. The expert and the researcher reached 95% agreement on the interpretations. Following is the criteria used to evaluate students' presentations:

1-Beginning: Students were not able to explain the concept of energy. (There was no claim, no evidence, and no reasoning.) Example: "The color that you see right here in the plasma globe is a light violet color. And these are like the streamers from the… it is from the metal inside. They use a lot of voltage to make it so you could have those streamers coming around. The way you are able to see the electric current is because the electrons inside the globe and the gas inside the globe combine to allow you to see the electric current. And the one thing you should notice is the lightening is going… it strikes everywhere" (Sheldon).

2-Approaching: Students were able to partially explain the concept of energy. (Information referenced the exhibit and provided one accurate element of explanation.) Example: "You can see the energy conversions [claim]; this is kinetic energy, which technically is its power. This is gravitational energy; it makes it go from the height, from up and down, and the chemical energy is the power from the pedals. The bars, the legs, and the elastic energy is from the person who is sitting over here [evidence]" (Anthony).

3-Meeting: Students were able to partially explain the exhibits in terms of energy. (Information referenced the exhibit and provided two elements of explanation.) Example: "The little silver balls represent molecules [evidence]; there is a little thing in the middle which stops; when the balls hit this little item, it stops the little molecules… the button here represents the motor, which keeps the outliers moving; they are going to rotate to keep the things rotating, the marbles which represent the movement of the molecules… first you have to press the buttons to start up the motor; the balls will rotate in circles and keep going; the thing will continue, and the marbles will continue to roll [evidence]… the explanation is that molecules are little thing that float around in the air… air particles flow around in the air. As you know, there's always an energy transfer to each and every item you get that's either chemical energy, elastic energy, potential energy, or kinetic energy [reasoning] (JaCarol).

4-Excelling: Students were able to fully explain the exhibit in terms of energy. (Information referenced the exhibit and provided two elements of explanation.) Example: "The pendulum moves so minutely that they need marbles to tell where it has been and where it is going to go… there is energy transfer going on while this happens [claim]… you will see that it reaches its highest point, and then it goes and swings back down [evidence]. At its highest point, it is at gravitational energy, and it loses gravitational and gains KE [evidence]. Once it is over the North Pole, it is at its full KE [evidence]. Once it starts going—swinging back up—it gains more GE [evidence]. Because the gravitational energy is pulling down, it depends on… once it reaches its highest point but then once it goes down, it loses all of it… the KE will have to leave and give GE back their energy [reasoning] (Cortez).

Focus-group interview. During the implementation of the IQWST interactive museum exhibits curriculum, students from the group of 18 were divided into five groups of three to four students and were required to develop a model on chart paper based on one interactive exhibit related to forms and transformation of energy learned in the classroom. Chart paper models were obtained from two groups because their models were closely related to the concept of energy and were completely developed. Based on one of the models created on chart paper (the Flywheel exhibit), the researcher conducted two focus-group interviews with one group of students about their understandings of the concept of energy. This interview took place in a mutually agreed upon time and place that was identified by the teacher. The group consisted of four students. Each focus-group interview lasted 30 minutes so that the researcher could probe for in-depth meaning about students' understanding of the concept of energy with their model. Each focus-group interview was audio-recorded and transcribed verbatim. These focus-group interviews were conducted primarily to corroborate quantitative results with qualitative analysis.

Validity and Reliability

Validity of this study was established by adopting Lincoln and Guba's (1985) principles of "trustworthiness"--i.e., credibility, confirmability, dependability, and transferability. The credibility of this study was established by the researcher's participation and observation in the classroom during the implementation of the curriculum; therefore, the context was well known. Rapport and mutual trust were developed between the researcher and the participants long before this component of the study began. In fact, the researcher and Cathy had met two years before the study began and engaged in conversations about how the study should be conducted prior to data collection.

Confirmability was achieved by systematically IC recording the classroom teaching and learning activities. To ensure that the findings were clearly linked to the data, the transcripts were read repeatedly, and evidence in the dialogue excerpts were color coded at the initial stages of analysis. For example, connections between the USC exhibits and the concept of energy revealed students using a model to demonstrate their learning. Excerpt 1, lines 1.1-1.5, for instance, provide evidence of students' discussion about using their model to show the connection to the Flywheel exhibit and the concept of energy. Interpretations were subjected to a member check as they were shared with the teacher of the science lessons.

Dependability was addressed by having two researchers with methodological expertise check the research plan and implementation. An external audit consisting of a U.S.-based researcher with a Ph.D. and graduate student, both with experience in statistics and psychometrics, reviewed the quantitative data for accuracy. These experts also determined whether the findings, interpretations, and conclusions reflected the data. Both external researchers agreed that the research was dependable. Validity was sufficient to establish reliability because Lincoln and Guba (1985) have stated that reliability and validity in qualitative research are congruent.

Results and Discussion

Students' achievement was calculated by conducting the following analyses: (a) mean scores and standard deviations of the IUAT for both groups (see Table 5); (b) one-way ANOVA to evaluate the scientific explanations from each group of students based on their exhibits (see Tables 6, 7, and 8); and (c) one-way ANOVA to evaluate teacher time spent with the students at the different exhibits (see Tables 9, 10, and 11). Students' qualitative understanding of the concept of energy were discerned through their (a) scientific explanations of science exhibits and (b) model development of the Flywheel exhibit. Qualitative evidence sheds light into the claims made through quantitative analyses.

Students' Achievement

An ANCOVA was conducted to determine the effect of a formal-informal science intervention on students' pre-test and post-test scores on the IQWST 7th Grade Physics Unit Test (see Table 5).

Table 5

Mean Scores and Standard Deviations of the IUAT for Both Groups

Comparison			Descriptive Statistics Interval for Bootstrapped Means			
			n	Mean	SD	*p*
Within Group	Control group	Pretest	31	11.77	3.62	
		Posttest	31	15.81	4.16	.001
	Experimental Group	Pretest	37	10.84	3.82	
		Posttest	37	15.62	4.57	.001
Between Groups	Control group	Pretest	31	11.77	3.62	
		Pretest	37	10.84	3.82	.306
	Experimental Group	Posttest	31	15.81	4.16	
		Posttest	37	15.62	4.57	.863

The statistical results of the scores of students' IUAT in Table 5 indicate that students (N=37) in the experimental group that did receive the intervention achieved about the same as the students in the control group (N=31) that did not receive the intervention. Students in both the experimental ($\Delta_{post\text{-}pre}$= 4.78) groups and control ($\Delta_{post\text{-}pre}$ = 4.04) groups achieved significant gains ($p<0.001$) from pre-test scores to post-test scores. Not finding significant achievement gains based on the augmentation of IQWST curriculum with the USC exhibits is not surprising. In fact, the negative outcome manifests the strength of the IQWST curriculum because it is built on the premises of project-based science (PBS). IQWST curriculum units, which have been designed to facilitate deep conceptual understanding and provide students sufficient time to actively engage in learning activities and to integrate their understandings (Fogelman, McNeill, & Krajcik, 2011), are expected to improve urban youth learning and achievement (Geier et al., 2008). The negative achievement result does not mean that the IQWST curriculum, or any other inquiry-based curriculum, should not be augmented with informal learning. Indeed, the augmentation of the IQWST curriculum with the USC exhibits provided the urban African-American students an opportunity to move between the two intellectual spaces and to translate their conceptual understandings.

A one-way ANOVA was conducted to evaluate the scientific explanations from each group of students based on their exhibits (See Tables 6, 7, and 8).

Table 6

One-Way ANOVA Descriptive Statistics of Scientific Explanations

Comparison	Descriptive Statistics Dependent Variable: Rating/Score (Continuous)		
Exhibit Number	n	Mean	SD
1 Flywheel	5	2.2000	.44721
2 Brownian Motion	3	2.3333	.57735
3 Giant Lever	2	3.0000	.00000
4 Electric Poles-Static Shock	2	1.5000	.70711
5 Giant Pendulum	3	3.6667	.57735
6 Plasma Globe	2	1.0000	.00000
Total	17	2.3529	.93148

Table 7

One-Way ANOVA Tests of Between-Subject Effects of Scientific Explanations

Source	Tests of Between-Subjects Effects Dependent Variable: Rating/Score (Continuous)			
	df	F	Sig (p)	Partial Eta Squared
Corrected Model	5	9.398	.001	.810
Intercept	1	331.277	.000	.968
EXHIB	5	9.398	.001	.810
Error	11			
Total	17			
Corrected Total	16			

Table 8

One-Way ANOVA Multiple Comparisons of Scientific Explanations

Multiple Comparisons

Dependent Variable: Rating/Score (Continuous)

Tukey HSD

(I) Exhibit Number	(J) Exhibit Number	Mean Difference (I-J)	Std. Error	Sig.
Flywheel	Brownian Motion	-.1333	.35732	.999
	Giant Lever	-.8000	.40936	.422
	Electric Poles-Static Shock	.7000	.40936	.552
	Giant Pendulum	-1.4667*	.35732	.016
	Plasma Globe	1.2000	.40936	.107
Brownian Motion	Flywheel	.1333	.35732	.999
	Giant Lever	-.6667	.44665	.676
	Electric Poles-Static Shock	.8333	.44665	.468
	Giant Pendulum	-1.3333	.39949	.056
	Plasma Globe	1.3333	.44665	.098
Giant Lever	Flywheel	.8000	.40936	.422
	Brownian Motion	.6667	.44665	.676
	Electric Poles-Static Shock	1.5000	.48928	.086
	Giant Pendulum	-.6667	.44665	.676
	Plasma Globe	2.0000*	.48928	.017
Electric Poles-Static Shock	Flywheel	-.7000	.40936	.552
	Brownian Motion	-.8333	.44665	.468
	Giant Lever	-1.5000	.48928	.086
	Giant Pendulum	-2.1667*	.44665	.005
	Plasma Globe	.5000	.48928	.901
Giant Pendulum	Flywheel	1.4667*	.35732	.016
	Brownian Motion	1.3333	.39949	.056
	Giant Lever	.6667	.44665	.676
	Electric Poles-Static Shock	2.1667*	.44665	.005
	Plasma Globe	2.6667*	.44665	.001

Multiple Comparisons

Dependent Variable: Rating/Score (Continuous)

Tukey HSD

Plasma Globe	Flywheel	-1.2000	.40936	.107
	Brownian Motion	-1.3333	.44665	.098
	Giant Lever	-2.0000*	.48928	.017
	Electric Poles-Static Shock	-.5000	.48928	.901
	Giant Pendulum	-2.6667*	.44665	.001

*Significant at the $p<0.05$ level.

One group only had one student that attempted to say her scientific explanation and therefore was not included in this analysis. These group members created their video on the Sailboat Systems exhibit. For the exhibit analysis, there was a statistically significant difference between groups as determined by a one-way ANOVA $F(5,11) = 9.4$, p = 001. The model explained 81% of the variance, $\eta^2 = .810$, p=.001. A Tukey post-hoc analysis revealed that there were no differences between all of the groups except the giant pendulum. The giant pendulum was significantly higher than the flywheel ($p = .016$), plasma globe ($p = .017$), and electric poles ($p = .005$). The giant pendulum score was not significantly higher than the Brownian motion score and giant lever score. All other comparisons were *n.s.*

A one-way ANOVA was conducted to evaluate teacher time spent with the students at the different exhibits (see Tables 9, 10, and 11).

Table 9

One-Way ANOVA Descriptive Statistics of Teacher/Students' Time Spent at Exhibits

Comparison	Descriptive Statistics Dependent Variable: Rating/Score (Continuous)		
Time Teacher Spent on Exhibit	n	Mean	SD
None	6	1.8333	.98319

Comparison	Descriptive Statistics Dependent Variable: Rating/Score (Continuous)		
Bare Minimum	3	2.3333	.57735
Some Time Spent	5	2.2000	.44721
Most Time Spent	3	3.6667	.57735
Total	17	2.3529	.93148

Table 10

One-Way ANOVA Tests of Between-Subjects Effects of Teacher/Students' Time Spent at Exhibits

Source	Tests of Between-Subjects Effects Dependent Variable: Rating/Score (Continuous)			
	df	F	Sig (p)	Partial Eta Squared
Corrected Model	3	4.302	.026	.498
Intercept	1	181.789	.000	.933
TIME	3	4.302	.026	.498
Error	13			
Total	17			
Corrected Total	16			

Table 11

One-Way ANOVA Multiple Comparisons of Teacher/Students' Time Spent at Exhibits

Multiple Comparisons

Dependent Variable: Rating/Score (Continuous)

Tukey HSD

(I) Time Teacher Spent on Exhibit	(J) Time Teacher Spent on Exhibit	Mean Difference (I-J)	Std. Error	Sig.
None	Bare Minimum	-.5000	.51764	.771
	Some Time Spent	-.3667	.44328	.841
	Most Time	-1.8333*	.51764	.017

Multiple Comparisons

Dependent Variable: Rating/Score (Continuous)

Tukey HSD

	Spent			
Bare Minimum	None	.5000	.51764	.771
	Some Time Spent	.1333	.53461	.994
	Most Time Spent	-1.3333	.59772	.166
Some Time Spent	None	.3667	.44328	.841
	Bare Minimum	-1.333	.53461	.994
	Most Time Spent	-1.4667	.53461	.070
Most Time Spent	None	1.8333*	.51764	.017
	Bare Minimum	1.3333	.59772	.166
	Some Time Spent	1.4667	.53461	.070

*Significant at the p<0.05 level.

For the analysis of the time the teacher spent with students at the various exhibits, there was a statistically significant difference between groups as determined by a one-way ANOVA $F(3,13) = 4.3$, $p = .026$. The model explained 50% of the variance, $\eta^2 = .498$, $p = .026$. A Tukey post-hoc analysis revealed that there were no differences between anything but None and Most Time Spent. Most Time Spent was significantly higher than None, $p = .017$. Most Time Spent was not significantly higher than Some Time Spent. All other comparisons were *n.s.*

Students' Understandings of Energy: Scientific Explanations of Science Exhibits

Each student's comments about his or her understanding of forms and transformation of energy based on their video creation of science exhibits are captured in Table 12 and Table 13. Table 12 represents how the students were scored using a rubric. Explanation = Claim, Evidence, and Reasoning (Songer & Gotwal, 2012; McNeill & Krajcik, 2012). The following criteria were used:

1-Beginning: Students were not able to explain the concept of energy. There was no claim, no evidence, and no reasoning.

2-Approaching: Students were able to partially explain the concept of energy. Information referenced the exhibit and provided one accurate element of explanation.

3-Meeting: Students were able to partially explain the exhibits in terms of energy. Information referenced the exhibit and provided two elements of explanation.

4-Excelling: Students were able to fully explain the exhibits in terms of energy. Information referenced the exhibit and provided two elements of explanation.

Table 12

Quality of Student Understanding of Energy Based on Video Evidence: Explanation of Energy--Making Claim-Evidence-Reasoning Connections

Students	Rating	Exhibits																											
		Flywheel				Brownian Motion				Sailboat Systems				Giant Lever				Electric Poles Static Shock				Giant Pendulum				Plasma Globe			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Darryl	2		x																										
Greg	3			x																									
Aaron	2		x																										
Anthony	2		x																										
Joshua	2		x																										
Kiah	2						x																						
JaCarol	3							x																					
Jaron	2						x																						
Kelli	3											x																	
Joseph	3															x													
Trey	3															x													

Students	Rating	Exhibits																											
		Flywheel				Brownian Motion				Sailboat Systems				Giant Lever				Electric Poles Static Shock				Giant Pendulum				Plasma Globe			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Kayla	2																		x										
Gerell	1																	x											
Cortez	4																								x				
Mark	4																								x				
Craig	3																							x					
Sheldon	1																									x			
Chris	1																									x			

All 18 students received scores ranging from 4 to 1 when the data were qualitatively analyzed for the quality of their understanding of energy connected to the USC exhibits. Based on the rubric, two students received a 4, six students received a 3, seven students received a 2, and three students received a 1. Students did not have a complete understanding of how to construct a scientific explanation using claim, evidence, and reasoning. Only one student actually talked about explanation but did not explicitly state the claim, evidence, and reasoning separately. The data reveal that students need to be taught how to construct scientific explanations. Constructing scientific explanations helps students learn important core science ideas and concepts (McNeill & Krajcik, 2012 p. xvii). With some additional instruction and support from the teacher, along with another opportunity to provide scientific explanations, the students could easily receive a higher rating.

Table 13 represents scientific explanations from 18 students with their ratings ranging between 4 and 1.

Table 13

Extracted Comments from Transcripts of Students' Videos on Scientific Explanations of Exhibits Connected to the Concept of Energy

No.	Name	Exhibit	Explanation of Energy: Claim, Evidence, and Reasoning	Rating
1	Darryl	Flywheel	1st comment--Starts w/chemical energy from the body that moves the pedals, which is kinetic energy that moves the chain.	2
2	Greg	Flywheel	The chemical energy is from your body, and you pedal; the flywheel keeps going, and that energy is converted so the flywheel can go in motion; kinetic energy is when the chains go in motion and then spin and make the flywheel go faster.	3
3	Aaron	Flywheel	Pedals stop moving; your energy is going to the flywheel; it keeps going and going until it runs out of energy and until it stops.	2
4	Anthony	Flywheel	You can see the energy conversions; this is kinetic energy, which technically is its power; this is gravitational energy; it makes it go from the height, from up and down, and the chemical energy is the power from the pedals, the bars, the legs; and the elastic energy is from the person who is sitting over here.	2
5	Joshua	Flywheel	This chain is kinetic energy cause it's in motion and it's going around on the chain the more you pedal.	2
6	Kiah	Brownian Motion	…starts with chemical energy because your body gives you the energy to do a change... there are 4 types of kinetic energy: the pipe, the marbles, the outliers, and the rotating thing. The outliers are the start of the kinetic energy cause they give the circular motion, and once the marbles hit it, it's being transferred to the marbles; the marbles can go anywhere… starts with chemical energy because your body gives you the energy to do a change… there are 4 types of kinetic energy: the pipe, the marbles, the outliers, and the rotating thing. The outliers are the start of the kinetic energy.	3
7	JaCarol	Brownian Motion	…the little silver balls represent molecules; there is a little thing in the middle which stops when the balls hit this little item; it stops the little molecules… the button here represents the motor,	3

No.	Name	Exhibit	Explanation of Energy: Claim, Evidence, and Reasoning	Rating
			which keeps the outliers moving; they are going to rotate to keep the things rotating, the marbles which represent the movement of the molecules… first you have to press the buttons to start up the motor; the balls will rotate in circles and keep going; the thing will continue, and the marbles will continue to roll… the explanation is that molecules are little things that float around in the air… air particles flow around in the air; as you know, there's always an energy transfer to each and every item you get that's either chemical energy, elastic energy, potential energy, kinetic energy.	
8	Jaron	Brownian Motion	I am going to talk about the energy transfer. As you can see right here, it starts off with chemical energy; then it moves on to elastic energy and then kinetic… when you eat food, it breaks down and gives you energy; for elastic energy, you turn your bones to push the button and turn the circle, and it's kinetic energy for when the ball moves and you turn your knob.	2
9	Kelli	Sailboat Systems	…our energy conversion starts with chemical energy, which is here, because you actually touch it and plug it up there in that area… chemical-electrical energy because when you plug it up, you get a lot of electricity all through there, and then thermal energy because behind the fans there is heat behind there, so that's where the thermal energy comes from. Wind energy is coming from the fans… and then there is kinetic energy because the boats, like, move…	3
10	Joseph	Giant Lever	The lever works on a pivot, so what it does is that we pull on one side, it pulls down—it pulls up on the other… the basic energy is kinetic and gravitational because when you're pulling it down, it goes down with gravity, and it is kinetic because you're using force to pull it up.	3
11	Trey	Giant Lever	So how the giant lever works is [that] it requires force on one side that lifts the other object on the other side up… its on a pivot called the fulcrum. A fulcrum does not go 360 degrees around like an axis, so it uses gravitational and kinetic energy… how gravity works is that it can be pulled—when you pull down on the rope, gravity helps pull you down. And when you use kinetic energy, it is	3

No.	Name	Exhibit	Explanation of Energy: Claim, Evidence, and Reasoning	Rating
			because you are using force to also pull down.	
12	Kayla	Electric Poles-Static Shock	This is the electricity; these are the poles and how the static is coming from the pole to the little domes… down here is the energy conversion… it starts off with none-electric energy, then kinetic energy, and then thermal energy, and then back to chemical energy. This is just showing the different types of electric energy.	2
13	Gerell	Electric Poles-Static Shock	This negative energy together with this positive energy… it connected, and electric circuits went through our fingers and it connected, so a negative and a positive connected equals the shock.	1
14	Cortez	Giant Pendulum	The pendulum moves so minutely that they need marbles to tell where it has been and where it is going to go… there is energy transfer going on while this happens… you will see that it reaches its highest point, and then it goes and swings back down; at its highest point, it is at gravitational energy, and it loses gravitational and gains KE. Once it is over the North Pole, it is at its full KE. Once it starts going--swinging back up--it gains more GE. Because the gravitational energy is pulling down—it depends on once it reaches its highest point but then once it goes down, it loses all of it… the KE will have to leave and give GE back their energy.	4
15	Mark	Giant Pendulum	The giant pendulum starts off at the top, and then we let it go; when it gets to the second part, it loses half of its gravitational energy and gains half of kinetic energy since it is moving, but it has not gotten to its full kinetic energy point; the giant pendulum reaches its kinetic energy and gains full kinetic energy while it loses another half of GE, or gravitational energy; gravitational energy is back to take its spot, and kinetic energy loses half and GE gains half. And then when we get to the last and final spot, gravitational energy finally comes back and gains full GE, and kinetic energy loses another half of KE.	4
16	Craig	Giant Pendulum	When the pendulum is at its highest point, it has full GE, but when it starts to go down, it loses GE; then KE takes fully over. GE comes back, and it is back to full GE. And it keeps repeating that same old chain of things over and over.	3

No.	Name	Exhibit	Explanation of Energy: Claim, Evidence, and Reasoning	Rating
17	Sheldon	Plasma Globe	The color that you see right here in the plasma globe is a light violet color. And these are like the streamers from the… it is from the metal inside. They use a lot of voltage to make it, so you could have those streamers coming around; the way you are able to see the electric current is because the electrons inside the globe and the gas inside the globe combine to allow you to see the electric current… and the one thing you should notice is the lightening is going--it strikes everywhere.	1
18	Chris	Plasma Globe	Gas is provided together when you put your hand on the globe; it is like your hand because the light follows your hand because the gas and electrons are attracted to your skin (inaudible).	1

Based on Table 13, Cortez and Mark received a rating of 4 because they were able to state a claim about energy transfer and then provide evidence of the energy transfer from kinetic energy to gravitational energy based on their observations of the Giant Pendulum. They then concluded with a statement regarding how the Giant Pendulum displays energy transfer. Three students--Sheldon, Chris, and Gerrell--did not provide a claim, evidence, or reasoning about energy evident in their exhibit. There was no mention of energy and no observable evidence stated about how energy was demonstrated in their exhibit. The remaining students who received a rating of either 3 or 2 provided some combination of claim, evidence, and reasoning in their statements; however, not all of these elements were present.

Students' Understandings of Energy: Model Development of the Flywheel Exhibit

A group of students demonstrated understanding of forms and transformation of energy using a model (see Appendix D) that they developed on chart paper to depict the Flywheel interactive science exhibit. Their model represented kinetic energy, gravitational energy, chemical energy, and elastic energy using various colors. The arrows represent the transformation of energy as the person pedals to make the flywheel move (see Appendix D).

Sharon took the opportunity to interview this group of students to determine whether they were able to translate what they had learned in class about forms and transformation of energy to the working of the Flywheel exhibit using their own model depicted on chart paper.

Excerpt 1:

1.1 Sharon What science center exhibit did you chose to demonstrate energy transfer?

1.2 Darryl: We did the flywheel from the science center because it seemed like it had the one with the most energy… and the most conversions because it's going from elastic to kinetic because you've got to push the pedals across for it to go to kinetic energy. And it's gravitational energy because of the seat—you're sitting up on the seat. And… what is that?

1.3 Aaron: Chemical energy…

1.4 Darryl: And it's chemical energy because the person moving his legs--that's chemical energy. And basically, we colored these red because when the chain is moving around. That's kinetic energy. And we colored the chain gray because it's stretching around—the chain. The chain is stretching around…

1.5 Aaron: The chemical energy comes from your body, and the chemical energy—it doesn't come from your feet moving, but it comes from the nutrients in your body. And so that's chemical energy. And so when you start pedaling, that starts doing kinetic energy motion. And then the chain—that's continuous of the kinetic energy. But in the middle, right there, it starts to have elastic

> energy—at the same time it has kinetic energy—so we really didn’t know how to show that. So we had to explain it to people.

Aaron and Darryl, in their interview with Sharon, explain why they chose the Flywheel exhibit as their model to develop and construct on paper (1.2). They also explain that they depicted the various forms of energy with different colors (1.4). Darryl reasons that energy is transformed from elastic to kinetic because one has to “push the pedals across for it to go to kinetic energy.” He also talks about gravitational energy “because of the seat” he is sitting on. Darryl continues to reason that the Flywheel exhibit also demonstrates chemical energy because of “the person moving his legs--that’s chemical energy.” And Darryl claims that the chain moving around is kinetic energy. Similarly, Aaron states that moving the legs is chemical energy (1.4). In contrast to Darryl’s reasoning, Aaron states that the chemical energy comes from the nutrients in the body. However, opposed to Darryl’s reasoning about where the energy comes from, Aaron states that the chemical energy comes from the body, meaning that it does not come from his feet moving, but rather it comes from the nutrients in the body. He adds that when one starts pedaling, kinetic energy is formed, and he defines kinetic energy as “motion.” Aaron adds that the continuous movement of the chain is the result of the kinetic energy. However, he points out that “in the middle, right there, it starts to have elastic energy—at the same time it has kinetic energy” (1.5). Aaron claims that they do not know how to visually represent two energies working together, so they had to give verbal explanation to others in the class. The dialogue between Sharon, Aaron, and Darryl regarding the energy conversions in the Flywheel exhibit shows evidence that learning has occurred in class and that these students were able to translate that knowledge into their understanding of the Flywheel exhibit. Sharon’s conversation with

Aaron and Darryl reveals that the students are able to translate their understanding of energy concepts developed in class to the Flywheel exhibit at the USC.

Sharon continues the focus-group interview with their model of the flywheel (see Figure 5) and the students' visits to the science center. The model was a visual representation of how the flywheel provided a representation of the concepts of energy (i.e., kinetic, gravitational, and chemical).

Excerpt 2:

2.1 Sharon Okay, did this model [referring to Figure 5] that you made help you learn a science idea… about all these different types of energy?

2. 2 Aaron: Yes, because at first when I was doing the engine conversion on a piece of paper, I had to start over because I forgot all about the elastic energy. Elastic energy is when something stretches out or bends. So I had to think about it, and once I got into the kinetic energy, I skipped the elastic energy part. So, I had to start over. I remembered that elastic energy… um… starts off ,and so we had to go back down to the science center and look at it one more time so I'd know if it's elastic energy or not—you know, a conversion.

2.3 Sharon: How many times did you actually have to look at the exhibit at the science center to really get a full idea of all these different types of energy?

2.4 Darryl: Five times…We didn't go five times… I go a lot.

2.5 Sharon: As a group, you went about how many times?

2.6 Darryl: Three times.

2.7 Sharon: And so each time you went, you learned something different about the concept of energy?

2.8 Darryl: Yeah, because chemical energy… I really didn't have a good understanding of that until this Flywheel exhibit.

2.9 Sharon: Before you went through this project of doing something like this… initially, if you had gone to the science center and just went to that particular exhibit… could you have gone into this much detail?

2.10 Darryl: I don't think I would—I probably wouldn't have known how to draw it because if I only went, like, once.

2.11 Joshua: Well, if we'd only been to the science center once, we wouldn't have known how a flywheel actually works, and we wouldn't have learned as much stuff as we have now… the different types of energy. And it would be hard to just draw it from what we know, like the engine conversion and what it actually means.

2.12 Sharon: Would you like to add anything, Anthony?

2.13 Anthony: Yeah, I think he was right, too, but just… we just forgot to draw this part. And this is like the only flaw that we had.

2.14 Darryl: Yeah, but if we would have worked on it after the first time we did it… it was incorrect. But even though we lost it, we could have fixed it. But we didn't have the chemical energy part and the elastic energy part. And so we went once, and if we didn't look at it again, we would have had it wrong.

The exchange in Excerpt 2 was revealing when students stated that just visiting the science center once to develop a model was not enough. Aaron discusses how his model had to be revised because he had forgotten the concept of elastic energy in his first attempt to construct his model (2.2). Students commented that it took several visits to the science center in order to gain a clear understanding of energy transformation as related to the flywheel (2.4-2.10). By examining and observing the Flywheel exhibit during approximately three visits, they were able to gain a better understanding of the concept in order to construct their model. Joshua expounds that if they had gone only once, they would not have learned about the different types of energy, and it would have been difficult to develop or draw the model, know what it actually means, and understand how the flywheel works (2.10). Anthony confirms that if they had not gone back to view the science center exhibit, they would not have been able to fix the flaw in their model (2.11). The students in the group agree in response to their learning being directly related to the number of times they visited the USC to view the Flywheel exhibit. According to Fogelman, McNeill, and Krajcik (2011), when using curriculum units designed to facilitate deep conceptual understanding, students need sufficient time to actively engage in learning activities and to integrate their understandings.

In conclusion, Sharon also asked students about the Flywheel exhibit and generated a discussion about the types of energy they studied in the classroom.

2.15 Sharon: How has this exhibit [the Flywheel] helped you to learn more about the concept in class? How has it helped you?

2.16 Darryl: Yeah. It has potential energy, which is changed to kinetic energy, which helps cars release energy that is generated from engines. So this is an important thing for cars.

2.17 Sharon: This is a good model of what?

2.18 Darryl: This is a good model of… it’s not really a model of something, but it’s a model. It’s good for learning how to help learn about energy. Like, you can learn about how energy is being stored. If it’s being stored energy, you’re not

> using it. It can change. You add the energy. I can add energy by pedaling harder.

Sharon gets students to talk more about how the exhibit has helped them learn more about the forms and transformation of energy (2.15). Darryl has learned the concept of kinetic and potential (gravitational) energy related to the Flywheel exhibit. This is evident in his statement regarding potential energy being changed to kinetic energy, which helps cars release energy that is generated from engines (2.16). Sharon introduces the idea of a model, and Darryl responds that the exhibit is not really a model of something but that it is a model for learning about how energy is stored (2.18). Darryl's thinking is in line with Schwarz et al. (2009) in that the IQWST curriculum requires students to build understanding of scientific models that are abstract, simplified representations of a system or phenomena that generate explanations and predictions. Students were able to articulate how the Flywheel exhibit was a model of how potential (gravitational) energy in the pedal was converted to kinetic energy, which caused a release in energy. The Flywheel exhibit shows how a car engine works. Darryl was able to articulate and apply the forms and transformation of energy involved in the Flywheel interactive science exhibit.

Implications

The implications of this study are three-fold: (a) implementing a standards-based augmented curriculum for improved achievement and science learning; (b) analysis of students' presented videos reveals scientific explanations; and (c) extended time on informal learning projects improves scientific explanations.

Standards-based Augmented Curriculum for Improved Achievement and Science Learning

Based on the findings, the study implies that with or without the augmentation of science exhibits, students will achieve with a well-designed and well-developed curriculum, such as the IQWST. This finding concurs with Geier et al.'s (2008) claim that historically underserved urban students are able to realize standardized achievement gains when teachers use standards-based, inquiry science curriculum.

This study is an example of how to provide access to urban African-American students with an opportunity to translate their conceptual understanding and apply their learning about energy concepts by moving between two spaces: the school and the USC. Dierking et al. (2003) and Falk et al. (2003) concur that exhibits with a STEM focus can indeed prepare students for increased learning in science when it is connected to what is taught in the classroom. Likewise, Bevan, Dillon, Hein, MacDonald, Michalchik, Miller, and Yoon (2010) assert that learning in an informal environment results in conceptual understanding of school science topics. Hung et al. (2012) have pointed out that improved learning is the outcome when students are given opportunities to observe science center exhibits that relate to topics discussed in the classroom. These authors further have argued that learning in both formal and informal contexts provides students with opportunities to deepen their knowledge about scientific topics. Thus, there is a need for students to have many opportunities to connect what they are learning in the classroom to learning environments outside of the classroom (Hung et al., 2012). As stated by Cox-Peterson et al. (2003), integrating the curriculum, exhibits, and student inquiry helps to prepare students for a meaningful visit to the science center. Using a standards-based researched curriculum, such as IQWST, in which achievement gains are realized provides an attainable context for augmenting the curriculum with science center exhibits to develop students' conceptual understandings. In-depth research on student learning that takes place at the intersection of the formal and informal should be continued.

Analysis of Students' Presented Videos Reveals Scientific Explanations

A novel way of analyzing data came to the surface because the teacher had students create a video presentation of their work. As this video analysis unfolded, a pattern emerged in the data indicating that the time spent at an exhibit in a science center focused on developing the concept of energy yielded greater student understanding of the concept as demonstrated in students' scientific explanations. In other words, increased student learning occurs when teachers spend a good amount of time at an exhibit with their students to make sure they understand the relationship between the concepts learned in the classroom and the concepts represented in informal learning environments, such as informal science centers. Afterwards, students can take what they learn and apply their understanding through project-based learning—in this case, a video project. For example, in O'Neill and Barton's (2005) study, students created a documentary project in an informal afterschool context that was intended to define student ownership of science learning as an outcome. In other words, students translate scientific explanations to understand energy-related science center exhibits.

Extended Time on Informal Learning Projects to Improve Scientific Explanations

Some may argue that spending extended time with exhibits to enhance student learning may take away time needed to cover the numerous topics that are required of teachers due to district or state mandates. The data in this study suggest that the extended time teachers spend with students can actually provide quality opportunities beyond the classroom to improve student achievement and learning. This extended time and support by the teacher actually increased students' ability to articulate their learning of difficult concepts such as the topic of energy using scientific explanations. This type of learning using an integrated curriculum with both formal and informal components can be cultivated when teachers are provided with professional development training on how to develop students' knowledge using exhibits, sufficient time to develop concepts with students using exhibits, and support from administration to modify the time required to cover certain topics in the curriculum with more time spent on those topics, such as energy, that require creative teaching methods. The more students are exposed to this type of learning, the more likely their scientific explanations will improve because science is fundamentally about explaining the world around us.

CHAPTER 5

CONCLUSIONS OF THE STUDY

Introduction

This study consists of a trilogy of articles within a common framework—the integration of formal and informal science education/learning. The teacher (Cathy) in this study implemented the IQWST curriculum and integrated it with the science exhibits in collaboration with the informal educator (Roger). This study was anchored in (a) the emergence of a third space, (b) teacher discursive moves in developing common knowledge, and (c) student science application and achievement. The study focused on the collaboration between formal and informal educators, classroom discourse, and students' science learning and achievement. A summary of each article is presented.

Summary of Article One

The purpose of this first article was to characterize the conversations of formal and informal science educators as they attempted to implement a standards-based curriculum with the support of science center exhibits. Accomplishing this goal required the discovery and exploration of a "third space" meant for personal growth—a space that provides insights into the distance and proximity of the interplay between formal and informal science educators. The research question that guided this article was as follows: What is the character of an emerging third space created through the interplay of a community of educators when they attempt to implement the standards-based IQWST curriculum with support of resources from the Urban Science Center? A case study featuring audio-recorded semi-structured interviews and field notes provided the methodological framework for this study.

This study provides insights into the distance and proximity of the interplay between formal and informal science educators at the emergence of a third space. The study also helps identify the position of formal and informal agendas that involve the nature of science learning in a third space. This study also provides a platform for future research conducted on the intersection of formal and informal institutions to improve science learning in schools. The theoretical framework includes (a) a third space for personal growth and (b) a hybrid third space for knowledge development.

The results and discussion revolve around five challenges that characterize the emergence of a third space: (a) to begin a science lesson without the focus on terminology, (b) to down-play or "dumb-down" science exhibits, (c) to explore lesson structure, (d) to decipher the meaning of model/modeling, and (e) to learn science content or explore science exhibit exploration. However, these challenges have been considered opportunities for personal growth. The results of this study suggest that a third space allows for reflection and transformation within formal-informal collaboration and communication.

Summary of Article Two

The purpose of this second article was to study the discourse between a middle school science teacher and her students as the teacher developed students' conceptual understandings in a unit on energy and energy transformation. The intention of the teacher was to develop student understanding of the concepts of energy and science inquiry processes before she took the students to observe energy-related exhibits at the urban science center. The two research questions formulated for this study were as follows: (1) What discursive interactions does a middle school science teacher make as she attempts to develop common knowledge related to the concept of energy and science processes? (2) How does the discourse reflect a sociocultural perspective on learning? This was an interpretive discourse study that adopted notions advocated by Mortimer and Scott (2000) as well as Hoon and Hart (2006). Selected IC recordings were transcribed verbatim. Student workbooks that contained activities were collected as evidence of the work completed in the classroom.

The study is significant in three ways: (a) it is important to understand how a teacher conducts whole class discussion and how she develops conceptual understanding of science concepts on the topic of energy in order to establish common knowledge over time because this understanding provides insights into the nature of classroom discourse; (b) the teacher enacted a standards-based science curriculum from a sociocultural perspective; therefore, it is important to know whether classroom discourse parallels the goals of the curriculum; (c) the study provides a platform for future research conducted on developing common knowledge through classroom discourse in order for teachers and administrators to be aware of how this plays out in the reality of an urban classroom consisting primarily of African-American students. The theoretical frameworks include the following: (a) a sociocultural perspective of learning and science classroom discourse and (b) related science classroom discourse studies. The findings of this study are discussed in the context of teacher-students' classroom discourse as the teacher uses lessons from the IQWST workbook. Four instructional events were selected for discourse analysis: (a) focusing on the inquiry process; (b) understanding of kinetic energy; (c) formulating scientific explanations; and (d) translating energy transformation. The discourse-excerpts representing the aforementioned instructional events revealed four teacher behaviors: (a) teacher-posed questions, (b) teacher-explanations, (c) teacher responses, and (d) teacher references to past learning. Of these teacher behaviors, teacher-posed questions dominated, and these consisted of fill-in-the-blank, affirmation, second-order, descriptive, and explanatory questions. Based on the findings, two related implications emerged as worthy of discussion: (a) the teacher's struggle with dialogic discourse, a communicative approach that fosters common knowledge through a social process, and (b) the need for professional development that fosters dialogic discourse.

Summary of Article Three

The purpose of this third study was to investigate whether the standards-driven, project-based Investigating and Questioning Our World Through Science and Technology (IQWST) curriculum unit on forms and transformation of energy augmented with science center exhibits had a significant effect on urban African-American seventh-grade students' achievement and learning. The research questions posed for this study included the following: (1) Are there significant gains in students' achievement scores from pre-test to post-test as a result of the intersection between IQWST unit and the interactive museum exhibits? (2) Are there statistically significant gains in students' achievement scores from pre-test to post-test as a result of including interactive museum exhibits as part of an IQWST unit on forms and transformation of energy? (3) What conceptual understandings do sub-groups of the same African-American students reveal based on the USC exhibits that demonstrate forms and transformation of energy?

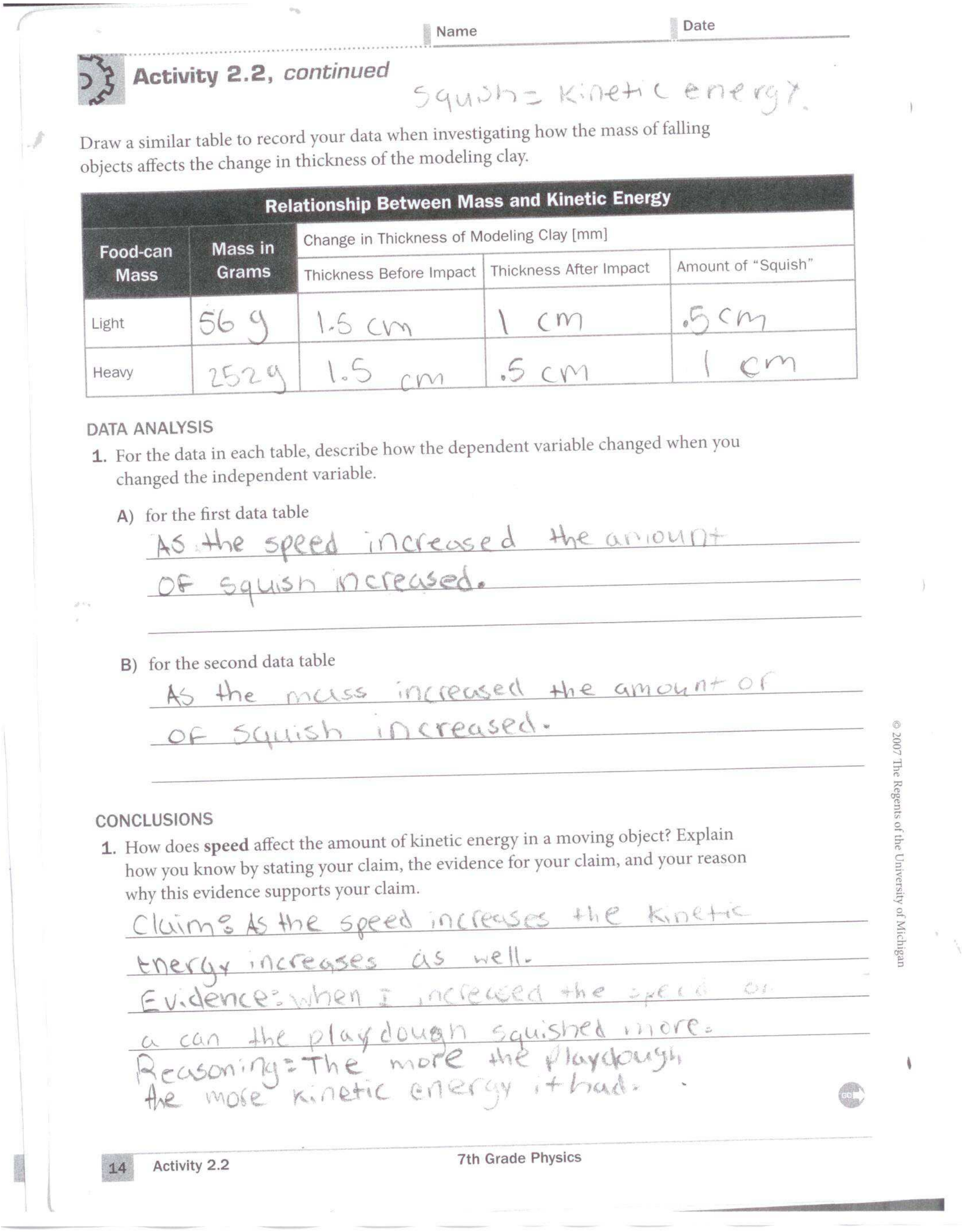
A mixed-method approach consisting of qualitative methods (classroom discussion, focus-group interviews, and student video creation) and quantitative methods (a multiple-choice and open-ended question instrument) were used to collect data.

The study is significant in four ways: (a) it contributes to the knowledge base of the IQWST program; (b) it demonstrates how to develop conceptual understanding of science concepts among urban students; (c) it illuminates how teachers may help urban students who come to school lacking prior knowledge about subject matter or who are not fortunate enough to experience learning outside the context of school that links such knowledge with school science; (d) it lays the theoretical and methodological foundation for future researchers who wish to study the combination of formal and informal teaching strategies on students' science learning and achievement.

The theoretical framework for this study consisted of (a) school science learning augmented with informal learning for urban minority students and (b) a literature review on students' understanding of forms and transformation of energy. The IQWST Unit Achievement Test (IUAT) indicated that students in the experimental group who were taught with the IQWST curriculum unit augmented with science center exhibits achieved scores about the same as students in the control group, who were taught with only the IQWST curriculum unit. However, both the experimental groups and control groups revealed significant gains from pre-test scores to post-test scores. The qualitative analyses of data indicated that students displayed reasonable understanding of the forms and transformation of energy. Students were also able to explain science exhibits using their understanding of the energy concepts developed in class. The findings confirm that underserved urban students' learning can be enhanced with an augmented standards-based curriculum unit. These students also can realize significant achievement gains when professionally developed and administration-supported teachers use standards-driven science curriculum, whether augmented or not. However, the results suggest that the use of science center exhibits can provide a context within which to observe whether students are able to translate and apply knowledge constructed in the classroom.

This study reveals the following insights: (a) science teachers and informal science educators can facilitate their understanding at the emergence and intersection of a third space because both formal and informal agendas involve science learning, communication, and collaboration; learning mediated through dialogue occurs across time and should be studied across time with the goal of conceptualizing the interactive cognitive development and learning of the teacher; (c) science centers can provide a context to observe whether students are able to translate classroom-constructed knowledge to the study of exhibits.

APPENDIX A: IQWST ACTIVITY 2.2



Name | Date

Activity 2.2, *continued*

squish = kinetic energy.

Draw a similar table to record your data when investigating how the mass of falling objects affects the change in thickness of the modeling clay.

Relationship Between Mass and Kinetic Energy

Food-can Mass	Mass in Grams	Change in Thickness of Modeling Clay [mm]		
		Thickness Before Impact	Thickness After Impact	Amount of "Squish"
Light	56 g	1.5 cm	1 cm	.5 cm
Heavy	252 g	1.5 cm	.5 cm	1 cm

DATA ANALYSIS

1. For the data in each table, describe how the dependent variable changed when you changed the independent variable.

A) for the first data table

As the speed increased the amount of squish increased.

B) for the second data table

As the mass increased the amount of squish increased.

CONCLUSIONS

1. How does **speed** affect the amount of kinetic energy in a moving object? Explain how you know by stating your claim, the evidence for your claim, and your reason why this evidence supports your claim.

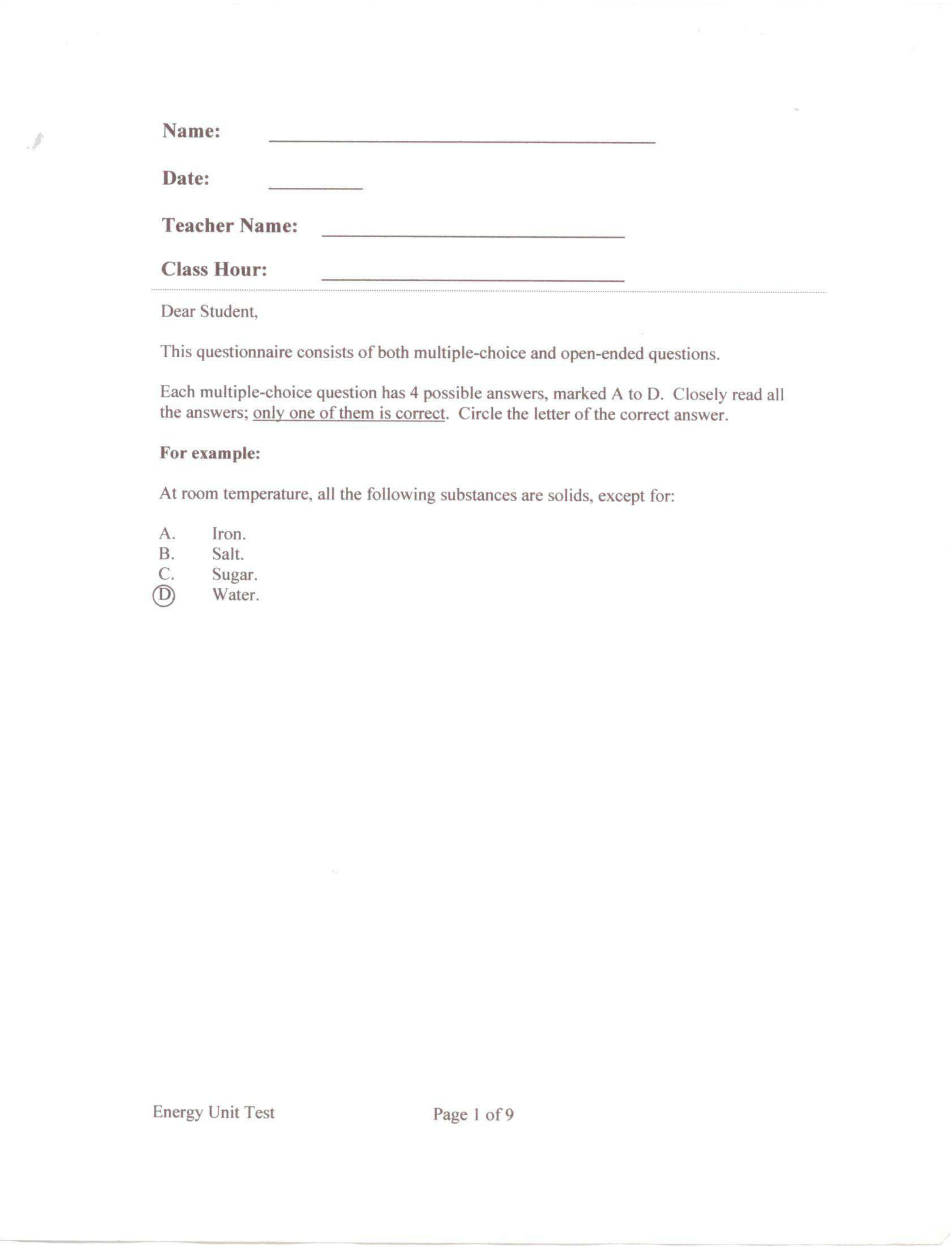
Claim: As the speed increases the kinetic energy increases as well.

Evidence: when I increased the speed of a can the playdough squished more.

Reasoning: The more the playdough the more kinetic energy it had.

14 Activity 2.2 7th Grade Physics

APPENDIX B: IQWST UNIT ACHIEVEMENT TEST (IUAT)



Name: ______________________________

Date: ________

Teacher Name: ________________________

Class Hour: ________________________

Dear Student,

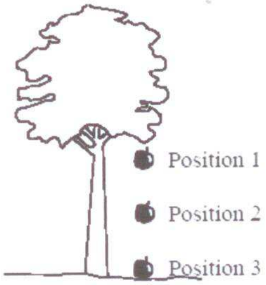
This questionnaire consists of both multiple-choice and open-ended questions.

Each multiple-choice question has 4 possible answers, marked A to D. Closely read all the answers; <u>only one of them is correct</u>. Circle the letter of the correct answer.

For example:

At room temperature, all the following substances are solids, except for:

A. Iron.
B. Salt.
C. Sugar.
[✓ D] Water.



The drawing shows an apple falling to the ground. Position 3 is the instant **before** the apple hits the ground. Use the drawing to answer questions 1-3.

1. In which of the three positions does the apple have the most gravitational energy.
   A. Position 2
   B. Position 1
   C. Positions 1 and 3
   D. Position 3

2. In which positions is the apple's total energy the greatest?
   A. Position 1
   B. Position 2
   C. Position 3
   D. It has the same total energy in all three positions.

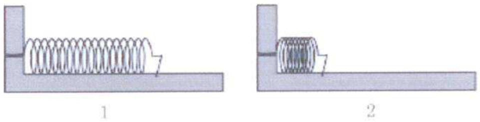
3. In which of the three positions does the apple have the most kinetic energy?
   A. Position 2
   B. Position 1
   C. Positions 1 and 3
   D. Position 3

4. Electrical energy is used to power a lamp. Is the amount of light energy emitted by the lamp more than, less than, or the same as the amount of electrical energy used?
   A. More than
   B. Less than
   C. The same as

   Explain your answer.

Correct Responses		Points
4a	Some of the electrical energy has been transformed into other types of energy such as thermal energy.	1
Incorrect Responses		
4b	Do not recognize energy dissipation	0
4c		0

5. Spring 1 and Spring 2 are identical springs. Spring 1 is pushed together a little and clamped in place. Spring 2 is pushed together a lot and clamped.



Which spring has more elastic energy?

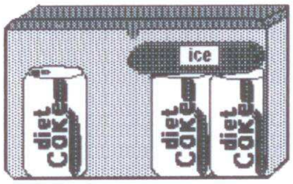
- A. Spring 1
- ***B. Spring 2***
- C. Both springs have the same energy
- D. You cannot tell unless you know what the springs are made of.

6. Where does the energy stored in food come from?

- A. Fertilizers
- **B. The sun**
- C. Vitamins
- D. The soil

7. People get energy from the food they eat. In what form is energy stored in food?
   - A. Thermal
   - **B. Chemical**
   - C. Gravitational
   - D. Elastic

8. Tenisha takes a Coleman cooler that is at room temperature and places a few room temperatures cokes in it. She takes a bag of ice out of the freezer and places it in the cooler. She then closes the cooler. After a while she opens the cooler and finds that the cokes and the air in the cooler are colder than when she originally closed the cooler



   A. Which objects in the cooler lost thermal energy while the cooler was closed? (Circle as many as appropriate)

   ice ***cokes*** ***air in the cooler*** none of these

   B. Which objects gained thermal energy? (Circle as many as appropriate)

   ice cokes air in the cooler none of these

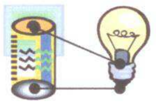
   C. Did any object's temperature increase while the cooler was closed? Explain.

Correct Responses		Points
Yes, the temperature (of ice) increased. Thermal energy is transferred from other substances (the air and cokes in the cooler) to the ice. Its temperature increased as a result of its thermal energy increasing	Yes the temperature of something (do not mention the ice) increases, providing the correct explanation as to the left	1
Partial correct Responses		
Yes, the temperature of ice increased, but does not give right explanation	Yes the temperature of something (do not mention the ice) increases, without explanation or with incorrect explanation	0
Incorrect Responses		
If the answer is "No" or other objects instead of "ice" such as cokes, air in the cooler and etc. If the answer to the first part of the question is incorrect, the explanation will be also incorrect	no answer	0

10. Consider four different situations: A) a ball bouncing on the floor, B) a candle burning, C) a lit light bulb connected to a battery, and D) two children moving up and down on a see-saw.


A


B


C


D

Which of the four situations A, B, C, and D, involves the following types of energy conversions? Write the letters in the appropriate boxes. Note – a situation can involve more than one type of energy transformation.

Kinetic → Gravitational	Chemical → Light	Chemical → Kinetic	Electrical → Thermal	Chemical → Electrical
A, D, (B-hot air rising)	***B***	***D, B-hot air rising***	***C***	***C***

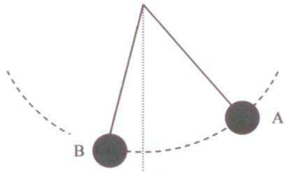
Correct Responses		Points
Kinetic → Gravitational	A, D, & B (option A)	3
	Any two of A, D, & B (option B)	2
	Any one of A, D, & B (option C)	1
	Option A or option B or option C + C	Same as option A, B, or C minus 1 point
	Only C	0
	Any other answer or no response	0
Chemical → Light	B	1
	B & C	1
	B & A or B & D	0
	Any other answer or no response	0
Chemical → Kinetic	D & B	2
	Either D or B	1
	D or B with C and/or A	0
	Any other answer or no response	0
Electrical → Thermal	Only C	1
	Any other answer or no response	0
Chemical → Electrical	Only C	1
	Any other answer or no response	0

11. A renewable energy source is a source that will not run out. Which is an example of the use of such a source?

A. A coal furnace heating a house.
B. A windmill pumping water on a farm.
C. A kerosene lamp lighting a room.
D. A diesel truck traveling along a road.

Use the drawing of the pendulum to answer questions 9 through 13.

When the pendulum swings, gravitational energy is transformed into kinetic energy and back. The following drawing shows the pendulum at positions A and B, **a few seconds after being released**. Position A is not the highest point the pendulum reaches.



12. How does the gravitational energy in position A compare to the gravitational energy in position B?

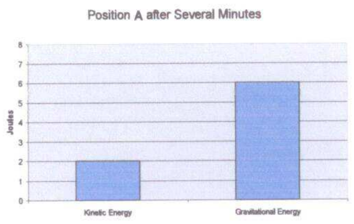
A. A is greater than B
B. A is less than B
C. Both are the same
D. Neither have gravitational energy.

13. The pendulum's gravitational energy decreases as:

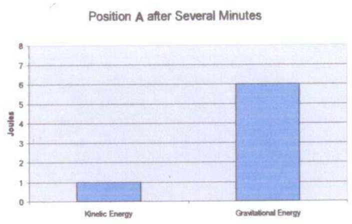
A. The pendulum gets higher.
B. The pendulum swings slower.
C. The pendulum's mass increases.
D. The pendulum swings faster.

15. After swinging back and forth for several minutes the pendulum once again moves through position A. Which of the following charts correctly shows the kinetic and gravitational energies the pendulum has now?

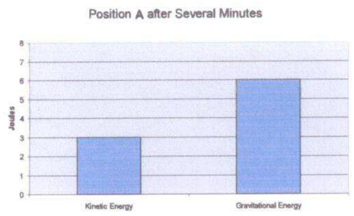
a. Chart I **_b. Chart II_** c. Chart III d. Chart IV



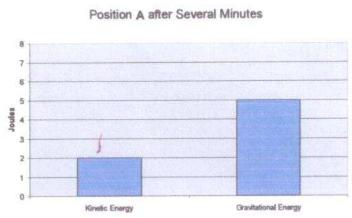
I



II



III



IV

16. Explain why you chose the graph you did.

Full answer includes: (1) The gravitational energy does not change, since it is still at position A. (The mass and height does not change.) (GE); (2) The KE has decreased since there is less total energy than before because some of the energy has been transferred to the surroundings. (KE)

Correct Response (include 2 parts)	Points
GE & KE	2
Partial correct Responses (includes 1 part)	1
Only KE	
Only GE	
Incorrect Responses	0
Any other response	

APPENDIX C: A COMPLETE LIST OF CLASSROOM EVENTS WITH DAYS AND DATES

All activities are taken from the following IQWST Physics Unit: “Why Do Some Things Stop and Others Keep Going?”

Teaching Days	Teaching Activities	Learning Activities
Day 1 Jan 5	Pre-Test for Physics Unit	Students took the pre-test in a traditional paper/pencil format
Day 2 Jan 7	Discuss kinetic energy Engaged students in generating questions about “Why some things stop and others keep going?” observations in groups	Students defined two variables that determine kinetic energy, analyze data, and make predictions about the relationship between energy and mass-Activity 1.1
Day 3 Jan 8	Reviewed answers to Activity 2.1 (Objects in Motion); Discussed independent and dependent variables	Same as Day 2 and did Objects in Motion (2.1); Kinetic energy investigation (2.2)
Day 4 Jan 12	Wrapped up Kinetic Energy Investigation (2.2); Began KE predictions(2.3) ; Discussed reading on Impact Crater; Introduced claim, evidence, and reasoning; Developed students’ understanding that mass and speed have an impact on kinetic energy	Identify two factors (mass and energy) that determine how much kinetic energy something has and analyze data based on data collection from previous lesson where they had to drop cans into the modeling dough
Day 5 Jan 14	Completed KE predictions(2.3); Discussed the concept of gravitational energy; ; Explained pendulum in relation to gravitational energy	Analyzed data to find two things related to gravitational energy; Students brainstormed about the connection between height & energy (3.1); Began energy conversion diagrams act. (3.2)
Day 6 Jan 19	Completed (3.1); Began homework on ; Modeled how to fill out a data chart; Guided classroom discussion	Continued (3.2)
Day 7 Jan 20	Discussed models/modeling and data patterns; Discussed (3.2),	Continued (3.2)
Day 8 Jan 21	Discussed (3.2) and was used as a quiz	Completed (3.2) quiz
Day 9	Continued lesson on energy	Students worked

Jan 22	conversions, focusing on what two things affect kinetic energy and what determines the amount of gravitational energy an object has	independently to complete their charts, a class data chart was developed, each group of students put information on the board
Day 10 Jan 30	Began act. 4.1, focus of the lesson was on elastic, kinetic, and gravitational energy, engaged students in classroom discussion	Engaged in classroom discussion on elastic, kinetic, and gravitational energy, watched a video examples of a basketball dropping and a soccer ball being kicked- conclusion- as the ball drops GE is converted to KE; when the ball hits the ground, KE is changed to elastic energy as the ball is compressed
Day 11 Feb 1	Lesson 4.1 reviewed, Introduced claims, evidence, and reasoning	Engaged in completing their lessons
Day 12 Feb 3	IQWST quiz given to students	Students reviewed for quiz and then took the quiz.
Day 13 Feb 4	Introduced students to energy transfer	Students worked on act. 5.1 & 5.2
Day 14 Feb 5	Same as Feb 4th	Same as Feb 4
Day 15 Feb 8	Discussed how to set up blog, helped students to understand the science center integration, and discuss rubric expectations for videos or podcast activity, discussed journaling and what it means to reflect	Students set up gmail account to do blogs,
Day 16 Feb 11 Museum visit	Teacher explained expectations for visit to the science center – behavior sheet and guided students on a pre-visit tour of the science center	Students toured the science center specifically the exhibits related to lesson #2, 3, & 4
Day 16 Feb 11	Teacher introduced journals to students by giving them an overview of how to write in their journals.	Students organized and decorated their journals
Day 17 Feb 17	Teacher showed a movie ON WHAT	Students watched a movie

Day 18 Feb 18	Introduced Triple Venn Diagram as a visual to help students understand the relationship between kinetic energy, thermal energy, and temperature	Students worked on act. 6.1 in groups in order to dialogue about the lesson
Day 19 Feb 23	Modeled how to go to website to complete blogs, emphasized journaling by including drawing, explanations, observations, and additional questions	Students worked on their blogs and their IQWST Physics Unit Journal
Day 20 Feb 25 Museum Visit	Teacher took the students on another trip to the museum to observe the exhibits and make connections to energy transformations Teacher directed the students to write in their journals	a.) Students visited the Science Center and observed the Flywheel, Simple Machines, and the Pendulum b.)After the exhibit visit, students debriefed with the teacher and began writing in their journal.
Day 21 Mar 2	Direct instruction on Lesson 6 (thermal energy) and began act. 7.1(sound energy)	In lesson 6, students defined and developed an understanding of thermal energy and in act. 7.1 began developing their understanding of sound energy
Day 22 Mar 11 Museum Visit	Teacher reviewed beliefs on journal writing and gave examples Teacher took the students to the science center to observe the exhibits again so that they could write about the observations	Students read meaning of scientific observations provided by the teacher and picked one journal to focus their writing on. Students visited the science center to focus on a specific exhibit to develop their journal writing and understanding of the concept of energy
Day 23 Mar 15		Students worked on blogs
Day 24 Mar 16	Teacher reviewed act. 7.1 sound energy, students brainstormed what they knew about sound, conducted classroom conversation on sound energy	Students participated in classroom discussion on sound energy.
Day 25	Teacher reviewed act. 8.1 and	Students conducted

Mar 17	guided students in their understanding of chemical energy	experiments to gain a better understanding of chemical energy. Students worked in groups to collect data.
Day 26 Mar 18	Teacher did demo of act. 8.2. The purpose of the activity was to investigate energy transformations during chemical reactions which include kinetic energy.	Students worked in groups, making predictions and observations as data collection, model used was an alcohol burner, ring stand, and cup attached.
Day 27 Mar 19	Teacher referenced predictions, observations, and evidence in an attempt to assist the students in developing their understanding of chemical energy and chemical energy at work. Reviewed hw assignment	Students worked individually to fill out their workbook pages.
Day 28 Mar 22	Concluded act. 8.4 pg. 105 and discussion, directed students on how to fill out chart on energy conversions and transfer, made some connection to what they were learning to the science exhibits	Completed act. 8.4 in their workbook
Day 29 Mar 23	Facilitated discussion on electrical energy and lectured using ppt, reviewed hw, instructed students to complete act. 9.1 pg. 115 on their own	As students developed their understanding of electrical energy, they took notes from what was presented on the ppt.
Day 30 Mar 24	Directed students on how to complete act. 9.1 to continue their understanding of electrical energy	Students worked in pairs to complete act. 9.1, noticed some students drew diagrams to demonstrate their understanding of electrical energy

APPENDIX D: STUDENTS' FLYWHEEL MODEL

REFERENCES

Aguiar, O. G., Mortimer, E. F., & Scott, P. (2010). Learning from and responding to students' questions: The authoritative and dialogic tension. *Journal of Research in ScienceTeaching*, *47*(2), 174-193.

Alexander, R. J. (2000) Culture and pedagogy: international comparisons in primary education (Oxford, Blackwell).

Alexander, R. (2004). Still no pedagogy? Principle, pragmatism and compliance in primary education. *Cambridge Journal of Education*, *34*(1), 7-33.

Anderson, R. C., & Nagy, W. E. (1993). *The vocabulary conundrum.* (Technical Report No. 570). Champaign, Il: University of Illinois at Urbana-Champaign.

Barmy, P., Kind, P., and Jones K. (2008). Examining changing attitudes in secondary school science. *International Journal of Science Education* 30(8), 1075-93. www.exploratorim.edu/cils/research/mapping.html.

Barnes, D. (1976). *From Communication to Curriculum*, Harmondsworth: Penguin Educational.

Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education*, *94*(5), 765-793.

Bevan, B., Dillon, J., Hein, G. E., Macdonald, M., Michalchik, V., Miller, D., & Yoon, S. (2010). Making science matter: Collaborations between informal science education organizations and schools. *A CAISE inquiry Group Report, Center for Advancement of Informal Science Education (CAISE).*

Bevan, B., Semper, R. (2006). Mapping Informal Science Institutions onto the Science

Education Landscape, *The Center for Informal Learning and Schools,* www.exploratorim.edu/cils/research/mapping.html

Bhabha, H. K. (1994). *The location of culture.* New York: Routledge.

Bouillion, L. M., & Gomez, L. M. (2001). Connecting school and community with science learning: real world problems and school–community partnerships as contextual scaffolds. *Journal of research in science teaching*, *38*(8), 878-898.

Braund, M., & Reiss, M. (2006). Towards a more authentic science curriculum: The contribution of out-of-school learning. *International Journal of Science Education*, *28*(12), 1373-1388.

Calabrese Barton, A. (2003). Teaching science for social justice. New York, NY:

Calabrese Barton, A. & Tan, E. (2009). Funds of knowledge, discourses, and hybrid space. *Journal of Research in Science Teaching,* 46, 50-73.

Calabrese Barton, A., Tan, E., & Rivet, A. (2008). Creating hybrid spaces for engaging school science among urban middle school girls. *American Education Research Journal* 45:68-103.

Campbell, D.T. & Stanley, J.C. (1963). Experimental and quasi-experimental designs for research. Boston: Houghton Mifflin.

Cazden, C. B. (2001). Classroom discourse: The language of teaching and learning. Second Edition, Portsmouth, NH: Heinemann.

Chin, C., & Brown, D. E. (2002). Student-generated questions: A meaningful aspect of learning

in science. *International Journal of Science Education*, *24*(5), 521-549.

Cox-Peterson, A., Marsh, D., Kisiel, J., & Melber, L. (2003). Investigation of Guided

School Tours, Student Learning, and Science Reform Recommendations at a Museum Of Natural History. *Journal of Research in Science Teaching, 40*(2), 200-218.

Creswell, J. W., Plano Clark, V. L., Gutmann, M. L., & Hanson, W. E. (2003). Advanced mixed methods research designs. *Handbook of mixed methods in social and behavioral research*, 209-240.

D'Acquisto, L. (2006). *Learning on display: Student-created museums that build understanding*. Association for Supervision and Curriculum Development.

Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., & Sherin, B. L. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *The Journal of the Learning Sciences*, *19*(1), 3-53.

Dierking, L., Falk, J., Rennie, L., Anderson, D., & Ellenbogen, K. (2003). Policy statement of the "informal science education" ad-hoc committee, *Journal of Research in Science Teaching,* 40 (2), 108-111.

Doll, W. E. edited by Trueit, D. (2012). Pragmatism, Postmodernism, and Complexity Theory: The "Fascinating, Imaginative Realm" of William E. Doll, Jr. New York: Routledge. Francis & Taylor Group.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational researcher*, *23*(7), 5-12.

Duit, R., & Treagust, D. F. (1998). 1.1 Learning in Science-From Behaviourism Towards Social Constructivism and Beyond.

Duit, R., & Treagust, D. F. (2003). Conceptual change: a powerful framework for improving science teaching and learning. *International journal of science education*, *25*(6), 671-688.

Duschl, R. (2003). Assessment of Inquiry. In J. M. Atkin & J.E. Coffey (Eds.), Duschl, R., & Schweingruber, H. H., and A. Shouse.(Eds.). 2007. Taking science to school: Learning and teaching science in grades K–8. *National Academies Press. Retrieved on*, *8*, 08-09.

Ebenezer, J., Chacko, S., Kaya, O. N., Koya, S. K., & Ebenezer, D. L. (2010). The effects of common knowledge construction model sequence of lessons on science achievement and relational conceptual change. *Journal of Research in Science Teaching*, *47*(1), 25-46.

Ebenezer, J., Kaya, O. N., & Ebenezer, D. L. (2011). Engaging students in environmental research projects: Perceptions of fluency with innovative technologies and levels of scientific inquiry abilities. *Journal of Research in Science Teaching*, *48*(1), 94-116.

Edwards, A. D., & Furlong, V. J. (1978). *The language of teaching: Meaning in classroom interaction*. Heinemann Educational Books.

Edwards, D., & Mercer, N. (1987c). *Common Knowledge (Routledge Revivals): The Development of Understanding in the Classroom*. Routledge.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in theapplication of Toulmin's argument pattern for studying science discourse. *Science education*, *88*(6), 915-933.

Eshach, H. (2010). An analysis of conceptual flow patterns and structures in the physics classroom. *International Journal of Science Education*, *32*(4), 451-477.

Falk, J. & Dierking, L. (1996). *Public Institutions for Personal Learning: Establishing a Research Agenda,* Washington DC: American Association of Museums.

Falk, J. & Dierking, L. (2000). *Learning from Museums.* California: AltaMira Press.

Fogleman, J., McNeill, K. L., & Krajcik, J. (2011). Examining the effect of teachers' adaptations of a middle school science inquiry-oriented curriculum unit on student learning. *Journal of Research in Science Teaching*, *48*(2), 149-169.

Fortus, David (2014) Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100, ISRAEL, +972 8-934-2493, david.fortus@weizmann.ac.il

Geier, R., Blumenfeld, P. C., Marx, R. W., Krajcik, J. S., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. *Journal of Research in Science Teaching*, *45*(8), 922-939.

Gerber, B. L., Cavallo, A. M., & Marek, E. A. (2001). Relationships among informal learning environments, teaching procedures and scientific reasoning ability. *International Journal of Science Education*, *23*(5), 535-549.

Griffin, P., & Mehan, H. (1981). Sense and ritual in classroom discourse. *Conversational Routine. The Hague: Mouton*, 187-213.

Griffin, J., & Symington, D. (1997). Moving from task-oriented to learning-oriented strategies on school excursions to museums. *Science education*, *81*(6), 763-779.

Gutiérrez, K. D., Baquedano-Lopez, P., & Tejeda, C. (1999). Rethinking diversity: hybridity and hybrid language practices in the third space. *Mind, Culture and Activity* 6(4):147, 286-303.

Gutiérrez, K. D, Rymes, B., & Larson, J. (1995). Script, counterscript, and underlife in the class-room: James Brown versus Brown v. Board of Education. *Harvard Educational Review*, 65, 445-471.

Gutiérrez, K. D. (1993, April). *Scripts, counterscripts, and multiple scripts.* Paper presented at the annual meeting of the American Educational Research Association, Atlanta, GA.

Hammond, L. (2001). Notes from California: An anthropological approach to urban science education for language minority families. *Journal of Research in Science Teaching,* 38(9), 983-999.

Harrison, A. G. & Treagust, D. F. (2000). Modelling in science lessons: Are there better ways to learn with models? *School Science and Mathematics,* 98(8) 420-429.

Hofstein, A. & Rosenfeld, S. (1996) Bridging the gap between formal and informal science learning. *Studies in Science Education,* 28, 87-112.

Hoon, S. L., & Hart, C. A cross-disciplinary analysis of science classroom discourse. *Redesigning pedagogy: Reflections of theory and praxis,* Netherlands: Sense Publishers, 191-202.

Hung, D., Lee, S. S., & Lim, K. Y. (2012). Teachers as brokers: Bridging formal and informal learning in the 21st century. *KEDI Journal of Educational Policy*,*9*(1), 71-89

Idaho Public Television. (2015). Simple machines facts. http://idahoptv.org/sciencetrek/topics/simple_machines/facts.cfm

Jolly, E. J., Campbell, P., & Perlman, L. (2004). *Engagement, capacity and continuity*: *A trilogy for student success.* Minneapolis, MI: GE Foundation.

Katz, P. (Ed.). (2001). *Community Connections for Science Education* (Vol. 2). NSTA Press.

Kimura, M. (2008). Narrative as a site of subject construction. Feminist Theory, 9, 5–24.

Kisiel, J. (2006). An Examination of fieldtrip strategies and their implementation within a natural history museum. *Science Education,* 90(3), 434-451.

Kisiel, J. (2014). Clarifying the complexities of school-museum interactions: Perspectives from two communities. *Journal of Research in Science Teaching,* (342-

367). Retrieved February 7, 2014 from DOI 10.1002/tea.21129.

Klein, C., Corse, J., Grigsby, V., Hardin, S., & Ward, C. (2001). *A Museum School: Building Grounded Theory as Two Cultures Meet.* Paper presented at the annual meeting of the American Educational Research Association. Seattle, WA.

Krajcik, J., & Reiser, B. J. (2004). IQWST: Investigating and questioning our world through science and technology. *Ann Arbor, MI: University of Michigan*.

Krajcik, J., Czerniak, C., & Berger, C (2002). *Teaching science in elementary and middle school classrooms: A project based approach.* (2nd ed.) Boston, MA: McGraw-Hill.

Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate project-based pedagogy. *Science Education*, *92*(1), 1-32.

Krajcik, J., Reiser, B. J., Fortus, D., & Sutherland, L. (2008). Investigating and questioning our world through science and technology. *Ann Arbor, MI: Regents of the University of Michigan*.

Krajcik, J. S., & Sutherland, L. M. (2010). Supporting students in developing literacy in science. *Science*, *328*(5977), 456-459.

Kyriacou, C., & Issitt, J. (2008). What characterizes effective teacher-pupil dialogue to promote conceptual understanding in mathematics lessons in England in Key Stages 2 and 3. *EPPI-centre report no. 1604R*.

Leach, J., & Scott, P. (1995). The demands of learning science concepts: issues of theory and practice. *School Science Review*, *76*(277), 47-51.

Lehesvuori, S., Viiri, J., & Rasku-Puttonen, H. (2011). Introducing dialogic teaching to science student teachers. *Journal of Science Teacher Education*,*22*(8), 705-727.

Lehesvuori, S., Viiri, J., Rasku-Puttonen, H., Moate, J., & Helaakoski, J. (2013). Visualizing communication structures in science classrooms: Tracing cumulativity in teacher-led whole class discussions. *Journal of Research in Science Teaching*, *50*(8), 912-939.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Ablex PublishingCorporation, 355 Chestnut Street, Norwood, NJ 07648 (hardback: ISBN-0-89391-565-3; paperback: ISBN-0-89391-566-1).

Lincoln, Y & Guba, G. (1985). *Naturalistic inquiry* (Vol. 75). Egon G. Guba (Ed.). Sage.

Linn, M. (2003). Technology and science education: starting points, research programs, and trends. *International Journal of Science Education*, *25*(6), 727-758.

Martinello, M. L., & Kromer, M. E. (1990). Developing and assessing lower-ses hispanic children's inferential thinking through a museum-school program. *Journal of Elementary Science Education*, *2*(2), 21-36.

Marx, R.W., Blumenfeld, P.C., Krajcik, J.S., Fishman, B., Soloway, E. (2004). Inquiry-based science in the middle grades: Assessment of learning in urban systemic reform. *Journal of Research in Science Teaching,* 41(10), 1063-1080.

McFarlane, A., & Sakellariou, S. (2002). The role of ICT in science education. *Cambridge Journal of Education*, *32*(2), 219-232.

McNeill, K. L., & Krajcik, J. S. (2011). Supporting Grade 5-8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing. New York: Pearson, Allyn, & Bacon.

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education*, *94*(2), 203-229.

Means, B. (1998). Melding authentic science, technology and inquiry-based teaching: Experiences of the GLOBE program. *Journal of Science Education and Technology, 7, 97-105.*

Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA: Harvard University Press.

Mercer, N. (2000). *Words and minds: How we use language to think together*. Psychology Press.

Mercer, N. (2008). Talk and the development of reasoning and understanding. *Human development*, *51*(1), 90-100.

Mercer, N. (2009). Developing argumentation: Lessons learned in the primary school. In *Argumentation and education* (pp. 177-194). Springer US.

Mercer, N. (2010). The analysis of classroom talk: Methods and methodologies. *British journal of educational psychology*, *80*(1), 1-14.

Mercer, N., Dawes, L., Wegerif, R., & Sams, C. (2004). Reasoning as a scientist: ways of helping children to use language to learn science. *British Educational Research Journal*, *30*(3), 359-377.

Mercer, N., Dawes, L., & Staarman, J. K. (2009). Dialogic teaching in the primary science classroom. *Language and Education*, *23*(4), 353-369.

Mercer, N., & Howe, C. (2012). Explaining the dialogic processes of teaching and learning: Thevalue and potential of sociocultural theory. *Learning, Culture and Social Interaction*, *1*(1), 12-21.

Michaels, S., & O'Connor, C. (2012). Talk science primer. *Cambridge, MA: TERC.*

Mishler, E. G. (1975). Studies in dialogue and discourse: II. Types of discourse initiated by and sustained through questioning. *Journal of Psycholinguistic Research*, *4*(2), 99-121.

Moje, E. B., Ciechanowski, K.M., Kramer, K., Ellis, L., Carrillo, R. & Colazo, T. (2004). "Working toward Third Space in Content Area Literacy: An Examination of Everyday Funds of Knowledge and Discourse." *Reading Research Quarterly* 39(1):38-70.

Mortimer, E., & Scott, P. (2000). Analysing discourse in the science classroom. *Improving science education: The contribution of research*, 126-142.

Mortimer, E., & Scott, P. (2003). *Meaning Making In Secondary Science Classrooms*. McGraw-Hill International.

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academies Press.

National Research Council. (2012). *A Framework for K-12 Science Education*. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: National Academies Press.

New London Group. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review,* 66(1), 60-92.

Pedretti, E., & Nazir, J. (2011). Currents in STSE education: Mapping a complex field, 40 years on. *Science Education*, *95*(4), 601-626.

Pedretti, E. (2002) T. Kuhn meet T. Rex: Critical conversations and new directions in science centres and science museums. *Studies in Science Education* 37.

Pinar, W.F., Reynolds, W.M., Slattery, P. & Taubman, P.M. (2006). Understanding curriculum. An introduction to the study of historical and contemporary curriculum discourses. New York, NY: Peter Lang.

Polman, J. L. (2004). Dialogic activity structures for project-based learning environments. *Cognition and Instruction*, *22*(4), 431-466.

Powell, A. B., Francisco, J. M., & Maher, C. A. (2003). An analytical model for studying the development of learners' mathematical ideas and reasoning using videotape data. *The Journal of Mathematical Behavior*, *22*(4), 405-435.

Pozuelos, F., Travé González, G., & Cañal de León, P. (2010). Inquiry-based teaching: teachers' conceptions, impediments and support. *Teaching Education*, *21*(2), 131-142.

Prawat, R. S. (1993). The value of ideas: Problems versus possibilities in learning. *Educational Researcher*, *22*(6), 5-16.

Rennie, L. (2007). Learning science outside of school. In S.K. Abell & N.G. Lederman (Eds.), *Handbook of Research on Science Education* (125-167). Mahwah, NJ: Erlbaum.

Rogers, R. (2004). A critical discourse analysis of literate identities across contexts: Alignment

and conflict. *An introduction to critical discourse analysis in education*, 51-78.

Schneider, R. M., Krajcik, J., & Blumenfeld, P. (2005). Enacting reform-based science materials: The range of teacher enactments in reform classrooms.*Journal of Research in Science Teaching*, *42*(3), 283-312.

Scott, P., & Ametller, J. (2007). Teaching science in a meaningful way: striking a balance between 'opening up'and 'closing down' classroom talk. *School science review*, *88*(324), 77.

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education*, *90*(4), 605-631.

Shwartz, Y., Weizman, A., Fortus, D., Krajcik, J., & Reiser, B. (2008). The IQWST experience: Using coherence as a design principle for a middle school science curriculum. *The Elementary School Journal*, *109*(2), 199-219.

Sinclair, J. M., & Coulthard, M. (1975). *Towards an analysis of discourse: The English used by teachers and pupils*. Oxford Univ Pr.

Singer, J., Marx, R. W., Krajcik, J., & Clay Chambers, J. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform.*Educational Psychologist*, *35*(3), 165-178.

Stake, R. E. (1995). *The art of case study research.* Thousand Oaks, CA: Sage.

Stocklmayer, S. M., Rennie, L. J., & Gilbert, J. K. (2010). The roles of the formal and informal sectors in the provision of effective science education. *Studies in Science Education*, *46*(1), 1-44.

Tan, E., & Barton, A. C. (2012). *Empowering science & mathematics education in urban schools,* (pp. 29-30, 66). Chicago: The University of Chicago Press.

The Physics Classroom. (1996-2015). Work, energy, and power. http://www.physicsclassroom.com

Toolin, R. E. (2004). Striking a balance between innovation and standards: A study of teachers implementing project-based approaches to teaching science. *Journal of Science Education and Technology*, *13*(2), 179-187.

Toulmin, S. (2003). The Uses of Argument. 1958. *Cambridge: Cambridge UP*.

Verma, G., Puvirajah, A., & Webb, H. (2015). Enacting acts of authentication in a robotics competition: An interpretivist study. *Journal of Research in Science Teaching*.

Viadero, D., & Johnston, R. C. (2000). Lags in minority achievement defy traditional explanations. The achievement gap. *Education Week*, *19*(28), 28.

Vygotsky, L. S. (1978). Mind and society: The development of higher mental processes.

Wang, H. (2004). *The call from the stranger on a journey home: Curriculum in a third space.* New York: Peter Lang.

Wang, H. (2006). Speaking as an alien: Is a curriculum in a third space possible? *Journal of Curriculum Theorizing*, 22(1), 111-126.

Wells, G., & Arauz, R. M. (2006). Dialogue in the classroom. *The journal of the learning sciences*, *15*(3), 379-428.

Wolf, M. K., Crosson, A. C., & Resnick, L. B. (2006). Accountable Talk in Reading Comprehension Instruction. CSE Technical Report 670. *National Center for Research on Evaluation, Standards, and Student Testing (CRESST)*.

Wood, L. C., Ebenezer, J., & Boone, R. (2013). Effects of an intellectually caring model on urban African American alternative high school students' conceptual change and achievement in chemistry. *Chemistry Education Research and Practice*, *14*(4), 390-407.

Yoon, S. A., Elinich, K., Wang, J., Steinmeier, C., & Van Schooneveld, J. G. (2012). Learning impacts of a digital augmentation in a science museum. *Visitor Studies,* 15(2), 157-170, DOI: 10.1080/10645578.2012.715007.

Yore, L. D., & Treagust, D. F. (2006). Current realities and future possibilities: Language and science literacy—empowering research and informing instruction. *International Journal of Science Education*, *28*(2-3), 291-314.

Youtube. (2008, October 24). *An Introduction to University Preparatory Academy.* Retrieved October 1, 2010 from www.youtube.com/watch?v=Of9Cr2.

Zhang, L. (2013). A meta-analysis method to advance design of technology-based learning tool: Combining qualitative and quantitative research to understand learning in relation to different technology features. *Journal of Science Education and Technology*, 1-15.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, *89*(3), 357-377.

ABSTRACT

ENGAGING A MIDDLE SCHOOL TEACHER AND STUDENTS IN FORMAL-INFORMAL SCIENCE EDUCATION: CONTEXTS OF SCIENCE STANDARDS-BASED CURRICULUM AND AN URBAN SCIENCE CENTER

by

SHAMARION GLADYS GRACE

August 2015

Advisor: Dr. Jazlin Ebenezer

Major: Curriculum and Instruction

Degree: Doctor of Education

This is a three-article, five-chapter doctoral dissertation. The overall purpose of this three-pronged study is to engage a middle school science teacher and students in formal-informal science education within the context of a standards-based science curriculum and an urban science center. The goals of the study were (a) to characterize the conversations of formal and informal science educators as they attempted to implement a standards-based curriculum augmented with science center exhibits; (b) to study the type of teacher-student classroom discourse that fosters the development of common science knowledge and an understanding of the concept of "energy" before observing science center exhibits on energy; (3) to investigate whether a standards-driven, project-based Investigating and Questioning Our World Through Science and Technology (IQWST) curriculum unit on forms and transformation of energy augmented with science center exhibits had a significant effect on the achievement and learning of urban, African-American, seventh-grade students. Overall, the study consisted of a mixed-method approach. Article 1 consists of a case study featuring semi-structured interviews and field notes. Article 2 consists of documenting and interpreting

teacher-students classroom discourse. Article 3 reflects the results both of qualitative methods (classroom discussion, focus group interviews, student video creation) and quantitative methods (multiple choice and open-ended questions). Oral discourses in all three studies were audio-recorded and transcribed verbatim. In Article 1, the community of educators'conversations were critically analyzed to discern the challenges educators encountered when they attempted to connect school curriculum to energy exhibits at the Urban Science Center. The five challenges that characterize the emergence of a third space were as follows: (a) difficulty with science terminology, (b) the "dumbing down" of science exhibits, (c) the idea that exploration distracts lesson structure, (d) the meaning of "model/modeling," and (e) the question of which comes first--science content learning or science exhibit exploration. These challenges were considered and discussed in this project as opportunities for personal growth. The third space allowed for participant reflection and transformation in formal-informal collaboration and communication. In Article 2, teacher-students' classroom discourse transcripts corresponding to the workbook lessons from the IQWST unit on physics were analyzed. Four instructional events were selected for discourse analysis: (a) focusing on the inquiry process; (b) understanding of kinetic energy; (c) formulating scientific explanations; and (d) translating energy transformation. The discourse excerpts representing the aforementioned instructional events revealed four teacher behaviors: (a) teacher-posed questions, (b) teacher explanations, (c) teacher responses, and (d) teacher reference to past learning. Of these teacher behaviors, teacher-posed questions dominated the discourse, and these consisted of fill-in-the-blank, affirmation, second-order, descriptive, and explanatory questions. Article 3 presents the results of the IQWST Unit Achievement Test (IUAT) and students' understanding of the concepts of energy and energy transformation. The IUAT indicated that students (N=37) in the experimental group, who were taught the augmented IQWST curriculum unit using the science center exhibits, achieved scores ($p<0.001$) about the same as students in the control group (N=31), who were taught only with the IQWST curriculum unit. However, the experimental ($\Delta_{\text{post-pre}} = 4.78$) and control ($\Delta_{\text{post-pre}} = 4.04$) groups revealed significant gains ($p<0.001$) from pre-test scores to post-test scores. These findings confirm that underserved urban students' learning can be enhanced with an augmented standards-based curriculum unit. The students also can realize significant achievement gains when teachers who are supported by their administration use standards-driven science curriculum regardless of whether it is augmented with science exhibits. The three qualitative analyses of data in Article 3 indicated that students had reasonable understandings of the forms and transformation of energy. They were also able to explain the working of science exhibits using their understanding of the energy concepts developed in class. The first study (Article 1) suggests that a third space allows for participant reflection and transformation in formal-informal collaboration and communication.

The second study (Article 2) identifies (a) the teacher's struggle with dialogic discourse, a communicative approach that fosters common knowledge through a social process, and (b) the need for professional development that fosters dialogic discourse. The third study (Article 3) suggests that an integrated curriculum with both formal and informal components can be successfully implemented to achieve content mastery when teachers are provided with (a) professional development about how to develop students' knowledge using science exhibits, (b) time to develop concepts with students using exhibits, and (c) support from administration to modify the time required to cover certain topics in the curriculum with

more time spent on topics (e.g., energy) that require creative teaching methods to help students learn science. Overall, these studies suggest that the science center exhibits can provide a context within which to observe whether students are able to translate classroom-constructed knowledge at the intersection of formal-informal instruction.

Key Words: formal and informal science learning, third-space emergence, dialogic discourse, sociocultural perspective, common knowledge, standards-based curriculum, science center exhibit, science achievement

AUTOBIOGRAPHICAL STATEMENT

SHAMARION GLADYS GRACE

Education:

2015 –Doctor of Education
Wayne State University, Detroit, MI
Major: Curriculum and Instruction

1996- Masters of Arts
Eastern Michigan University, Ypsilanti, MI
Major: Guidance and Counseling

1985- Bachelor of Science
University of Michigan-Flint, Flint, MI
Major: Biology

Professional Experience:

2014-present	Curriculum Strategist, Flint Community Schools, Flint, MI
2013-2014	Interim Executive Director of Curriculum & Instruction, Flint Community Schools, Flint, MI
2011-2013	Director of Curriculum & Instruction, Flint Community Schools, Flint, MI
1999-2011	Science Coordinator, Flint Community Schools, Flint, MI
1999	Acting Assistant Principal, Southwestern Academy, Flint, MI
1992-1999	Science Teacher, Southwestern Academy, Flint, MI

Professional Memberships:

American Education Research Association (AERA)
National Association of Research in Science Teaching (NARST)
Association for Supervision and Curriculum Development (ASCD)
Phi Delta Kappa (PDK)
International Reading Association (IRA)

Fellowships:

Graduate Professional Scholarship (2010), $10,000, Wayne State University
King Chavez Parks Scholarship (2010), $10,000, Wayne State University

Special Awards:

2005 Dedicated Service Award-Director of Under-represented Groups – Michigan Science Teachers Association