5-2019

Seeing the World Differently. An Exploration of a Professional Development Model Bridging Science and Lay Cultures

Michael D. Garrett
East Tennessee State University

Recommended Citation

Garrett, Michael D., "Seeing the World Differently. An Exploration of a Professional Development Model Bridging Science and Lay Cultures" (2019). *Electronic Theses and Dissertations.* Paper 3524. https://dc.etsu.edu/etd/3524

Seeing the World Differently. An Exploration of a Professional Development Model Bridging Science and Lay Cultures

---

A dissertation
presented to
the faculty of the Department of Early Childhood Education
East Tennessee State University

In partial fulfillment
of the requirements for the degree
Doctor of Philosophy in Early Childhood Education

---

by
Michael D. Garrett
May 2019

Dr. Jane Broderick, Chair
Dr. Pam Evanshen
Dr. Carol Trivette

Keywords: Scientific reasoning, Scientific cognition, Modeling, Epistemology, Ontology, Cultural knowledge

ABSTRACT

Seeing the World Differently. An Exploration of a Professional Development Model Bridging Science and Lay Cultures

by

Michael D. Garrett

This study explores the rationale, efficacy, and social validity of a professional development model designed to move elementary school science activities closer to the practices of working scientists as required by the United States' "Next Generation Science Standards." The model is culturally sensitive and aims to create experiences with high subjective task value. The formal theory of change uses scaffolding, Piagetian agency, and Vygotskian learning opportunities to argue that culturally familiar representational tasks in culturally natural intersubjective contexts can lead to work prototypical of scientific modeling under particular facilitation conditions: when participants (a) are allowed free use of their cognitive and culturally native tools; (b) work in open dialog amongst themselves and with a science cultural adept; (c) work in groups in contexts that represent cultural aspects of science work; (d) are pressed to follow some of the epistemic and ontological imperatives of working science; and (e) maintain their agency in resolving cognitive conflict. The study implemented the model with fidelity as a professional development workshop around exploring physics with simple, everyday materials over two afternoons with a small group of elementary-school teachers in southern Appalachia. Analysis indicates that participants engaged in representational tasks with little off-task behavior, exhibited all of the targeted modeling behaviors, felt all components were inherently interesting and useful, and rated the workshop highly as professional development in science teaching but lower as coherent with local evaluation standards. Data on outcome-expectancy beliefs were largely inconclusive but may suggest that the workshop caused teachers to doubt their current ability to teach science to their students. The workshop model provided "cultural modeling" and access to participants' "funds of knowledge," created a "third space," and attended to intrinsic task interest as recommended in the National Research Councils' *How People Learn II*. Overall, the study endorses using genuine dialog around teachers' descriptions and explanations of the physical world to bridge native cultural norms and behaviors with science practices.

ACKNOWLEDGEMENTS

I would like to give special thanks to my committee chair, Dr. Jane Broderick, for what amounts to an amazing act of faith in bringing an ex-physics teacher into doctoral work in early childhood education and, over many years, consistently believing that his hop-scotch method of moving through the academic program would end well. Thank you.

I would like to acknowledge and thank the other two members of my doctoral committee for their general and particular contributions to that good end. Thank you Dr. Pam Evanshen for turning me around the corner back to the original conception behind this work and then pleasantly affirming again and again that I almost had it done. That all helped so much. And thank you Dr. Carol Trivette, who sat me down and helped me work through a methodology that shaped my initial flounderings into a passable path to research.

I would like to acknowledge the help of my fellow graduate students in collecting data for this dissertation. Thank you Tsitsi Nyabando, Ehichoya Edokhamhen, Hongxia Zhao, and Cathy Landy for helping me follow small groups of teachers around a room as they played/worked with ketchup, Pikachu, a box, and a marble. The video recordings you made were the basic stuff of the truly interesting parts of this work. Your willingness to spend your time over several days to help made me feel like a real researcher. Much appreciated.

I would like to give a special thanks to my research assistant (and sister), Sandra Garrett. Besides helping to record the videos and bringing treats, she watched all engagement videos with extreme attention over and over and over again. Her coding of teachers' behaviors gave essential strength to my rendering of what the teachers did when they worked. In addition, the hours of conversations over whether their saying X meant Y or Z is what let me move toward operationalizing modeling into a systematic form. Couldn't have done it without you.

DEDICATION

I dedicate this bit of work to my two sons, who spent much of their teenage years asking in various ways, “what is it you do?” It turns out your eccentric, sciencey dad was thinking about culture. Who’d have thought that, eh? Not me, not at first at least. Funny where the quirks of your own mind take you. I now see that the science and math that I so love to help others make peace with is an odd little “pocket culture.” To my credit, I’ve always tried to listen to others as they confronted this culture, especially in schooling, and that’s been the greatest help and a big part of the fun.

You’ve grown to be such thoughtful, kind, and earnest young men. Stick with that, boys. What lies ahead may be more than a hoot. As your dad sees it, “our” culture is undergoing seismic pressures and all kinds of pocket cultures will be looking for hegemony. I don’t find that listening is a natural behavior when people feel powerful or when their power is threatened. So, I task you with that: listen earnestly, thoughtfully, act on your kindness… but I tell you, find what it is you value and are, and hold on.

Love you both. Always and forever.

TABLE OF CONTENTS

Page

ABSTRACT 2

ACKNOWLEDGEMENTS 4

DEDICATION 5

LIST OF TABLES 15

LIST OF FIGURESS 16

Chapter

1. INTRODUCTION 17
   - Motivation, Definitions, and Purpose 17
     - Definitions of Problematic Terms 18
       - Culture and cultural change 18
       - Terms from philosophy 19
     - Purpose of the Study 20
   - Description of the *Seeing the World Differently* Workshop Model 21
     - Target Population 22
     - Key Themes of the Workshop Model 23
     - Fundamental Constructs in the Workshop Model 24
     - Theory Behind the Workshop Model 26
     - The Design of the Workshop Model 28
   - The Present Study 31
     - Research Questions 31
     - Methods 32
   - Summary 34
2. LITERATURE REVIEW 35
   - New Standards for Student Work in School 36
     - Progression Toward Professional Practices in Science Education 36

Committing to nationwide science literacy 37
Rebuilding STEM as facilitated professional practice 37
The New STEM Standards 38
The Common Core State Standards for mathematics 38
The Next Generation Science Standards 39
A shift to work prototypical of science 39
Attention to students’ culture in the new standards 42
Using funds of knowledge of non-dominant groups 42
Using funds of knowledge of those lay to science generally..................42
Elementary-School Teachers as Facilitators of Science Practices 43
Classroom culture will change...43
Teachers’ work will change 44
Elementary-school teachers’ aversion to science-related tasks 44
Scientists as Cultural Productions 45
What Do Scientists Really Do?...46
From positivism to social constructs 46
Thinking embedded in a particular culture..47
Cultural Imperatives of Science Work..47
Examples of How Science Culture Is Historically Bound..48
Abstract logic is not compelling 48
Knowledge can’t be disembodied...49
Motion is not real...49
Curiosity doesn’t need support 50
Science Education as Cultural Conflict 52
Cultural Differences and Cognitive Engagement 52
Science Education Furthers Oppressive Power Relationships..53
Science Education Creates Artificial Incompetence 54

  Science Education Is Distant And Unengaging 55
  Recommendations for Addressing Cultural Distance in Schooling 57
Science Work And School Science 59
  Science as Compelling Work 59
  "Students Rarely Do Science" 60
Learning as Cultural Acquisition 62
  Bronfenbrenner, Proximal Processes, and the Salience of Outcomes 63
    Environment, experiences, and processes of interaction 64
    Salience of outcomes from cues in the environment 65
    Culture organizes inputs into the brain's architecture 66
  Piaget, Cognitive Conflict, and the Agency of the Child 67
    Piaget and *The Origins of Intelligence* 68
      Functional invariants of hereditary intelligence 69
      Coordination of experience with mental structures 70
      Mental operations 70
      Adaptation, assimilation, and accommodation 71
      Cognitive organization and cognitive equilibrium 71
      Stages of intellectual development 71
    Piagetian constructivism as a psychological theory of learning 72
    Piaget on how pedagogy promotes intellectual development 73
    Piagetian agency 74
  Vygotsky, Higher Thinking, and Opportunities for Cultural Transmission 75
    Humans are an unfinished species 76
    Social history and social engagement 77
    Social history determines "humanness." 78
    Internal drivers and the "zone of proximal development." 79
    Formal instruction and Vygotskian opportunities. 80

Leading Children to Engagement with Science Work 81

Children Are Born to Think About Their Environment 82

Children Are Not Little Scientists..84

Academic war and the “child scientist” movement 84

Natural enculturation from “life culture.”..85

Confusing cognitive drivers with formal thought...86

A Small Illustration..87

“Scientific thinking.” 87

“Another mind, older and equally curious.” 89

Environments that Draw Children to Cultural Tools..90

Seeing the World Differently...90

Exemplars with Young Children 91

Being Asked to Draw What Is Really There 92

Drawing a real crab...92

“Benefiting from suggestions.”...93

The *Young Scientist Series*..94

Motivation for Engaging Achievement Tasks 96

Mediators for Choosing to Engage in Academic Tasks..96

Lack of Attention to Intrinsic Value as a Driver for Choosing to Engage 97

Attribution and Learners’ Interpretations of Events 97

Summary 98

3. METHOD 100

Research Questions 100

Population and Sample 101

Sample 102

Ethical Treatment of Participants...102

Treatment 103

Planned Workshop Schedule 103

Provocations for Representational Tasks 104

The physical phenomena and enacting materials 104

Task prompts 104

Representational materials 105

Facilitator and Facilitation Protocols 107

Qualifications of the facilitator 107

General standards for facilitation 107

Measures 107

Fidelity Measures 108

Presentation of key workshop themes 108

Facilitator reference to canonical science 110

Facilitator attribution statements 110

Prototypical Scientific Modeling Behaviors 112

Constructs measured 112

Development of the instrument 113

Arranging for the conditions of seeing 114

Inventing measures 114

Developing representational competence 115

Developing an epistemology of modeling 116

Subjective Task Value 117

Constructs measured 118

Development of the instrument 118

Expectancy for Success 119

Constructs measured 119

Development of the instrument 119

The STEBI-B 120

The STEBI as modified for this study 120
Social Validity of Workshop as Professional Development..121
Constructs measured 121
Development of the instrument...123
Data Collection 123
Pre-treatment Survey 123
Video Recording 124
Personnel..124
Extent and quality 125
Transcription 125
Participant Journals..125
Teacher reactions to workshop components 125
Evaluation of the workshop as professional development.................................126
Artifacts of Small-Group Work 126
Post-Treatment Survey..126
Data Analysis 127
RQ1. Prototypical Scientific Modeling Behaviors 127
RQ2. Subjective Task Value...128
RQ3. Expectancy for Success 129
RQ4. Social Validity of the Workshop as Professional Development 129
4. RESULTS..131
Fidelity of Implementation of the Workshop Model 131
Workshop Schedule 131
Day one 133
Day two 133
Implementation of the Initial Meeting 134
Timing and schedule 134

Content and process themes 134

Reference to canonical science 136

Fidelity of the initial meeting 138

Implementation of the Research Phase Engagements 139

Timing and schedule 139

Scaffolding practices 139

Reference to canonical science 140

Causal attributions 141

Implementation of the Conference Phase 144

Reference to canonical science 144

Causal attributions 146

Implementation of the Final Meeting 148

Research Questions 148

RQ1. Prototypical Scientific Modeling Behaviors 149

Construct validity 151

Overall assessment of RQ1.1 154

Overall assessment of RQ1.2 157

Overall assessment of RQ1.3 159

Overall assessment of RQ1.4 161

RQ2. Subjective Task Value 162

Constructs measured 163

Overall assessment of RQ2.1 166

Overall assessment of RQ2.2. 169

Overall assessment of RQ2.3 172

RQ3. Expectancy for Success 172

Constructs measured 172

RQ4. Social Validity of the Workshop as Professional Development 174

Constructs measured 174

Overall evaluation of RQ4 178

5. DISCUSSION 179

Findings of the Study 179

RQ1. Prototypical Scientific Modeling Behaviors 179

Arranging for conditions of seeing 180

Inventing measures 180

Developing representational competence 180

Developing epistemological competence 180

Did workshop participants move toward science practices? 181

RQ2. Subjective Task Value 181

Intrinsic task value 181

Utility task value 182

Did participants find this work engaging? 182

RQ3. Expectancy for Success 182

RQ4. Social Validity of the Workshop as Professional Development 183

Summary 183

Recommendations 183

Implementation and Fidelity 184

Measures 184

Limitations of the Study 185

Significance of the Study 185

REFERENCES 187

APPENDICES 199

Appendix A: Coded Transcript of the Initial Meeting 199

Appendix B: Provocations for Representational Tasks 205

Appendix C: Research-Phase Facilitation Checklist 208

Appendix D: Modified Science Teaching Efficacy Belief Inventory..209

VITA 210

LIST OF TABLES

Table Page

1. Coding Table for Key Themes of the Workshop Model 109
2. Coding Table for Facilitator Attribution Statements 111
3. Coding Table for Protoscientific Modeling Behaviors 113
4. Component Value Measure (CVM) 118
5. Dimensions of the Workshop Evaluation Questionnaire (WEQ) 122
6. Key Workshop Themes Appearing in the Workshop's Initial Meeting 136
7. Facilitator's Initial-Meeting References to Science 137
8. Facilitator's Research-Phase References to Science 141
9. Facilitator's Research-Phase Causal Attributions 142
10. Sample of Facilitator's Conference-Phase References to Science 145
11. Sample of Facilitator's Conference-Phase Causal Attributions 147
12. Review of the Data Collection Schedule 148
13. Percent of Intervals in Research-Phase Sessions with Prototypical Scientific Modeling Behaviors 151
14. Descriptive Statistics of Intrinsic Task Value of all Workshop Components 164
15. Population Effect Sizes and Statistical Significance for Intrinsic Task Value Construct 165
16. Descriptive Statistics of Utility Task Value of Workshop Components 167
17. Population Effect Sizes and Statistical Significance for Utility Task Value Construct 169
18. Descriptive Statistics of Subjective Task Value Measures by Workshop Phase 170
19. Descriptive Statistics of Teacher Outcome Expectancy Measures (Modified STEBI-A) 173
20. Descriptive Statistics of Social Validity Measures (WEQ) 176
21. Population Effect Sizes and Statistical Significance for Social Validity Measures (WEQ) 176
22. Coded Transcript of Initial Meeting 199

LIST OF FIGURESS

Figure Page

1. Causal model behind the theory of change of the workshop 27
2. Model plan of the *Seeing the World Differently* workshop 29
3. Planned delivery of the workshop model as a study treatment 104
4. Example of a group's representation of a phenomenon assembled into a flipbook 106
5. Comparison of workshop model, treatment plan, and workshop as implemented 132
6. Pattern of facilitation in the workshop as implemented 140
7. Distribution of intrinsic task value measures for each workshop component 164
8. Distribution of utility task value measures for each workshop component 167
9. Distributions of subjective task value measures for each workshop phase 170
10. Individual CVM scores across workshop components, paneled by participant 171
11. Distributions of pre- and post-treatment outcome expectancy measures (modified STEBI-A) .. 173
12. Distributions on social validity measures (WEQ) 175

CHAPTER 1

INTRODUCTION

This introduction motivates for, presents, and explicates the professional development model being explored in this study and defines key terms. The ideas introduced here are developed from the literature in Chapter 2. The introduction also states the purpose and research questions of the study and gives a brief overview of the methods used to collect and analyze data. The methods are developed in Chapter 3 and the data collected is presented and interpreted in Chapter 4. In Chapter 5, the findings, limitations, and significance of the study are reviewed and discussed, and some recommendations are made for future work.

Motivation, Definitions, and Purpose

The workshop model *Seeing the World Differently* aims to be culturally sensitive, engaging, and prototypical of science practices in important ways. It is built on the idea that asking people who are unused to science work to bring their native intelligence to bear in “sciencey” situations can be an effective way to make the content and culture of science reasonable and useful.

The model is motivated by a problem in early-years science education forefronted by a decades-long movement to reform school science into a sustained experience mimicking working science: There is a mismatch between the culture—the practices, beliefs, values, and emotional responses—of actual science work and the cultures of the children and adults who find themselves tasked to learn or teach science in school. People, including little children, are simply not “natural scientists.” Many of the values, beliefs, and practices that the accomplishments of science are built upon are not part of most communities and are quite askew of basic and highly functional cognitive tools that people develop naturally by living in those communities. Attempting to acquire these foreign tools as “the way the world works” leaves most humans averse to trying. Moving children—and the adults who teach them—toward being adept in science culture requires solving the problem of bridging that culture with the local cultures of people who are in school. However, pedagogy that promotes incorporation of science tools by individuals rather than assimilation of individuals into science is not well developed. A better understanding of the nature of school activities that bring adults and children into satisfying and productive engagements with science work is needed.

Definitions of Problematic Terms

The model and its rationale use problematic terms from several disciplines in specific ways. Below are brief discussions of problem areas and a lexicon of problematic and technical terms as used in this study. Where possible, terms are used in a sense common to academic English operationalized using Merriam Webster's online dictionary of American English (Merriam Webster, n.d.). Where this strategy fails, the words are considered as technical terms, and the needed sense of a term is drawn from academic literature.

Culture and cultural change. This study defines "culture" following Phelan, Davidson, and Cao (1991) in their study of the difficulties adolescents face maintaining a stable sense of self in school. Terms that describe cultural transmission as an abstract process often are intended to carry power-relationships as well, but the distinctions are not agreed upon. This study consistently uses the terms "assimilation," "enculturation," and "incorporation" as defined below. The study uses the power-neutral terms "lay" and "adept" to describe outsiders and insiders relative to a culture, but may use "outgroup" and "ingroup" when the context makes connotations clear. The literature wrestles with how to describe the conceptions that people lay to science bring with them into learning, variously calling them "misconceptions", "alternative conceptions", or "naïve," in comparison to the "correct" or "mature" understandings as developed by science. This study avoids those terms.

- *Culture.* The "values and beliefs, expectations, actions, and emotional responses familiar to insiders" of a localized community of people. (Phelan et al., 1991, p. 225).
- *Adept* (noun). "A highly skilled or well-trained individual; expert" (Adept (noun), 2016). A "cultural adept" signifies a person who is expert in a culture. Many science teachers, though they have content knowledge in a discipline, would not be considered as cultural adepts of science (Bartholomew, Osborne, & Ratcliffe, 2004). They do not understand, practice, or attempt to transmit the culture of actual science.

- *Lay* (adjective). “Not trained in a certain profession; not having a lot of knowledge about a certain thing” (Lay (adjective) [Def. 3], 2016). In this study, “lay culture” is meant to name the values and beliefs, expectations, actions, and emotional responses of people as they operate in their daily lives, as distinct from science work. It is a lay culture that individuals who do not practice science bring to learning and teaching science within classrooms. The distinction is not meant to indicate a presumption of differences in cognitive abilities between scientists and others, and the power of groups lay to or adept in science may change depending on context.
- *Assimilation.* Cultures assimilate outgroups with the expected outcome that the outgroup’s culture will diminish or disappear. The agent is the more powerful culture and the object is a less powerful individual or group. So, assimilation is the coerced replacement of an individual’s or group’s culture. It should be anticipated that individuals will tend to resist this type of cultural transmission, or just resign themselves to the process.
- *Enculturation.* Cultures enculturate outgroups with the expected outcome that the outgroup’s culture will largely remain intact but that individuals in the outgroup will incorporate significant parts of the acting culture. The agent is a more powerful culture, and the object is a less powerful individual or group; however, agency is ceded to the individuals by the powerful culture to some degree. So, enculturation is the augmenting of an individual’s or groups culture. In this process, individuals may negotiate the cultural transmission and come to welcome it.
- *Incorporation.* Individuals in outgroups in contact with another culture incorporate elements of another culture, either taking them in outright or modifying them, with the expectation that their own cultural identification may change but will not flip wholly to the other culture. So, incorporation is the adoption or modification of outside cultural tools by an individual. The individual does not resign herself to this change but chooses to pursue or accept it.

Terms from philosophy. Problematic terms from the philosophy of science are “epistemology” and “ontology.” These terms are highly technical in academic philosophy, but this study uses the colloquial definitions below. The terms “reify” and “warrant” are introduced as technical terms.

- *Epistemology.* The study of, or a theory about the nature and grounds of knowledge, especially with reference to its limits and validity. In this study, “epistemology” and “epistemic” will refer generally to questions about what English speakers mean by phrases like, “I know.”
- *Ontology.* The study of, or a theory about the nature of being or the kinds of things that have existence. In this study, “ontology” and “ontological” will refer generally to questions about what English speakers mean by phrases like, “it exists” or, “it is real.”
- *Reify.* “To consider or represent (something abstract) as a material or concrete thing: to give definite content and form to (a concept or idea)” (Reify, 2018). More colloquially, to act like or talk like something is real.
- *Warrant* (noun). A proposition that acts as a justification or backing for a claim of knowledge. This idea was introduced to the rhetorical analysis of formal arguments by Toulmin (2003) in a model that has become widely accepted, for example in the AERA standards for reporting research (American Educational Research Association, 2006). One of the functions of the facilitator in the workshop model is to ask teachers to make their warrants explicit, a cultural norm of science work.

Purpose of the Study

The purpose of this study was to explore a professional development model, *Seeing the World Differently*. The model presents a workshop in five “phases:” an initial and a final meeting and three core phases that engage participants in representational tasks centered on dialog about representations of the participants’ own thinking about simple, physical phenomenon that they enact using everyday materials. These tasks are considered *prototypical of scientific modeling* in that they aim to parse phenomenon into systems of interacting constructs, and work is construed as successful if it accomplishes specified imperatives of science culture. The pedagogy is *constructivist* in that the facilitator presses participants to look at and resolve cognitive conflict, and students are viewed as decision makers, choosing their level of engagement based on both the subjective value of the work and their expectancy for success in future work. Learning is viewed as *cultural transmission* in that the facilitator scaffolds epistemic, ontological, and social norms inherent in science work. The workshop aims to be *culturally sensitive* in that participants' lay cultures are viewed as strengths to be used, not weaknesses to be overcome, and participants develop their local culture by creating intersubjective standards for success and by incorporating the scaffolded norms and standards for their own reasons.

Specific aims of the study were (a) to see whether, under this model, elementary-school teachers engage tasks in ways prototypical of science work, (b) to determine how they value their work during workshop components, (c) to measure whether the workshop affects their attitudes about teaching science, and (d) to gauge whether they consider their experiences as valuable science teaching professional development.

The study successfully implemented four phases of the model as a workshop for a small group of elementary-school teachers. Fidelity measures show that the workshop facilitation adhered closely to protocols in the initial workshop meeting and in the small-group engagements with the prototypical modeling tasks (research phase), and though not conclusive, gave no indications that facilitation departed from protocols in the whole-group dialog around representations (conference phase) and in the final workshop meeting (final phase). A final round of small-group engagements (publishing phase), was not implemented in this study.

Data include video recordings of the research-phase engagements with prototypical scientific modeling tasks, measures of individuals' attitudes toward all workshop components, individuals' journal entries about the components, pre/post-workshop assessments of participants' science teaching self-efficacy beliefs, and participants' assessment of the workshop overall.

Description of the *Seeing the World Differently* Workshop Model

This study presented and analyzed a professional development workshop based on a model intervention, *Seeing the World Differently,* designed by the study author. The main thesis behind the model is that drawing people who are inexperienced in science work toward using their native intelligence and experience on representational tasks in contexts and under imperatives that are prototypical of actual science work will bring them closer to understanding and valuing the way physicists approach building knowledge of the physical world and will help make the findings and conventions of physics meaningful.

In the *Seeing the World Differently* professional development model, a facilitator first presents to the whole group of teachers content and process themes intended to draw the teachers away from seeing science and science education as scripted work and toward seeing it as work pursuing questions about the physical world which have no set answers. Then, teachers respond in small-groups to provocations asking them to enact a target phenomenon using simple, familiar materials and to represent what they see and why it happens on semi-structured pages, which they assemble into booklets that can be flipped through to review how their thinking developed. Teachers are free to think, draw, and write as they wish, but are pressed by the facilitator to represent carefully what they think in ways that others could follow and that matches what they saw. After these engagements, teachers discuss their findings in a whole-group session. They then return to their small groups to revisit each phenomenon and work on final representations, also presented in “flipbooks.” Finally, the facilitator presents to the whole group canonical physics descriptions of each phenomenon and leads the teachers to compare these to their work and to harvest terms, concepts, and conventions to take away.

All work is facilitated by a science cultural adept who works under strict facilitation protocols. Except in the final meeting, the adept does not present or elaborate on terms or concepts from canonical physics. During the engagements, the adept does not compare participants’ findings to canonical views on the phenomenon and does not attribute participants performance to the nature of canonical science or science education. During the final meeting, the adept does not aim to assimilate teachers to canonical science but does help teachers incorporate their own conventions for understanding the phenomenon, and guides teachers to compare the way they see the world to the way physics does.

Target Population

The author designed the workshop as an intervention into adults’ established norms for observing, parsing, and representing phenomena in the physical world. This model has been implemented with early-years inservice teachers (Geiken, 2015) and with early-childhood teacher candidates. These groups rated their experience as highly engaging and instructive and as helpful in reinterpreting daily experience in ways they viewed as more scientific. Facilitators and informal observers judged that the participants both enjoyed the work on its own and stayed engaged with the core tasks of representing and describing the physical world in ways more like science work.

Key Themes of the Workshop Model

To draw participants toward a way of working that asks people to bring their native intelligence and cultural tools to bear in sciencey situations, the line of thinking behind the workshop should be made clear to the participants in the initial meeting: The work of science is not what most people expect. It is an unusual way of looking at the world developed over centuries. It is a cultural legacy similar to language and mathematics. Getting good at it involves a particular kind of work in the classroom, work that they and their students can do and can enjoy. This line of thinking is elaborated in six content themes and six process themes.

Content themes are meant to draw teachers away from thinking about science work as scripted and toward it as a compelling human behavior that needs special but achievable conditions to develop. The six key content themes are: (1) This work aligns with teachers' work and can be taken into their classrooms with few resources; (2) The work is "sciencey," not direct instruction in science content; (3) Like physics, the work is to describe and explain simple physical phenomena; (4) The work is not the normal way people look at the world; (5) The work emphasizes representing your own thinking clearly and concisely and having conversations around those representations; (6) Because the work is about teachers' thinking, there is no one right way to represent their descriptions and explanations.

Process themes are meant to point teachers to a way of working that is intended to better model actual science work, built around provocations to engage with the physical world and around discussions and intersubjective standards of knowledge. The six key process themes are : (1) Teachers will work in different ways, sometimes in small groups and sometimes altogether; (2) They will work as groups in centers around provocations about how they see and explain the physical world, and will transition between centers to engage different phenomenon; (3) They will use simple materials to enact everyday phenomenon in ways they can manipulate and modify; (4) They will use simple pencil and paper forms assembled into booklets to represent what they see and how they explain that; (5) They will have chances to dialog with each other and the facilitator on how they are representing their thinking; (6) They will have a chances to revisit and modify their representations.

Fundamental Constructs in the Workshop Model

The model explored in this study conceptualizes key constructs in specific ways. This section gives summaries of those conceptualizations. The constructs are developed from the literature in Chapter 2.

The workshop model simulates four cultural *imperatives of science*: (a) to carefully and iteratively look at isolated phenomenon; (b) to articulate and reify constructs that describe and explain a mechanistic world (scientific ontology); (c) to warrant claims in specific statements about observations, models, theories, and established fact (scientific epistemology); and (d) to represent thinking in conventional ways and to clearly communicate thinking to peer groups.

The workshop model simulates three *science contexts*: The research lab, where small groups of people in regular communication give joint attention to isolated problems of understanding the physical world; a plenary conference, where individuals across research labs join irregularly to present and discuss findings from research labs; and publishing, where individuals working within research labs finalize the findings of the lab and communicate them clearly and concisely to peers.

In the workshop model, a *provocation* is a written statement and a collection of simple, familiar materials. The statement (a) outlines a simple, mechanical phenomenon; (b) tasks participants to enact the phenomenon without directions on how to do so; and (c) tasks participants to "describe and explain" the phenomenon using pencils and semi-structured paper forms.

In the workshop model, participants are given *representation tasks* to "describe and explain" in semi-structured booklets a simple, familiar phenomenon that they enact using simple, familiar materials. This representational task leverages an individual's ability to externalize his mind concretely to make his own thinking visible to himself and to others in a way that survives the moment. Conversations around these representations are the main mechanism for pushing development of individuals' capacities along the lines of science practices. These tasks are considered modeling tasks because they aim to parse a phenomenon into components, to explain the phenomenon as interactions among these things, and to represent this system symbolically. The tasks are considered prototypical of science culture because work is construed as successful in the workshop context to the extent that it accomplishes certain imperatives of science culture.

In the workshop model, an *intersubjective context* is a social environment created by several people jointly engaging in work evaluating what is real or what is true in their immediate experience. These contexts press individuals to "deprivatize" (J. Broderick, personal communication, August 15, 2012) their thinking by encouraging discussion about the phenomenon and the groups' representations. The workshop model intends deprivatized thinking to fill three functions: encourage cognitive conflict within individuals; create opportunities for individuals to exercise the power of cognitive tools; and encourage common conventions that function as cultural capital.

In the workshop model, the adept follows *constructivist facilitation*, meaning he allows the participants to manipulate the enacting materials freely and to use and create conventions as they wish but presses them to make their representations consistent with what they think. This facilitation strategy uses *Piagetian agency*, meaning that lasting and fundamental changes in the cognition of individuals are built by individuals driven to resolve inconsistences in their own thinking and allowed to act on the world in those efforts; *Vygotskian opportunities*, meaning that competence in a high-order cognitive tool is built by cultural transmission, with an individual in natural contact with others already adept in those tools, especially when acting among peers; and *scaffolding*, meaning the facilitator presses participants back into the provocation and helps them manage and understand their frustrations, models the targeted values, beliefs, and practices, and breaks tasks distal from participants' competence into ones more proximal (Wood, Bruner, & Ross, 1976).

In the workshop model, *prototypical scientific modeling behaviors* are (a) arranging materials so a phenomenon may be carefully observed in isolation; (b) conceptualizing observed phenomena mechanistically so that properties can be counted, categorized and related; (c) signifying aspects of a phenomenon by representing them on paper and discussing their validity; (d) evaluating representations for fit to the observed phenomenon. These behaviors are considered prototypical of science modeling in that they are workable versions of the target practice, scientific modeling, that captures targeted essential characteristics of the intended final version and allows for evolution toward the intended final version.

The intervention described in the model is theorized to affect teachers' *choosing behavior* about whether to engage in science-related academic achievement tasks. The representational tasks are academic achievement task because individuals' performance is evaluated both by their own, internal standards and by external standards, the views of the science adept, peers within the group, and by peers in "competing" groups. In the workshop model, the *subjective task value* is an individual's composite view of the positive and negative experiences in engagement with an academic achievement task. It comprises the *intrinsic task value,* an individual's valuation of how interesting or enjoyable engaging in an academic achievement task is or would be, and the *utility task value,* an individual's own valuation of how useful mastering work of an academic achievement task is or would be. An individual's *expectancy for success* is their presumed probability for success in an academic achievement task, combining the individual's own conception of her ability and her estimate of the difficulty of future tasks.

Theory Behind the Workshop Model

The hypotheses behind the workshop model are that (a) much of the actual work undertaken within science cultures is cognitively approachable by most adults and children at some prototypical level; (b) such work can be intellectually and emotionally satisfying to adults and children, but may be culturally foreign; (c) given agency to resolve cognitive conflict in a familiar intersubjective milieu where cultural norms of science have differential power in meaningful situations, adults and children will choose to engage science work; and (d) engagement with science work that builds competence and capacity will lead the participants to incorporate some of the fundamental practices, values, and beliefs of science culture.

The formal theory of change for this intervention (Figure 1) uses three stages of cause and effect: In stage 1, self-awareness of inconsistencies in an individual's understanding drives them to rebuild their theories of the world (Forman & Hall, 2005; Gopnik, 2012; Piaget, 1963) and hence to engage the world and their representations, while constructivist facilitation in science imperatives moves individuals to engage the task in ways approaching science work. In stage 2, experiencing increased competence in meaningful tasks and acquiring an admired culture is subjectively valuable to individuals (Rogoff, 2003; Vygotsky, 1962) and increases their sense of agency (Bandura, 1977). In stage 3, increased subjective task value and expectancy of success cause individuals to preferentially choose to engage and complete related tasks (Eccles, Barber, Updegraff, & O'Brien, 1998).

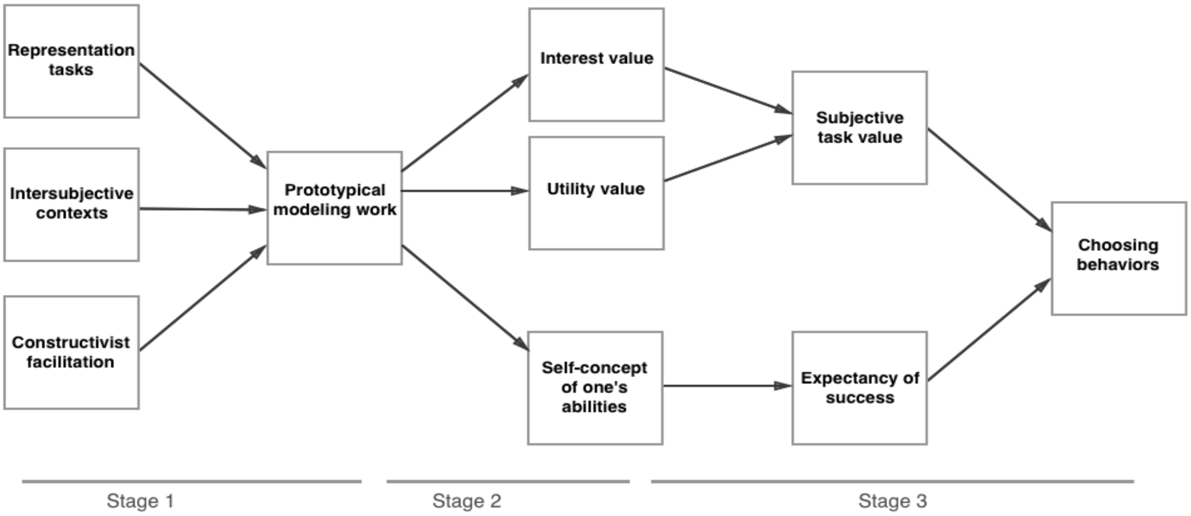


Figure 1. Causal model behind the theory of change of the workshop

In stage 1, the intervention leads to engagement in prototypical science modeling tasks. The combination of culturally sensitive provocations to representational tasks, culturally natural intersubjective contexts, and constructivist facilitation are expected to engage the participants in work prototypical of scientific modeling. Enacting materials are familiar and easy to manipulate and observe. Task prompts challenge participants to look at the physical world and reinterpret and represent their lived experience of their own thinking. Contexts encourage discussions within and across peer communities. Facilitation presses participants to examine a familiar phenomenon past what is considered functional, but it accepts as useful and meaningful the cognitive tools brought forward by the group. Facilitation presses participants to represent their thinking symbolically past what is considered functional, but accepts coinages and revision strategies. Facilitation presses discussions among participants to develop an intersubjective standard for clarity, correctness, and precision, past what is considered normal. These intervention features provide opportunities for participants to use and develop their cognitive and cultural tools in situations prototypical of scientific modeling.

In stage 2, engagement builds subjective value and self-concept. Participants' lived experiences of their work are expected to give the tasks higher intrinsic and utility value compared with others of their experiences working with science, and should increase participants' sense of self-efficacy in science-related achievement tasks, including teaching science to children. The modeling abilities to parse physical reality and hold the components symbolically are "higher-order" cognitive functions similar to the use of expressive language to parse and express one' own mind and, like competence in language, are experienced as a movement toward mastery of the self and the environment and are experienced by the individuals as participation in a culture supporting actual science work. These experiences make work on academic science tasks both more internally valuable and useful in understanding the immediate environment, and useful for individual professional goals.

In stage 3, increased subjective value and expectancy of success affects future choices. Belief in the personal value of this work, construed as science-like tasks, should increase participants' subjective value of academic science tasks generally. Increased sense of competence in the high-order thinking characteristic of science work will increase the individual's belief that they are able to succeed at future science-related tasks. These changes should increase participants' likeliness to choose, engage in, and persist in achievement tasks around science, including professional development around science and teaching science in their classrooms.

The Design of the Workshop Model

The workshop model uses small-group and whole-group activities that give teachers opportunities to engage in prototypical scientific modeling tasks in culturally sensitive contexts simulating some of the imperatives of science work (Figure 2).

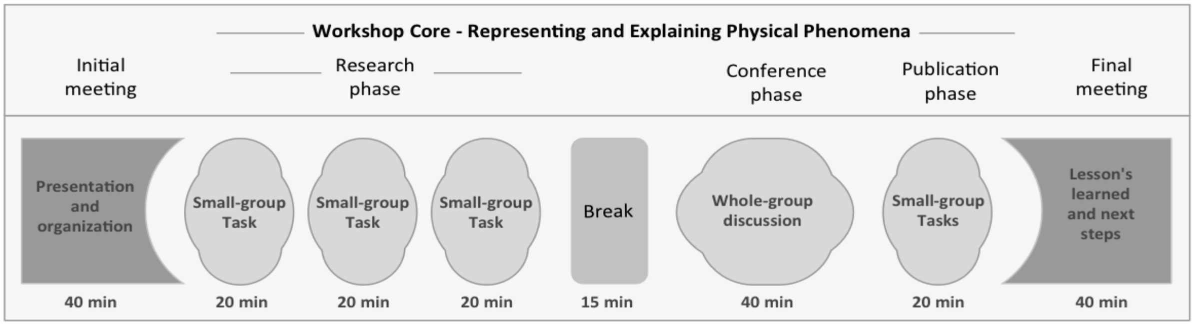


Figure 2. Model plan of the *Seeing the World Differently* workshop

The workshop model has five phases. The general purpose and content of each phase and guidelines for facilitation are presented below:

1. *Initial meeting*. The initial meeting draws teachers away from a view of science and science education as scripted and toward seeing that work as open-ended and exploratory, with uncertain outcomes but guided by imperatives to clearly and concisely describe and explain the physical world. To the whole group, the facilitator lays out the line of thinking behind the workshop through a presentation built around key content and process themes. To the extent that canonical science occurs in the key themes, the facilitator can talk about what science work looks like and how to get children to engage in it. The facilitator does introduce norms of physics as a type of science—mechanistic explanation, systematic comparison between experience and understanding, the creation of models—but does not offer or elaborate on physics terms, symbols, or concepts.
2. *Research phase*. The research phase engages teachers in representational tasks in contexts prototypical of research lab work and under imperatives prototypical of science work. In small groups, teachers transition through a sequence of provocations. Each provocation tasks the teachers to explore one simple, familiar phenomenon, but does not tell them how to proceed. Each provocation presents simple, familiar materials to enact a phenomenon and prompts teachers to describe and explain what they see as clearly and completely as they can using semi-structured pencil-and-paper representations. The facilitator uses scaffolding practices to press the teachers to increase their competence in following the target science imperatives. The facilitator does not refer to canonical

physics content or attribute difficulty or degree of success to science content, but does attribute these to the nature of observing, describing, explaining, and representing the phenomenon at hand.

3. *Conference phase*. The conference phase engages teachers in a plenary discussion of their thinking and representations in a context prototypical of a science conference and under imperatives prototypical of science work. In a whole-group meeting, the facilitator organizes a discussion of the problems and successes of the small-group work. The facilitator asks the teachers to tell about what they saw at work in the phenomenon, how these things interacted to produce the phenomenon, and how they represented their thinking about the phenomenon. The facilitator uses scaffolding practices to press the teachers to increase their competence in following the target science imperatives. The facilitator does not refer to canonical physics content and does not attribute difficulty or degree of success to science content, but does attribute these to the nature of enacting, observing, describing and explaining a phenomenon at hand and to representing thinking.
4. *Publication phase*. The publication phase engages teachers in the representational tasks in contexts prototypical of the science work of making public careful representations of thinking intended for a critical audience of peers. In their small groups, teachers revisit their earlier representations and the enacting materials and produce definitive representations of each phenomenon. They freely discuss their work across small groups if they wish. The facilitator uses scaffolding practices to press the teachers to increase their competence in following the target science imperatives. The facilitator does not refer to canonical physics content and does not attribute difficulty or degree of success to science content, but does attribute these to the nature of observing, describing, explaining, and representing the phenomenon at hand.
5. *Final meeting*. The final meeting closes teachers' engagements with the physical world, moves the work out of contexts prototypical of science, and leads teachers to engage the content and process of the workshop itself. To the whole group, the facilitator lists the key content themes of the workshop and then briefly presents how physics would describe and explain the phenomenon they studied. The facilitator then leads a critical evaluation of both the small-group work and the physics and uses scaffolding practices to press the teachers to articulate the benefits and costs of each. Finally, the

facilitator lists the process themes of the workshop and leads brainstorming around how these might work in teachers' own classrooms.

The Present Study

The general purposes of this study are to look at effects at stage 1 and stage 2 of the causal model and to gauge the social validity of the model. Specifically, it aims to (a) implement the model in a controlled way; (b) assess whether it elicits prototypical scientific modeling behaviors; (c) evaluate whether early childhood teachers value this kind of work as personally enjoyable, interesting, and useful; (d) measure the intervention's effect on teachers' beliefs about the task of getting children to learn science; and (e) evaluate whether early childhood teachers think the workshop as a whole was valid science professional development.

Research Questions

For the Seeing the World Differently workshop model:

1. Do workshop participants engage in prototypical scientific modeling behaviors?
    - 1.1. Do participants engage in arranging materials to create conditions for them to see and formulate questions about the physical phenomenon they are tasked to describe and explain?
    - 1.2. Do participants invent measures for characteristics of the physical phenomenon they are tasked to describe and explain?
    - 1.3. Do participants display representational competencies in externalizing their thinking about the physical phenomenon they are tasked to describe and explain?
    - 1.4. Do participants follow an epistemology of modeling while engaged in the prototypical scientific modeling tasks?
    - 1.5. Do participants' modeling behaviors differ between the research phase and the publication phase of the core treatment?
2. Do workshop participants find subjective task value in the activities of the workshop?
    - 2.1. Do participants find intrinsic task value in the activities of the workshop?
    - 2.2. Do participants find utility task value in the activities of the workshop?

    2.3. Do participants value the workshop phases (initial meeting, research phase, conference phase, publication phase, final meeting) differently?
3. Do workshop participants' expectancy for success in science tasks differ before and after the workshop?
    3.1. Do participants self-efficacy beliefs toward teaching science differ before and after the workshop?
    3.2. Do participants outcome-expectancy beliefs toward teaching science differ before and after the workshop?
4. Do workshop participants find social validity in the workshop as professional development?
    4.1. Do participants believe the workshop focused on science content and pedagogy appropriate for elementary classrooms?
    4.2. Do participants believe the workshop provided them with opportunities for active learning?
    4.3. Do participants believe the workshop was coherently aligned with their curricula, standards, and the ways they will be evaluated professionally?
    4.4. Do participants believe the workshop focused on science content and pedagogy that would be supported at their school or district level?
    4.5. Would participants pursue opportunities for follow-up activities to assist in incorporating either the physics content or the teaching methods they learned into their classrooms?

Methods

This study implemented a modified version of the *Seeing the World Differently* model in a series of two 1.5-hour after-school professional development workshops.

The design of the study followed a single, small sample without a comparison group. The fidelity of the implementation of the model is assessed throughout. The entire workshop is considered a treatment for effects on teacher self-efficacy beliefs. Teacher behavior prototypical of scientific modeling is assessed for small-group engagements. Subjective task value is assessed for each workshop component. The social validity of the workshop as a whole is assessed.

Participants were a volunteer sample of 7 early childhood teachers from a Northeast TN urban school district. All participants were predisposed to enjoy science activities and to teach science. This limits the population of inference to regional elementary-school teachers who enjoy science-like activities and who believe in their abilities to teach science.

Each teacher kept a structured journal to capture quantitative and qualitative data on their experiences during the workshop, and each filled out a workshop evaluation questionnaire at the end. Study staff video-recorded small-group and whole-group sessions. Pre- and post-treatment assessments of teacher beliefs were collected online using a modified version of the Science Teaching Efficacy Belief Inventory. During the workshop, the facilitator filled out a protocol checklist between workshop components.

To answer questions about teachers' targeted modeling behaviors (RQ1.1-4), counts of codes of targeted modeling behaviors were made from video recordings of the small-group modeling tasks. Whether participants' modeling behavior differed between the research-phase and the publishing-phase modeling tasks (RQ1.5) could not be answered because the study workshop did not implement the publishing-phase of the model. To answer questions about teachers' perceived value of workshop components (RQ2.1-2), distributions in individual's evaluations of each component are given, and generalizations to ideal populations are tested with *t*-tests against a null hypothesis of no strong feelings. To judge whether the participants reacted differently to different phases (RQ2.3), trends in mean evaluations and individual's evaluations across components are plotted, and a MANOVA is run using phase as the independent factor and construct-level measures of intrinsic task value and utility task value as dependent variables. To answer questions about teacher self-efficacy and teaching outcome expectancy beliefs (RQ3.1 & RQ3.2), distributions in individual evaluations are given for both before and after treatment, and generalizations to ideal populations are tested with one-sided *t*-tests against a null hypothesis of no mean difference. To answer questions about the social validity of the workshop as professional development (RQ4.1-5), distributions in individual's evaluations are given, and generalizations to ideal populations are tested with *t*-tests against a null hypothesis of no strong feelings.

Summary

This chapter stated the main line of thinking behind the model being explored: The work of science is not what most people expect. It is an unusual way of looking at the world developed over centuries. It is a cultural legacy similar to language and mathematics. Getting good at it involves a particular kind of work in the classroom, work that teachers and their students can do and can enjoy.

The introduction then presented the model in detail and clarified key terms and constructs. Finally, it gave the purpose of the study and the specific research questions addressed and outlined the methods of data collection and analysis used. Ideas introduced in this introduction will be developed in the review of the pertinent academic literature in Chapter 2.

CHAPTER 2

LITERATURE REVIEW

The thesis developed in this review is that the problems of teaching science in ways that do not alienate most people are not to be solved by thinking just about thinking. They require attention to the mechanisms through which people develop their competence in dealing with their own worlds, which in turn requires attention to culture.

This review will attempt to make three main points, outlined here and developed below from the literature:

1. National STEM standards in the United States have evolved over the last decade to require that elementary school education bring into the classroom work that is prototypical of actual science work, a change that will require different work for both students and teachers.

The context of elementary school science is changing in ways that may exacerbate old problems in science education. This change, if honored, will require elementary-school teachers to change the work they ask of their students, and in turn, their own engagement with science-related work, something they historically are averse to doing.

2. The tools of science work are more akin to a different way of being in the world, and they take sustained, culture-bound processes to develop.

The culture that science work is embedded in developed in isolated cultural communities over centuries. Those who work at science—scientists—think in ways that most people have capacity in; however, they function under demands that are very much at odds with the communities most people are already highly functional in. The new standards address this, but only in special cases. The problem is more general than that.

3. Small, regular interactions among people working through cognitive conflict within a familiar culture but organized around science cultural imperatives could draw people along the developmental paths leading to the cultural tools of science.

The intervention explored in this study is an attempt to meet this last challenge. It tasks adults to do work prototypical of scientific modeling within peer groups using familiar materials in contexts that simulate the contexts and imperatives of science work.

New Standards for Student Work in School

The view that improvement in science achievement across all cultural groups in the United States is best served by moving science education in K-12 closer to the professional work of science has gained ascendency among academics and policymakers studying science education. Several national calls for reform map out specific practices that teachers should bring into the classroom (American Association for the Advancement of Science, 1990; National Research Council, 2012). This reform movement emphasizes students working in groups, posing questions, designing and carrying out investigations, creating, testing and revising models, and arguing for their views based on evidence. These activities are meant to be like the work that practicing scientists advocate as compelling. Research in cognitive psychology (Gopnik, 2012) shows that young children are capable, with support and at developmentally appropriate levels, of the kind of intellectual work being demanded. These recommendations for "taking science to school" (National Research Council, 2007) have been incorporated into the "science and engineering practices" of the Next Generation Science Standards (NGSS Lead States, 2013). As of 2014, nearly two-thirds of students in the US are learning under science standards influenced directly by this movement (National Science Teachers Association, 2014).

Progression Toward Professional Practices in Science Education

In the 1980's, in response to the publication of *A Nation at Risk* (Gardner, 1983) there was a vigorous call for clear standards across public education (Good, 2010; van Eijck & Roth, 2010). Subsequently, several groups of considerable means and national scope began initiatives to establish the agenda for science education reform. This launched a sustained effort by major players in scientific research communities to formulate a national consensus on what science, mathematics, and technology education should accomplish.

Committing to nationwide science literacy. In 1985 the premier professional science organization in the United States, the American Association for the Advancement of Science (AAAS), launched *Project2061* (American Association for the Advancement of Science, n.d.) as "a long-term initiative to help all Americans become literate in science, mathematics, and technology." Project2061 produced a series of recommendations: a general statement of what constitutes science literacy, *Science for All Americans* (AAAS, 1989), guidelines for science standards, *Benchmarks for Science Literacy* (AAAS, 1993), and a guide for the development of science teachers, *Resources for Science Literacy: Professional Development* (AAAS, 1997). Along with the National Science Teachers Association, the AAAS also developed an online teaching resource, the *Atlas of Science Literacy*, *Volume 1* (2001) and *Volume 2* (2007). In 1996, the National Research Council, building off the work of the AAAS and the NSTA published the *National Science Education Standards* (National Research Council, 1996).

Rebuilding STEM as facilitated professional practice. In 1996, an independent effort by a committee of governors and business leaders created a non-profit organization, *Achieve, Inc.*, (Achieve, Inc., 2018) to help states establish a nationwide consensus on what graduation from high school should mean (the "Diploma Project") based on contemporary articulations of targets for students. By 2008, Achieve published work promoting the utility of a "common core" of standards in English and math, and in 2009, in partnership with the National Governors Association and the Council of State School Officers launched the Common Core State Standards (CCSS) initiative. The CCSS published the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010b), folding together position papers from the National Council of Mathematics and the National Research Council, and other published academic work. Achieve managed the follow-up assessment project as well, the Partnership for Assessment of Readiness for College and Careers (PARCC).

This initiative challenged mathematics standards nationally to become "substantially more focused and coherent" and more competitive with international norms, and to emphasize "*why* a particular mathematical statement is true or where a mathematical rule comes from" and to incorporate general "mathematical practices" that stretched expertise in mathematics to include perseverance, argumentation, communication, and the disposition to think of mathematics as useful (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010b, p. 4).

Following the publication of the *Common Core*, in 2011 Achieve began managing the development of new science education standards based on the document *A Framework for K-12 Science Education. Practices, Crosscutting Concepts, and Core Ideas* (National Research Council, 2012), a formalization of an earlier NRC position paper, *Taking Science to School* (National Research Council, 2007). By 2013, the taking science to school reforms were publicly embodied in the Next Generation Science Standards (NGSS Lead States, 2013), which quickly influenced state standards across the United States (National Science Teachers Association, 2014).

The New STEM Standards

Standards for science, technology, engineering, and mathematics (STEM) education is addressed in three documents of national scope. Two are outlined below. A third, the Common Core State Standards for English (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a), includes a strong science literacy component addressing practices more specific to reading and argumentation but is not considered here as it does not pertain directly to professional practice.

The Common Core State Standards for mathematics. The Common Core State Standards for Mathematics task teachers at grades K12 to develop their students' abilities to act more in accord with professional practices, many of which overlap with science practices. These standards are separated into Standards for Mathematical Content and Standards for Mathematical Practice. The content standards are focused on fewer core ideas than typical state and local math standards, and emphasize understanding over procedures. The practice standards were created as appropriate precursors of how adults who work with math, specifically science and engineering workers, typically use math.

There are eight Standards for Mathematical Practice: (1) make sense of problems and persevere in solving them; (2) reason abstractly and quantitatively; (3) construct viable arguments and critique the reasoning of others; (4) model with mathematics; (5) use appropriate tools strategically; (6) attend to precision; (7) look for and make use of structure; and (8) look for and express regularity in repeated reasoning. As an example of the demands these standards will put upon teachers, as early as kindergarten teachers are tasked to guide young children to competence in using numbers and shapes to "model their physical world" (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010b, p. 4).

The Next Generation Science Standards. The Next Generation Science Standards (NGSS) are articulated as sets of performance expectations, statements of "what students should be able to do in order to demonstrate that they have met the standards" (NGSS Lead States, 2013, p. xii), organized around statements of domain-specific topics. Following the 2011 framework document, the NGSS articulate three areas of competence: *Disciplinary core ideas* are domain-specific statements of knowledge used in the traditional scientific disciplines such as biology, earth-science, etc. *Crosscutting concepts* are "big ideas" (p. 30) that emphasize that some basic ideas extend across disciplines and make the world understandable through science. *Practices* are behaviors meant to mirror the work of professional scientists and engineers. In this sense, they are similar to the Common Core State Standards, which expect teachers to integrate content with practice at all levels.

The NGSS differ from the *Common Core* and from earlier science standards by *systematically* integrating professional behaviors *into each performance indicator at each grade level*. If taken at face value, in effect the practice standards push actual scientific practices—the work of science—regularly into public schooling even down into kindergarten. These practice standards task teachers to find ways to engage young children in the definitive science work of "asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information" (NGSS Lead States, 2013, p. 4).

A shift to work prototypical of science. The NGSS are explicit in stating that they constitute a major change in the way science education should work, "a new vision for science education rooted in scientific evidence [for] kindergarten through the end of high school" (NGSS Lead States, 2013, p. iv). The document explicitly states that the standards rework the pedagogy of "inquiry" from statements about “hands-on” or “minds-on” engagements to focus teachers on what those who work in science actually do, “the major practices that scientists employ as they investigate and build models of and theories of the world and a key set of engineering practices that engineers use as they design and build systems.” The NGSS emphasize that “practices” are meant to “better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires” (p. xviii). In sum, they build expectations of student performance at each level to include these practices, calling on teachers to focus on integrating student work broadly across the work of science.

The overall intent seems to be to have adults to not prescribe engagements with the world or to not just talk to children about the world as science paints it, but to immerse them into the world of science work. “Learning science depends not only on the accumulation of facts and concepts but also on the development of an identity as a competent learner of science with motivation and interest to learn more” (NGSS Lead States, 2013, p. xviii). The NGSS task teachers of children as young as five years old to enact curricula that have the children participate in the actual culture of modern science, so that through their schooling, children come to understand how science builds trustable knowledge and to integrate those methods and that knowledge into the cultures they bring into the classroom.

To motivate for this substantial revision in the work of teachers, the standards document recounts the advantages for taking science to school. It emphasizes that children will not make sense of the products of science without being embedded in the work of science: “students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined” (National Research Council, 2012, p. 218). It emphasizes science practices to accomplish a number of outcomes that address longstanding complaints about science and culture: science work “makes students’ knowledge more meaningful and embeds it more deeply into their worldview” (p. 42). It helps to call forth “the diverse knowledge and skills that members of different cultural groups bring to… science learning contexts” (p. 288). Science practices also build epistemological norms of science work: “engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world” (p. 42).

The list below excerpts language from the NGSS (NGSS Lead States, 2013, pp. 50-64) defining each science practice standard:

1. *Asking questions and defining problems*. “Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations.”
2. *Developing and using models*. “Modeling can begin in the earliest grades, with students’ models progressing from concrete ‘pictures’ and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system.”
3. *Planning and carrying out investigations*. “At all levels, [students] should engage in investigations that range from those structured by the teacher to those that emerge from students’ own questions.”
4. *Analyzing and interpreting data*. “[Students] are expected to expand their capabilities to use a range of tools for tabulation, graphical representation, visualization, and statistical analysis [and] to improve their abilities to interpret data by identifying significant features and patterns, use mathematics to represent relationships between variables, and take into account sources of error [and to] present data as evidence to support their conclusions.”
5. *Using mathematics and computational thinking*. “Students are expected to use mathematics to represent physical variables and their relationships and to make quantitative predictions [and] to engage in computational thinking.”
6. *Constructing explanations and designing solutions*. “Students are expected to construct their own explanations, as well as apply standard explanations they learn about from their teachers or reading [and] to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed.”
7. *Engaging in argument from evidence*. “Students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose [and] to

use argumentation to listen to, compare, and evaluate competing ideas and methods based on their merits."

8. *Obtaining, evaluating, and communicating information*. "To read and produce domain-specific text [and] to recognize the salient ideas, identify sources of errors and methodological flaws, and distinguish observations from inferences, arguments from explanations, and claims from evidence."

Attention to students' culture in the new standards. The Next Generation Science Standards clearly were written to address social justice critiques, citing that literature numerous times throughout the document. Appendix D of the NGSS (NGSS Lead States, 2013), "All Standards, All Students: Making The Next Generation Science Standards Accessible To All Students," guides teachers to teaching science to specific groups. That discussion references "dominant groups," identified as having "social prestige and institutionalized privilege," and "non-dominant groups," identified as "traditionally underserved by the education system" (p. 25), though it does not identify specific groups this way. It separately references "student groups that have traditionally been underserved in science classrooms" (p. 25), which from context seem to be: the economically disadvantaged, students from racial and ethnic groups, students with disabilities, students with limited English proficiency, girls, students who have been moved out of mainstream schooling, and gifted and talented students. Though the discussion is hard to thread together, the main point made seems to be that evidence has shown that the cultural tools and references used in teaching science have predisposed to success in science classrooms boys from White, non-Hispanic, English-speaking, economically secure households.

Using funds of knowledge of non-dominant groups. The standards give specific recommendations for teaching each of the groups identified as more challenged by learning science in current classrooms, but generally, they ask teachers to capitalize on students "funds of knowledge," which they identify as "culturally based understandings and abilities... and the social and intellectual resources contained in families and communities" (NGSS Lead States, 2013, p. 30) and specifically task teachers to make use of these cultural resources.

Using funds of knowledge of those lay to science generally. The earlier and superseded *National Science Education Standards* (National Research Council, 1996), barely addressed the science education of cultural out-groups, but did have a general warning for teachers that in teaching science they will "represent a culture and a way of thinking that might be quite unfamiliar to students" (p. 88). The framework the NGSS were built upon (National Research Council, 2012) makes the point that all "students come to the classroom with preconceptions about how the world works."

> If their initial understanding is not engaged, they may fail to grasp new concepts and information presented in the classroom, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom. This finding requires that teachers be prepared to draw out their students' existing understandings and help to shape them into an understanding that reflects the concepts and knowledge in the particular discipline of study. (p. 2)

Appendix D of the NGSS develops this idea for the "non-dominant" groups referenced above, but this study maintains that this call applies quite generally: most people have little access to referents that would make science work naturally accessible in the classrooms of today. The workshop model aims to present a way to help bridge the culture of working science with that of science students, regardless of their status within "dominant" or "non-dominant" groups.

Elementary-School Teachers as Facilitators of Science Practices

The discussion above leads to the conclusion that the Next Generation Science Standards and the Common Core State Standards for Mathematics move beyond the goal of developing a nationwide pool of talent to fill a STEM pipeline and beyond the goal of creating a citizenry that is literate in the accomplishments of science work and that believe in its relevance. They set a further goal to have people who are outside of science work embed science norms of practice and knowledge into their work world by facilitating children's participation in experiences of a professional culture. Yet the mismatch between the culture—the practices, beliefs, values, and emotional responses—of actual science work and the cultures of the children and the adults who find themselves tasked to learn or teach science in school are in some ways vast.

Classroom culture will change. By requiring students to participate in a world of science work, these math and science standards, to be met, will require a profound change in both the work of young children in school *and the work of their teachers*: Actual science is not scripted (Tinker, 1997) as most of the questioning in schooling is (Bartholomew et al., 2004; Engel, 2011; Heath, 1982). Its end-product is a moving target met by a process that does not end (Medawar, 1984), unlike the stable articulations in textbooks, learning objectives, and tests. Actual science values tentative knowledge and self-correction (Feynman, 2000). It requires a belief that the world is organized around things that cannot be seen but that are somehow measurable and that predict the behavior of the visible world (Penrose, 2005).

Teachers' work will change. The new standards will require classrooms in which adults manage unscripted and unpredictable work. Classrooms will have to task children to create order from a complex situation; to feel good about openly trying, failing, adjusting, and trying again; and to build pictures of how the world works from their own experiences and, then, to accept that getting some of it right is an admirable outcome. Teachers will have to embrace a process of questioning and answering that allows problems to be resolved within each child's mind by activities that are distributed across individuals and over time. Children and adults will necessarily create, use, challenge, and modify representations of the physical world. I ague below that these new tasks, processes, and emotional responses signal a profound difference in what is valued within a classroom culture, what actions and activities are normal, what constitutes knowledge, and how people should react to success, failure, and disagreement.

Elementary-school teachers' aversion to science-related tasks. In the United States, elementary-school teachers at some point in their lives have been in science classes themselves, and for the most part, they did not like the experience (Kazempour, 2014). Research shows that elementary-school teachers themselves are aversive to teaching science based on their own experiences in schooling (Brigido, Borrachero, Bermejo, & Mellado, 2013) and that these attitude factors reduce their effectiveness as science teachers, reduce their students' learning, and may cause their students to have negative attitudes toward science (Munck, 2007). In sum, elementary-school teachers do not want to try to teach the science they failed to learn in their own schooling.

Though the national trends in K-12 science and math standards described above require pedagogy that elicit behavior that is more characteristic of actual science work—modeling and representation, critical dialog within peer groups, and discourse around the epistemic and ontological strength of statements about the physical world—research shows that these behaviors are unfamiliar and culturally foreign to most K-12 teachers and their students, and interventions (Bartholomew et al., 2004; Bencze et al., 2003) attempting to move teachers toward methods that might deliver the pedagogy required by the standards have poor results. That is, it is proving difficult to change the actual practice of school teachers toward enacting productive prototypes of science work in the classroom. However, professional development interventions directly targeting the attitudes of elementary teachers toward teaching science have had some success (Lumpe, Czerniak, Haney, & Beltyukova, 2012; Thomson & Kaufmann, 2013; van Aalderen-Smeets & Walma van der Molen, 2015; Young & Kellogg, 1993) and show promise in increasing both elementary teachers' interest in teaching science and their engagement with science-related professional development.

Scientists as Cultural Productions

Humans develop most of the cognitive tools that we take for granted as being naturally human—including language, mathematics, and formal reasoning—through enculturation from being embedded in an existing culture and using access to it to develop competence and mastery (Rogoff, 2003; Vygotsky & Luria, 1994). Though very early on developing humans can unselfconsciously think the way scientists consciously do (Forman, 2010; Gopnik, 2012), which is largely the way most people think when curious and wondering (Giere, 1990; Tinker, 1997), seeing the world as working scientists do is not a natural consequence of being human. It is a cultural legacy built over centuries (Burt, 1980; Hestenes, 1992; Kuhn, 1962; Maier, 1982), quite at odds with functional and longstanding cultures. As a consequence, there are many beliefs, values, and behaviors characteristic of science work that are not common coin of popular culture. As Osborne, Simon, and Collins (2003b) put it when arguing for science education as important cultural transfer:

> the cognitive tools used by science have emerged historically as a contingent, cultural product of specific contexts—an accident of history... cognitive tools, resources and styles of reasoning that have been used to argue for a set of ideas—ideas that initially seemed absurd. (p. 11)

This section first presents a brief overview of how the understanding of science work has evolved from positivist claims of absolute knowledge, through counterclaims by social critiques that science is an empty construction, to the current view that science work involves normal cognition, though highly developed and supported by specialized cultural communities. It then outlines some of the general cultural imperatives of those communities. Finally, it illustrates how the norms and beliefs of the science cultures of today appear idiosyncratic.

What Do Scientists Really Do?

Misunderstanding about how the actual thinking and social interactions of working scientists relate to the capacities and proclivities most humans are born with has debilitated science teachers (Giere, 1990; Kind & Osborne, 2017; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003a). And though some want to leverage the cognitive capacities and ways of engaging the world of children into “science” (Chaillé & Britain, 2002; Forman, 2010; Gopnik, 2012), a clear picture of how people in and out of science build knowledge challenges this as counterproductive (Brewer, 2008; Solomon, 1992a).

From positivism to social constructs. Early attempts by academic philosophers to understand science thinking cast the cognitive work of scientists as approximations of idealized principles of rationality, necessary systems of logic connected to the world by careful observation (Giere, 1990). From this view, it was argued that the difficult work of teaching science to children should present the rationality of scientists and should insist that science gives the logically correct view of physical reality (Matthews, 2000). That is, the knowledge built by science was our best understanding of the way the world works.

Partially in reaction to the authority this explanation for the success of science seemed to give “Western science” over non-scientific cultures and over subcultures of “the West” viewed as not privileged, academic sociologists recast science thinking as negotiations within privileged groups, “social constructions” that should not be pushed by schooling onto others (Aikenhead, 2008; van Eijck & Roth, 2010).

Thinking embedded in a particular culture. Recent work studying what those who work in science *actually do* shows that modern science is well understood as normal thinking about physical reality developed and organized within distinct social groups with particular characteristics (Giere, 1990; Nersessian, 2002, 2005, 2008). From these accounts, understanding the achievements and limitations of science requires examination of both the cognition of scientists and the norms and practices of the culture in which they work. Those who do science may tend to have certain cognitive strengths and social histories, but their natural capacities have been developed through years of personal practice and enculturation (Forman, 2010; Taber, 2008; Tinker, 1997). And though they are driven by, and make use of, internal experiences that are available to humans from the early years on, people adept in science culture tend to see the world in a particular way and work under strict norms.

Cultural Imperatives of Science Work

Many practices of actual scientists are cultural idiosyncrasies. Science work calls for people to articulate and reify constructs that describe and explain a mechanistic world (scientific ontology) (Bartholomew et al., 2004; Hestenes, 1992; Lehrer, Schauble, & Lucas, 2008; Sandoval, 2003). Science work requires people to warrant their claims in specific statements about observations, models, theories, and established fact (scientific epistemology) (Osborne et al., 2003a; Toulmin, 2003). Science work requires people to represent their thinking in conventional ways and clearly communicate their thinking to peer groups (National Research Council, 2012; Olson, 1994).

When the Common Core State Standards for Mathematics ask teachers to get children to attend to precision, model patterns in the physical world, and argue from evidence, they draw people away from norms of everyday behavior. These practices are functional in some contexts but dysfunctional in others. Valuing knowing simple things very precisely and the behavior of continually challenging the obvious, for example, are not necessary parts of anyone's life. These imperatives of science culture do not come naturally from humans young or old despite their natural capacities. Likewise, when the Next Generation Science Standards require children to "explain their world" based on "cross-cutting concepts" of science, the presumption is that descriptions and explanations will stay connected to a mechanistic view of the world. These cultural features and many others are hardly natural: They developed fitfully over hundreds of years (Maier, 1982; Olson, 1994; Penrose, 2005) and still are major source of contention in schooling, as evidenced by popular agitation around coerced learning about evolution in school.

However, pinning down what science work is like is not easy. Osborne et al. (2003a) motivates his attempt to survey a consensus view among disparate practitioners, communicators, and critics of science and science education by reviewing the record of attempts to spell out what should be taught in school: “So far, where individuals have thought extensively about the nature of science, and about an account that should be offered to others, they have experienced considerable difficulty in its specification” (p. 714).

Examples of How Science Culture Is Historically Bound

A mechanistic world view, highly valuing computational thinking, and reworking the obvious into formal representations are perhaps the more apparent idiosyncrasies of science culture. Below are a few less obvious illustrations from the academic literature of things that currently are or in the past were against the values, beliefs, expectations, actions, or emotional responses assumed as natural by science culture.

Abstract logic is not compelling. Rogoff (2003) illustrates the difficulty in knowing how a person thinks about thinking and how that depends on schooling by excerpting from a study Soviet psychologists Lev Vygotsky and Alexander Luria made of literate and illiterate adults in rural Central Asia. Bruner (Bruner, 1984) notes that Vygotsky used this study to argue that adults living in traditional peasant communities could be moved from “spontaneous” to “scientific” ways of thinking (Bruner, 1984) by changing their work from single farms to more mechanized and organized collectives. The assessment task presented a standard syllogistic form and then asked the subject to draw a conclusion:

> In the Far North, where there is snow, all bears are white. Novaya Zemlya is in the Far North and there is always snow there. What color are the bears there?
>
> Luria reported that many illiterate interviewees did not [answer “white”], though literate ones did. He gives an example response:

> “We always speak only of what we see; we don’t talk about what we haven’t seen... If a man was sixty or eighty and had seen a white bear and had told about it, he could be believed, but I’ve never seen one and hence I can’t say.” (2003, p. 39)

When Luria pressed the interviewee to follow the reasoning, he refused, consistently saying it would be dishonest to talk about things he knew nothing of. This is an epistemological stance, one set against the epistemology of science, which says that you know something if you can make a general statement about it without context.

Knowledge can’t be disembodied. Ingold (2004) studied how very basic ontological differences between Ojibwa and European-Canadian cultures create “cognitive barriers” between individuals trying to bridge their understandings of the world. He relates how insisting that a person represent their experience abstractly devalues it in their own eyes:

> It is not by representing the world in the mind that [Ojibwa people] get to know it, but rather by moving around in their environment, whether in dreams or waking life, and by watching, listening, and feeling, actively seeing out the signs by which it is revealed. Experience, here, amounts to a kind of sensory participation, a coupling of the movement of one’s awareness to the movement of aspects of the world... the kind of knowledge it yields is not propositional, in the form of hypothetical statements or ‘beliefs’ about the nature of reality, but personal, consisting of an intimate sensitivity to other ways of being,... such knowledge... is not easily articulated in propositional form, and would seem to be devalued by any attempt to do so, to disembed it from its grounding in the context of the knower’s personal involvement with the known. (p. 40)

This barrier directly challenges one of the imperatives of science, to communicate descriptions and explanations clearly and coherently so that others can discuss it.

Motion is not real. When the Next Generation Science Standards require that 5 and 6-year-old children conduct investigations on the effects of pushes and pulls on the motion of an object, they quietly presume that “motion” is an uncontroversial and self-apparent idea. However, it is a cultural acquisition.

Parsing physical reality by analyzing an object's changing position over time is a cultural practice, based on a recent ontology, developed out of difficult academic discourse among the great minds of the late middle ages (Maier, 1982). In the 14th century, scholastic philosophers argued over the "ontological definition" of motion as the sum of real stationary states that an object passes through in succession. The states were real and the sequence was real, but the idea of a "rate change" was inconceivable. To the "scientists" of that time,

> … nothing real corresponds to the concept of motion; it is merely a word or label [and] do not have any objective referents. They are merely superfluous and dispensable names or words that were created for the sake of elegance in discourse rather than from necessity and do not stand for anything external to the soul. (p. 31)

Over the next two centuries, some of the great minds of the time slowly developed methods of using numbers to describe motion, leading to Galileo's declaration that God speaks to us in mathematics (Galilei, 1957).

Curiosity doesn't need support. Does curiosity have a place among the values and beliefs, expectations, actions, and emotional responses within science education? In a review of how curiosity works in American formal schooling Engel (2011) relates an anecdote from an observation of a middle-school class illustrating how "science" can mean different things to the same person. During a prescribed hands-on activity to lead children to discover that wheels reduce friction and the force needed to move something, some children moved away from the written instructions and began using the given materials to explore different things. The teacher intervened: "Ok, kids. Enough of that. I'll give you time to experiment at recess. This is time for science." (p. 627)

Engel (2011) notes that the activity was "the kind of hands-on activity promoted by many educators," but that "just as the children became interested in formulating and answering their own questions—when curiosity, the mechanism that underlies the best learning, kicked in," the adult in the room redirected them back to scripted "science" (p. 627).

Engel (2011) reviews the literature on how curiosity, what she calls “possibly the most valuable asset a child brings to her education” (p. 633), appears in formal schooling. She finds that though teachers “passively endorse” curiosity, they don’t act as if it is has a place in their work with children. In one sample of middle-school teachers, when given a list of things they wanted to nurture in their students, three-quarters chose curiosity as one of the top five qualities, but when asked to name their own, few mentioned it. In a study of “curiosity episodes” in well-funded classrooms, not overcrowded and with good social atmosphere, she observed in kindergarten there were only 2–5 episodes among 22 students per two-hour period, and in fifth grade, there were 0–2. In summary, she concluded that “children are spending hours a day in school without asking even one question or engaging in one sequence of behavior aimed at finding out something new” (p. 633).

Engel (2011) identifies many reasons for this, usually enacted through subtle cues given by adults to children in their regular interactions. As far as institutional support for curiosity, she points to two polar opposite views, both of which lead science education to disvalue the development of curiosity: on one hand, class time should be scripted to meet measurable standards within time constraints, and on the other, adults should resist intervening during exploratory activities to allow children to discover the workings of the world. What is not understood generally, Engel says, is that “talking about what interests or perplexes children gives them a chance to cultivate and expand their curiosity as an intellectual tool” (p. 637). Here, Engel understands curiosity not as a fixed attribute, but as a natural capacity of humans, responsive to the culture around it: “Curiosity doesn’t thrive merely because it’s tolerated or allowed now and then. It must be encouraged, facilitated, and guided” (p. 641).

The adults who teach and manage schooling are the products of decades of formal schooling themselves, and are not likely to have incorporated curiosity as an intellectual tool. It is arguable that those who, for whatever reason, develop this capacity and continue to value it choose professions that allow its free play, thus further biasing the pool of science teachers against this core cultural feature of science work.

Science Education as Cultural Conflict

Small, localized communities use patterns of adult-child interactions to move their children into competence in their worlds, patterns which appear repeatedly across cultures; but formal, institutional schooling is different (Rogoff, 2003). That the transitions from daily life to schooling and back are difficult and extremely important for the actual lives of students is well-documented in early childhood (Rimm-Kaufman & Pianta, 2000), adolescence (Phelan et al., 1991; Pianta & Hamre, 2009), and generally across the years (National Academies of Sciences, Engineering, and Medicine, 2018).

This section looks at the transitions into science classes in particular as cultural transitions. It briefly reviews social justice criticisms of science education and notes where those criticisms maintain for a broader population. It ends with a summary from a recent research synthesis on teaching and learning of recommendations for managing the transitions.

Cultural Differences and Cognitive Engagement

A sizable literature addresses why students from some cultures—the "non-dominant" groups—do worse in science classes than others based upon social justice criteria—race, ethnic background, gender, language, income. In these views, individuals from those cultures who find themselves facing the task of learning science through school are not challenged cognitively because the experience of school science work is entirely negative for cultural reasons and the actual cognitive work of real science is never even approached. These students leave their time in science schooling indifferent to the subjects, cynical about their usefulness, and often shamed, angry, and resentful at having to go through the ordeal.

These concerns, as noted above, have been brought into the recommendations of the Next Generation Science Standards. They are addressed for education generally in a more recent federal initiative summarizing new research around teaching and learning, *How People Learn II* (National Academies of Sciences, Engineering, and Medicine, 2018), which will be discussed below. What is notably lacking in these discussions is any accommodation for the difference between what science work expects and the values and beliefs, expectations, actions, and emotional responses not differentiated by those social-justice criteria. In particular, it is quietly presumed, though not mentioned in those documents, that White, English-speaking, economically secure, males (the "dominant group") will naturally do well in science classrooms. However, most students experience science education as an attempt to assimilate them into a strange and dysfunctional culture, and develop similar negative attitudes toward science (Osborne et al., 2003b).

Science Education Furthers Oppressive Power Relationships

The view that science education is appropriate for everyone is dismissed by some as cultural hegemony. Cultural-critical views of science stem in part from an analysis (Foucault, 1972) that language and knowledge organically "privilege" people belonging to the groups that historically and culturally define terms and reify them. This mode of analysis denies any epistemology based on a methodological engagement with "real" things. Instead, knowledge is "[constituted by] the relations of power that privilege the particular voices and hands who articulate" it, and so "academic science discourse privileged in school science may actually discourage socially helpful and responsible uses of science" (van Eijck & Roth, 2010, p. 191). Science at work in the real world is fragmented by the political and cultural allegiances of those who are representing science culture "in the wild," and the "voices allowed to speak" contend to frame "legitimate knowledge" (van Eijck & Roth, 2010, p. 192).

Aikenhead (2002) criticizes the "science-for-all" movement as defining "a mono-culture in which material progress is linked to the success of Western science—science for a privileged class who determines what that mono-culture will be" (p. 2) and that "motivates students by drawing upon… the contribution Western science and technology have made to a mono-culture determined by a privileged class" (p. 3). The "subculture of science education" (Aikenhead, 2008, p. 13) evolved to maintain this system as an elite priority, one held, Aikenhead judges, even over the need to provide a pipeline of individuals interested in and capable of work in Western Science.

The literature that frames education this way sees the educational goals of the science curriculum as "used to screen out students belonging to marginalized groups, thereby providing high status and social power to the more privileged students who make it through the science 'pipeline'" (2008, p. 13). The language is often strident: students are coerced into inhabiting a culture that is foreign, personally unproductive, and threatening to their identities. For example, “Western science” is a subculture characterized as “materialistic,” “masculine,” “exploitive,” “elitist,” and “violent” (p. 10). It is foreign to non-Western—and most Western—students. “Non-masculine students” find it particularly problematic, “as do humanities-oriented non-Cartesian thinking students; and as do students who are not clones of university science professors” (Aikenhead, 2008, p. 15).

In this framework, a student’s persistence in his beliefs about the physical world in the face of science instruction (Driver, Leach, Millar, & Scott, 1996; Solomon, 1992b) is a form of integrity in the face of attempted assimilation into strange cultural beliefs. Students “are not stupid” and do not “risk altering a useful commonsense conception in favor of a counter-intuitive abstraction advanced by a teacher or textbook” (Aikenhead, 2008, p. 3). In this analysis, high-achieving students in school science simply “caught on quickly to the cultural expectations of the classroom” while most students have to practice “‘cognitive apartheid’... the isolation and segregation of school science content within the minds of students” (p. 13). The most successful of those follow the typical rules of resistance to assimilation: evasiveness, manipulation, deceit, or resignation. The least successful simply drop away, avoiding opportunities to learn science in school whenever possible.

Science Education Creates Artificial Incompetence

A different social-justice criticism of the way science education is misaligned with the lives of students from specific cultures recognizes that science work is imbedded in a unique culture at odds with many people, but in this critique achievement in science is blocked (a) because students lay to science are not allowed to work using their own cultural tools, and (b) because work in the science classroom lacks the natural drivers of actual science work that might motivate students to engage classwork (Angela, 2002; Lee, 2002).

Lee (2002), working with children from Haitian families in the US, discusses how in science class in particular, students are discouraged from talking, acting, and thinking as they do outside the science classroom. Because these classes tend to deliver an authoritative view on how the world works, students’ views on things they already know a good deal about are routinely deprecated, and their language and descriptions are flagged at the start as insufficient. Further, because science education currently dwells on the products of scientific thinking and on prescribed enactments of encounters with the physical world, students are thrown into a made-up arena of scripted work, pre-determined thoughts, and insider knowledge.

> We are arguing for the need to analyze carefully, on one hand, the ways of knowing and talking that comprise everyday life within linguistic and ethnic minority communities and, on the other hand, the ways of talking and knowing characteristic of scientific disciplines. (p. 23)

In this view, though students experience science education as assimilation into a strange and dysfunctional culture, they are not immediately threatened by it. They are confused by what is going on but are denied access to the cognitive tools and cultural practices that would help them in moving toward the actual science work. This literature denies that students' native way of seeing the world represents deficits in need of replacement. Instead it views them as tools with which individuals engage the world and build interpretations.

As in other critiques, this view focuses on the alienation of out-groups relative to "the West" (the "non-dominant" groups) from the culture presented in science education classrooms. However, these criticisms could also be applied more generally.

Science Education Is Distant And Unengaging

Phelan et al. (1991) set out to understand which experiences of adolescents in a multicultural urban school district require them to be significantly "other" than the cultures of their families or peers, and how this affects their engagement with the classroom environment. Their results frame transitions between home and school contexts as "border crossings" into "worlds" potentially hazardous to a student's cultural identity. In her model, the degree of hazard experienced by a student depends upon the level of discord between a particular classroom and the mélange of microcultures the adolescent uses to assemble his or her self.

The factors Phelan et al. (1991) identified were whether a student's peer community had clear life goals, whether the student's peer community valued school as a means to advancement, whether the student's family and peer community's way of being together conflicted with class culture, whether the student's peer community was antisocial and oppositional, for example involved in violence or crime, and whether the student perceived herself as an outsider because of language or other cultural features. Notably, none of the contributions listed had to do with the content of the courses or the intrinsic value of academic work.

Costa (1995) uses Phelan's framework to understand students' response to science education in particular. She begins by marking science education as cultural transfer, stating that "learning science demands a different way of being in the world" (p. 314). Unlike Phelan, Costa includes ways of thinking as a marker of the difference between worlds.

Instead of listing cultural features that predict difficult transitions, Costa (1995) describes five patterns of engagement connecting cultural differences with success in science classes. Of the academically successful students, most did well in all classes, but experienced science classes as monotonous, even though they valued them as preparatory for college. A few academically successful students had built peer groups around a keen interest in science, either because it was intrinsically satisfying or useful for understanding things, or because science classes typified the careers to which they aspire. The largest group of students had no clear life goals and experienced all classes about the same: They did not know what the content was about, experienced school work as endurable busywork, but participated sufficiently to avoid bad grades. Students in the fourth group had some life goals, but these were not addressed by school. They did not think about science and experienced class as meaningless busywork, but did not value grades and were oppositional toward being in school. A last, small group of students were thoughtful about science and expressed interest in science as work, but were estranged from school for various reasons and remained disengaged in science classrooms.

Costa (1995) does not identify social justice categories as the main determinate of estrangement from science classes, though she notes that most of the group who had peer groups with a keen interest in science were male. What emerged strongly from this study is that most students experienced science class as teacher-directed busywork and found no immediate application to their own lives, and found nothing in the classroom to engage them.

This view is corroborated generally by a more recent review by Pianta and Hamre (2009), who found that in school, “youth routinely describe experiences in classrooms that fail to capitalize on their interests, goals, and motivation and instead promote disengagement and alienation” (p. 40). Pianta and Hamre (2009) paint a bleak picture of life in the classroom and highlights missed opportunities to bring adolescents into contact with targeted content in ways that would push their development:

> academic opportunities have a pronounced and almost singular focus on performing basic skills, tasks that require a discrete answer that is correct or not rather than eliciting analysis, reasoning, or problem solving around a more ambiguous challenge. (p. 41)

That this is the case in science classes, as noted below by practicing scientists, is ironic. The picture painted extends what the social justice literature documents as the alienation of students and the insensitivity of classrooms to the values and beliefs, expectations, actions, and emotional responses of students in specific cultures:

> youth in secondary classroom settings have few, if any, individual interactions with their teacher, and those are too often characterized by insensitivity and a failure on the part of the teacher to respect and support (appropriately) the very powerful drive toward autonomy and a sense of competence. (p. 41)

The overview below of learning as cultural transmission highlights the tragedy of this situation. It emphasizes that it is the regular interactions between the environment and developing humans seeking to extend their competence in their world that actualizes the genetic capacities of children, and in particular, working with adults who are adept in cultural tools is the way humans develop their intellect.

Recommendations for Addressing Cultural Distance in Schooling

In a major research synthesis around the implications for education of research into the mind and the brain, *How People Learn* (National Research Council, 2004) identifies young children as born investigators with capacity for sophisticated reasoning, who learn through problem posing and solving, and self-initiated challenges. The updated synthesis, *How People Learn II* (National Academies of Sciences, Engineering, and Medicine, 2018), represents a major extension of the earlier work toward a "sociocultural view of learning" (p. 22) that grounds any understanding of what learning looks like in cultural practices.

The review emphasizes that culture explains differences in what people believe is important to learn, what excellence in learning looks like, how children working with adults should behave, and core features of how people learn, including how they perceive physical things and what they remember. To those who teach, they advise that "everyone brings to their opportunities to learn the experiences they have acquired through participation in cultural practices in their communities" (National Academies of Sciences, Engineering, and Medicine, 2018, p. 27) and formulate guidelines specifically to address issues brought out by the social justice literature:

- *Students' outside culture provides assets, not deficits.* Classroom practices should move away from a "deficit" model of cultural differences, in which some groups are seen to lack things needed for academic success, to an "assets" model, in which "cultural practices of students are viewed as resources, tools, or assets" (National Academies of Sciences, Engineering, and Medicine, 2018, p. 140).
- *Academic classroom culture requires explicit development.* Teachers need to support students as they transition to making their thinking public and practicing criticism. Teachers should establish as group norms that claims should be explicitly warranted and that warrants can be challenged.
- *Cultural modeling facilitates incorporation of distal competences.* Students should be tasked to first locate their own competence in tasks prototypical of targeted work when academic tasks are inaccessible because the material is so foreign, and then use that internal experience as they turn to new material. Work should be organized to match peer structures.
- *Funds of knowledge are essential to incorporating targeted competence*. Funds of knowledge connected with everyday experience and student identity should be drawn out and used as assets generally, and specifically to "capture students' imaginations and foster deeper understanding in domain knowledge" (National Academies of Sciences, Engineering, and Medicine, 2018, p. 142).
- *Classrooms need a "third space" for conversations bridging daily and academic life*. Classrooms should allow for genuine conversations between teachers and students that allow students to talk from

> their own backgrounds about the things they experience in academic tasks. This naturally connects "types of knowledge and discourse outside of school" with the "conventional knowledge and discourse valued by schools" (National Academies of Sciences, Engineering, and Medicine, 2018, p. 142).

Science Work And School Science

This section briefly compares the apparent motivations for those who engage in science practices with what science in school is like, and how bringing those two experiences closer together might help engage students and bring them closer to the practices of science in the classroom.

Science as Compelling Work

> What makes scientists want to devote their professional lives to science? Of course, there are many responses to this question, but most scientists would agree that the excitement of exploring the unknown, of discovering something new, of adding to the storehouse of knowledge, is central to their vision of science and their own motivation (Tinker, 1997, p. 1).

Here, physicist and educator Robert Tinker is describing the "total immersion in a fascinating problem" that he believes characterizes work in science, the type of work the Nobel Prize winning theoretical physicist Richard Feynman called, "the pleasure of finding things out" (Feynman, 2000). Tinker believes this work is a very human activity made of "common sense" and "collaboration." Feynman agreed. Those who think science work is alien and elitist mystified him. He believed the pleasure was there for anyone.

The Piagetian educator Eleanor Duckworth (2006) calls middle-school children's experiences trying to understand the physical world as "the having of wonderful ideas" characterized by the "virtues of not knowing" (p. 62) and available to the academically successful and unsuccessful alike. The early-childhood educators Christine Chaillé and Lory Britain see young children as naturally inclined to the practices and enthusiasms characteristic of science (Chaillé & Britain, 2002):

> The actual doing of science or engineering can also pique students' curiosity, capture their interest, and motivate their continued study; the insights thus gained help them recognize that the

> work of scientists and engineers is a creative endeavor—one that has deeply affected the world they live in. (p. 48)

“Students Rarely Do Science”

Tinker and Duckworth both bank success in science education upon the compelling experiences of actually doing science. Tinker (1997) follows up on his enthusiasm for science work as a compelling human experience with this comment about science education:

> … you might conclude that discovery and exploration would play an important part in science education. Unfortunately, the excitement of exploration has been effectively squeezed out of most science education at all levels. In the rush to put more science into science education, to prepare students for the next exam, the essence of science has been largely ignored. Science education has developed into a separate entity divorced from science and scientists. From kindergarten through college, students rarely do science; they rarely participate in the creative act. (p. 1)

Lee (2002) agrees with the specifics of Tinker’s assessment, as do many commentators on science education in the United States (Bartholomew et al., 2004; Lehrer et al., 2008; Lustick, 2009; Osborne et al., 2003a).

Duckworth (2006) views all children endowed with “intellectual virtues.” She was once asked to distinguish between passive and “nonpassive” intellectual virtues. What must passive virtues be? “Knowing the right answer,” Duckworth believes, must be the most passive intellectual virtue, one that schooling dwells upon. She goes on to add that,

> In most classrooms, it is the quick, right answer that is appreciated. Knowledge of the answer ahead of time is more valued, on the whole, than ways of figuring it out.… It would make a significant difference to the cause of intelligent thought, in general, if teachers were encouraged to focus on the virtues involved in not knowing… Surprise, puzzlement, struggle, excitement, anticipation, and dawning certainty—those are the matters of intelligent thought. As virtues, they stand by themselves. Even if they don’t, on some specific occasion, lead to the right answers. In the long run, they are what count.” (p. 62)

Phelan et al. (1991) in their study of borders between the worlds of schooling and home defined culture as the "values and beliefs, expectations, actions, and emotional responses familiar to insiders" (p. 225), the working definition for this study, and noted that the emotional responses expected in a classroom were among the barriers students experienced in crossing successfully into engagement in school. It is worthwhile to note the emotional responses listed by Tinker and Duckworth. The children who went off script in the anecdote related above by Engel were on target for science culture.

The views of Tinker (1997) and Duckworth (2006) are representative of the latest thinking on the necessity of bringing facilitated practices of intellectual communities into the classroom culture (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010b, 2010a; NGSS Lead States, 2013) and on the broad ability of individuals to engage in core tasks of inquiry (Bonawitz & Lombrozo, 2012; National Research Council, 2004; Schulz & Bonawitz, 2007).

Tinker and Duckworth each have experience working with students not of Western, White, middle-class culture. Tinker was a successful physics teacher in impoverished minority communities in America, and Duckworth helped develop successful science programs for children in Africa. The reforms they advocate are framed in a type of educational constructivism and interestingly have significant overlap with those advocated by the cultural critics. However, they do not view these as cultural tools, but simply cognitive ones. This leads me to wonder whether part of the success of people who are adept at scientific inquiry in transferring their expertise and interest to others is explainable by thinking about how they handle cultural factors.

Osborne et al. (2003b) reviews the literature on the poor attitudes of students across cultural groups in "Western" societies, and decides that since there are no clear prescriptions for what constitutes good activities in science schooling, research should focus on what motivates students to engage in academic work; however, they admonish the culture of school science for being radically different from what it is meant to lead students to:

> School science, as currently taught and constituted, and because of its power and the consensus that science commands, offers 'little space for the pupil as an autonomous intellectual agent' (Donnelly 2001). The essential irony of a discipline that offers intellectual liberation from the

> shackles of received wisdom is that the education it offers is authoritarian, dogmatic and non-reflexive (p. 1074).

This seconds Lee’s (2002) critique that school science both alienates individuals from their tools and misrepresents science work, and it foreshadows a theme to be developed below: that science education, to be culturally sensitive and successful needs to forefront the agency of students to pursue the resolution of real cognitive conflict.

Learning as Cultural Acquisition

Based on decades of experience studying how culture interacts with learning, Rogoff (2003) concludes that in some senses, the human species is preprogrammed to learn: “In our species, each generation comes prepared to learn to participate in the practices and traditions of their elders, aided by shared engagement in valued and routine cultural activities” (p. 75). There is growing evidence that we are also preprogrammed to teach using a “natural pedagogy” (Csibra & Gergely, 2009) that leads cultural adepts to automatically cue in to the psychological biases of infants and children “to transmit to novices a variety of different types of cultural knowledge” (Csibra & Gergely, 2011, p. 1). Both of these analyses view learning outside of school as cultural transmission.

In these senses—being predetermined to both take in and to present adaptations that heredity does not determine—humans are born an unfinished species that develops along genetically defined capacities in directions laid out within “cultural communities” (Rogoff, 2003) and, in literate cultures, within formal schooling (Vygotsky, 1979) as well. Language is not natural, but the capacity to learn a language from a language community is. Similarly, mathematics is not natural, but the capacity to learn numerical reasoning from a community that is expert with numbers is: “mathematics in the ‘real world,’ like all thinking, is shaped by the dynamic encounter between the culturally endowed mind and its total context” (Lave, 1988, p. 218). Though people do not naturally behave like those who are expert in science work, it is reasonable to expect that they, to varying degrees, have the capacity. The behaviors are a cultural legacy and one should expect that humans would need a science cultural community to develop their capacity along those lines.

When viewed as cultural transmission, learning science in school is not very successful, often engendering resignation or resistance and failing to transmit the cultural knowledge that was targeted. As was discussed above, culture, the "values and beliefs, expectations, actions, and emotional responses of individuals" (Phelan et al., 1991, p. 225), has been used to understand key determinants of the sustained experiences of people in educational institutions, in particular, whether students experience "teaching science" as *assimilation* (coerced adoption of culture) or *enculturation* (valued adoption of culture) and to understand why they either choose to *incorporate* cultural elements (learning) or to passively resign themselves to an unwanted and unproductive experience or to actively resist.

Before looking at ways to improve upon this poor outcome, this section will develop some theoretical positions on how culture and learning are connected. It begins by highlighting sustained interactions and environmental cues as the proximal causes of development in Bronfenbrenner's bioecological framework. It then looks at how those interactions enter into two positions on experience and intellectual development, Piaget's understanding of how the intellect develops by the agency of an individual acting on his environment to resolve cognitive conflict, and Vygotsky's theory that the intellect develops by internalizing cultural tools during facilitated activities.

Bronfenbrenner, Proximal Processes, and the Salience of Outcomes

The genetic make-up of an individual human is far from a blueprint of who that person will be, but instead is the game plan for processes that engage experience and enfold it into the developing organism. In particular, the brain has "a developing architecture...[meant to] incorporate experiences into itself" (Shonkoff & Phillips, 2000, p. 53). The same genetic endowment produces a wide range of functioning, and the relationship between that endowment and the environment it is expressed in is subtle, complex, and rich with possibilities. Most children do not need special inputs to develop well, but all need certain things and some need more. Most cultural practices of child rearing provide these inputs for most children (Rogoff, 2003; Shonkoff & Phillips, 2000). At least outside of schooling, "natural pedagogy" (Csibra & Gergely, 2009) suffices to transmit cultural knowledge leading children to become functional members of their worlds. However, as noted above, in cultures that require adults to have very specific and abstract learning to be successful, the inputs are far from uniformly effective.

Uri Bronfenbrenner (Bronfenbrenner & Ceci, 1994; Bronfenbrenner, 1977) developed a research framework that sought to extend efforts to explain human development simply as additive effects of individual inheritance and environmental factors. The "bioecological model" (a) includes complex interactions between an individual and various systems that organize the environment, and (b) seeks mechanisms that mediate between genetic potential and the individual's experience of her immediate environment. It is the latter part that this study uses to formulate how science culture might be brought into a classroom.

Environment, experiences, and processes of interaction. The "environment" that any individual is embedded in is rich and complex, but often so familiar and taken for granted that it does not appear well in the analyses of how humans develop. This was the central critique of Bronfenbrenner's (Bronfenbrenner, 1977) seminal work laying out the requirements that research should meet to have "ecological validity." In later work, Bronfenbrenner and Ceci (1994) charge researchers to identify the *proximal processes* mediating between individual development and the world the individual experiences:

> Especially in its early phases, and to a great extent throughout the life course, human development takes place through processes of progressively more complex reciprocal interaction between an active, evolving biopsychological human organism and the persons, objects, and symbols in its immediate environment. To be effective, the interaction must occur on a fairly regular basis over extended periods of time. (p. 572)

As an example of a proximal process that was experimentally demonstrated to have significant and marked effects on important child behaviors, they reference a study where mothers "speak[ing] a lot to their infants" and "point[ing] to and nam[ing] objects and persons" caused higher levels of exploratory behavior and preference for novel over familiar items (p. 573). Presuming that an infant reacted to the mother's engagement and the mother responded, the speaking, pointing, and naming generated "complex, reciprocal interactions" regular and over time between the "human organism" and a person in his immediate environment. In another example, the “reciprocal interaction” was between an adolescent child and the child’s parents, who regularly monitored and limited the child’s activities outside the home. This was shown to markedly affect the grade point average of the adolescent children. Bronfenbrenner and Ceci (1994) note that, in this example, “the results reveal that the effects of proximal processes are more powerful than those of the environmental contexts in which they occur” (p. 577), that is, the positive effect occurred across differences in family income and structure.

In this formalization, the cognitive development of an individual, whether viewed as “learning” or “cultural acquisition” or some unnamed growth in competence, depends on the *sustained and regular reciprocal interactions* between the individual and the “people, symbols, and objects” around her.

Salience of outcomes from cues in the environment. Bronfenbrenner and Ceci (1994) maintain that development also depends upon which of the many possible outcomes of sustained experience are cued as important, relating the type and direction of intellectual development to cultural factors, to the “beliefs and the behaviors of both self and others:”

> which innate potentials become manifested in phenotypic form depends on whether the environments in which the human beings are living allow and instigate the actualization of particular inherited abilities and behavioral dispositions. The key factor is whether, in a particular family, school, community, workplace, culture, or place and period in history, the outcome in question is given salience in the beliefs and the behaviors of both self and others in each of these environmental contexts. In short, which features of the environment become, or are made, salient plays a critical role in determining which of a multitude of innate possibilities have the most chance of finding realization. (p. 583)

This is a dense passage, to be sure. The genetic makeup of an individual (the genotype) considerably limits the form, proclivities, and capacities of the individual, but it is the sustained, reciprocal interactions of the environment with that individual during the organism’s development that determines how much—and even in what direction—along the lines of her potential that the individual organism will develop (the phenotype). The “key factor” influencing which capacity is developed is environmental, not in the individual. If the sustained, regular and "progressively more complex reciprocal interactions between an active, evolving [individual] and the persons, objects, and symbols in its immediate environment" (Bronfenbrenner & Ceci, 1994, p. 572) do not *allow development* along a line and do not *instigate development* along a line, that line will not be much traversed. We will see that this is also the basic concept behind Vygotsky's theory of the development of higher-order thinking in humans, but is only marginal to Piaget's exposition of intellectual development.

Culture organizes inputs into the brain's architecture. Culture, the learned "values, beliefs, expectations, actions, and emotional responses" (Phelan et al., 1991, p. 225) of individuals in a group, organically organizes the inputs that allow an individual brain's architecture to fold experience into itself. Bronfenbrenner (Bronfenbrenner & Ceci, 1994; Bronfenbrenner, 1977) was chiefly interested in improving the design and analysis of research into human development, but he made clear (Bronfenbrenner & Ceci, 1994) that his vision was fixed on how best to inform the design of social institutions:

> [relating proximal processes to development] would suggest that many human beings may possess innate potentials for development significantly beyond those that they are presently manifesting, and that such unrealized capacities might be actualized through social policies and programs that enhance exposure to proximal processes in environmental settings that, in turn, can provide the stability and resources that enable such processes to be most effective. (p. 583)

Applying the bioecological framework to the design of classroom culture leads to at least one simple statement: if we want students to develop their potential to do the cognitive work of science and to be adept in the culture of science work, we have to arrange the environment in which they develop to *allow and instigate* intellectual and dispositional development along those lines. To do this, we have to pay attention not only to specific proximal processes behind the mechanisms of that development, but also to the salience of the outcomes as made clear in the beliefs and behaviors of the individuals—the peers and teachers—who to a large extent constitute the students' environment in the classroom. These requirements motivate for the emphasis on professional science and math practices targeted by the Next Generation Science Standards and the Common Core State Standards for mathematics discussed above.

Piaget, Cognitive Conflict, and the Agency of the Child

For decades, Piaget's influence on pedagogy generally has been profound (DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002; Duckworth, 1964; Fosnot, 1996; National Research Council, 2004), and his influence on science education in particular has been significant (Bybee et al., 2006; Duckworth, 1991; Taber, 2006). However, in some respects, that influence was changing as the "taking science to school" movement was developing (Bruner, 1997). The document presenting the basic framework for that movement makes this explicit: "Virtually all contemporary developmentalists agree that cognitive development is not as general stage-like or grand stage-like as Piaget and most of the rest of the field once thought" (National Research Council, 2007, p. 42, quoting Flavel). In relation to early-years science education, one review summing up research in the cognitive development of young children that informed that framework, considering Piaget's view that preschoolers' work was prescientific, wrote that "these claims have turned out to be wrong... early learning is also remarkably similar to scientific induction" (Gopnik, 2012, p. 1623).

Piaget was not an educator or an educational theorist (Bruner, 1997; Duckworth, 1964). *The Origins of Intelligence* (Piaget, 1963) makes clear that he was a philosopher, an epistemologist pursuing experimentally a line of thinking developed in the 19th century and working to organize the psychology of the early 20th century. This work changed the way children's mental development was thought about (Beilin, 1992; Bruner, 1997; Vygotsky, 1962), partially by forefronting the role of cognitive conflict as a driver of a learner's behavior and the importance of the agency of the child in her own development (Duckworth, 1964; Shonkoff & Phillips, 2000).

In early childhood education, the influence of this thinking remains profound. A foundational text on early childhood constructivist pedagogy (DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002) defines its field directly using Piagetian constructs: "Constructivist education takes its name from Piaget's research showing that children actively interpret their experiences in the physical and social worlds and thus construct their own knowledge, intelligence, and morality" (p. 35). This work and many others (Broderick & Hong, 2011; Castle, 1997; Chaillé & Britain, 2002; Duckworth, 2006; Forman & Hall, 2005; Kroll, 2013; National Association for the Education of Young Children (NAEYC), 2009; Zan & Geiken, 2010) develop the implications of this notion extensively and have made general and specific recommendations for how adults should work with young children.

Because of the ongoing importance of Piaget's thought in early-years pedagogy, this section first examines the language used in Piagetian constructivism as laid out in one of his later, summary works, *The Origins of Intelligence* (Piaget, 1963). It then briefly examines an extended academic articulation of Piaget's thought as a psychological theory of learning. Then, it reviews Piaget's view that learning environments should encourage individuals' exploration of their physical world. Finally, it considers core features of this psychology as proximal processes that mediate between the environment and the intellectual development of humans. This will motivate for this study's use of a key construct from that psychology, the "Piagetian agency" of an individual.

Piaget and *The Origins of Intelligence*. Piaget (1963) says in *The Origins of Intelligence* that "the whole of this work is devoted to" understanding how the "essential mechanisms of organization, assimilation and accommodation" create their own mental "organs" and "structures" within a single organism bound into a fluctuating environment (p. 13). In this work, Piaget sets out to present his solutions to problems posed by Enlightenment philosophy, particularly by the philosopher Immanuel Kant, by building a model of how intelligence develops in humans. Where do epistemological primitives like space, time, causality, substance (Kant's categories of reason) come from? What in the mind is innate and *a priori*? How can we justify abstract, formal systems like geometry and algebra? In answer, Piaget (1963) asserts that the Kantian categories, schemata, and theoretical judgements are inevitably created by invariant mental mechanisms helping the organism adapt to the external world while being driven internally toward coherence and logicalness. "It is by adapting to things that thought organizes itself and it is by organizing itself that it structures things" (p. 8). Piaget's brilliance in his earlier work was in making the questions of knowledge an empirical study of the actual activities of developing humans. He looked at real organisms, children 0 – 8 years, building and testing knowledge of the world, and he systematically tried to understand how this works. In *The Origins of Intelligence*, Piaget presents a synthesis of that experimental work.

In *The Origins of Intelligence*, Piaget (1963) presents human intelligence as an extension of the biological adaptation of an individual when she interacts with her environment. Piaget argues here by seemingly using Lamarck's confusion between (a) how species evolve over geologic history (phylogenesis) and (b) how individuals develop over a lifetime (ontogenesis), framing development as an adaptation-for-survival:

> There is [cognitive] adaptation when the organism is transformed by the environment and when this variation results in an increase in the interchanges between the environment and itself which are favorable to its preservation. (p. 5)

Evolutionary theory discarded the Lamarckian view that the adaptations of a single organism to its environment are useful to explain how traits vary across generations. However, in this work Piaget distances his analogy from Lamarckian evolution and instead proposes that intelligence illustrates a different kind of adaptation other than hereditary adaptions. In intelligence, the results of the unfolding ontogenesis of the individual transcends biological development so that intelligence "progresses simultaneously in the conquest of things and reflection on itself" (p. 18). A human organism's biological existence appears "to consciousness as being external to it" (p. 19), and the organism reflects upon itself and is able to create abstract reality from its experience.

Under this framework, in its ontogenesis, intelligence does not so much develop as survive ecological disruptions, in analogy with biological evolution. "If biological adaptation is a sort of material understanding of the environment," then that adaptation would have to produce "later [mental] structures" in order to have a "conscious and gnostic image" of the external world (p. 8). In this way, Piaget parses the analogy between biological adaptation and the development of intelligence to develop the familiar Piagetian concepts "coordination", "operations", "assimilation", "accommodation", and "equilibration."

Functional invariants of hereditary intelligence. In Piaget's (1963) theory of mental development, intelligence develops from infancy to adulthood driven by an inner need for coherence and noncontradiction and by an external reality that forever imposes itself. Each child's mind evolves into an adult's through adaptation in a struggle to maintain its internal coherence while in contact with a changing environment. Two features of intelligence, however, are *functional invariants*, processes that are predetermined by the nature of the organism (humans), and not altered by experience or changed as an individual develops. These processes, *adaptation,* "the accord of thought with things," and *organization,* "the accord of thought with itself" (p. 8), work seamlessly together to inevitably build Kant's categories.

Coordination of experience with mental structures. In *The Origins of Intelligence* (1963), Piaget's epistemology follows the construction of knowledge down to the physical agency of infants and children acting on their world. When a developing individual first engages with the world, adaptation and organization work to *coordinate* experiences provided by the senses with the agency of muscular control to produce basic schema (*sensorimotor intelligence*). The more "real" (p. 15) categories of reason—object, space, causality, and time—are inevitable constructions of sensorimotor intelligence trying to adapt to and organize earliest experience. Piaget, in this work, again directly answers Enlightenment questions: Kantian categories are not innate, in that they do not exist in the mind at birth, but they are *a priori*, in that they inevitably come from the species' engagement with an external world.

Mental operations. Piaget's (1963) invariant mechanisms proceed to adapt intelligence to the external world through the agency of the individual until there are sufficient mental structures (schemata) to drive intelligence to act on these elements of the mind itself so that "every schema is thus coordinated with all the other schemata" (p. 7), causing intelligence to adapt the structures they earlier produced and then to organize them again into a coherent whole. These mental operations are experienced as thought (reflective intelligence or gnostic intelligence). Operations on schemata that are bound to experience of the physical world are concrete operations and operations on schemata that are removed from concrete experience are formal operations. Thus Piaget answers other Enlightenment questions: Kant's more formal categories—quality, class, quantitative logic, and number—develop as the general mechanisms of intelligence work upon the structures formed earlier, and Kantian theoretical judgement is the effect of formal mental operations abstracting from experience.

Adaptation, assimilation, and accommodation. Piaget (1963) sees the mind as a totality driven to maintain what he calls "the equilibrium between the organism and the environment" (p. 6). To Piaget, all "adaptation is an equilibrium between assimilation and accommodation" (p. 6).

For a given chain of experiences, if the organism can coordinate elements of the environment with elements of itself without modifying itself, it *assimilates* the environment. This "relationship which unites the organized elements [of itself] with the environmental elements" is assimilation (p. 5). Piaget saw assimilation at three levels: biological organisms "materially elaborates [its physical] forms and assimilates to them the substances and energies of the environment," while sensorimotor intelligence "organizes acts and assimilates to the schemata of motor behavior the various situations offered by the environment" (p. 5), and finally, gnostic intelligence develops by "thinking of forms or constructing them in order to assimilate to them the contents of experience" (p. 6). However, if the organism has to modify cognitive elements to coordinate elements of the environment with its internal structure, it *accommodates* the environment.

Cognitive organization and cognitive equilibrium. Piaget (1963) imposes a metaphysical condition upon the ideal mind. The human intellect is forever approaching an ideal of coherence. Since even "the most elementary perceptions are simultaneously related to each other and structured into organized totalities" (p. 11), a human engaged with the world or just engaged in thought experiences a need to act upon their thoughts or the world in order to adapt and organize their own intellect. The internal sense of completion, of "finality," is "the subjective translation of a process of putting into equilibrium," and the drive to act, what he calls "desirability," "is the indication of a rupture in equilibrium or of an uncompleted totality to whose formation some element is lacking and which tends toward this element in order to realize its equilibrium" (p. 11). In sum, the individual experiences *equilibration* (the process of putting the intellect into equilibrium) as the resolution (finality) of the sense (desirability) that the mind is incoherent (rupture in equilibrium or some element is lacking). Equilibration is the act of reorganizing the mind after it has accommodated input from the environment.

Stages of intellectual development. Piaget (1963) sees the mind as moving naturally through a progression based on how distant its schemata are from direct sensory experience. Sensorimotor intelligence is adaptation and organization, both working together to coordinate an individual's sensory experience with his motor agency. Gnostic intelligence—producing knowledge of the world—is adaptation and organization, both working together to coordinate ever-changing schemata with themselves. First concrete operations coordinate experience-bound schemata, and at some point in an individual's life, intellectual development gives access to higher thought, what Piaget calls formal operations.

Piagetian constructivism as a psychological theory of learning. Fosnot (1996) in an extended discussion of constructivism works to synthesize into a "new paradigm" (p. 21) the developmental psychology of Piaget and Lev Vygotsky. In doing so, she goes into the details of the abstract language used by Piaget and presents a dense "psychological theory of learning that describes how structures and deeper conceptual understanding come about, rather than one that simply characterizes the structures and stages of thought or one that isolates behaviors learned through reinforcement" (p. 30). In summarizing her articulation, Fosnot emphasizes two basic constructs: cognitive conflict as the driver of action and the agency of the individual in her own learning.

Fosnot (1996) develops the analogy between intellectual development and biology found in *The Origins of Intelligence* and extends it to include Piaget's later work in which he compares his concept to newer thinking in thermodynamics. Fosnot (1996) quotes Piaget, who is quoting the physicist, Ilya Prigogine: "Cognitive equilibriums are closer to those of stationary but dynamic states, mentioned by Prigogine, with exchanges capable of 'building and maintaining a functional and structural order in an open system'" (p.14). The main point here is that the mind is able to maintain an evolving order, even though it continually exists as an "open system," bringing in new material and changing itself. This is not very far from the conceptions made in *The Origins of Intelligence.*

The cause of disequilibration is still cognitive conflict within an individual, framed as "contradictions to their actions and ideas," which as in *The Origins of Intelligence*, are either in the form of "actions on objects" that do not fulfill the individual's attempt to coordinate elements of the mind with elements in the environment (i.e., a failure of concrete operations to coordinate mental structures with experience of the world), or in the form of "two theories that both seem plausible and yet contradictory" (Fosnot, 1996, p. 15) (i.e., a failure of formal operations to coordinate two mental structures).

Fosnot (1996) takes pains to point out that it is not the external world that disrupts mental equilibrium, but the individual's attempt to bring it into her mind in some coherent way: "the data by themselves are not contradictory; they are contradictory only in relation to the meaning that the learner attributes to them" (p. 16). Finally, once again, this disequilibrium drives the intellect to change: "it is the contradiction that causes the imbalance providing the internal motivation for an accommodation" (p. 16). Fosnot concludes her synthesis by reaffirming an earlier core tenet that learning is "an interpretive, recursive, building process by active learners interacting with the physical and social world" (p. 30).

Piaget on how pedagogy promotes intellectual development. For Piaget, education should create an environment where children experience inner conflict that they resolve through their active intelligence:

> The goal in education is not to increase the amount of knowledge, but to create the possibilities for a child to invent and discover. . . [T]eaching means creating situations where structures can be discovered (Piaget, as cited in Duckworth, 1964, p. 174).

Piaget separated the drivers of intellectual development into (a) internal, physical maturation, (b) experiences, (c) cultural transmissions, and (d) an inherited mechanism of mental self-modification (DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002; Duckworth, 1964; Fosnot, 1996). Duckworth (1964), who worked closely with Piaget, wrote that Piaget thought that all of these relate to education in some way, but dwelled upon the latter because mental self-modification signals an active role of the mind of the child while the others happened to the child. Bruner (1997) agrees, saying that "disequilibrium," the rupture in equilibrium, as Piaget put it in *The Origins of Intelligence*, was what impelled intellectual growth in Piaget's theory.

Duckworth (1964) continues her rendering of Piaget's thinking: the mind itself has to reach a sufficiently disordered state due to its increasing inability to assimilate new experiences that it rearranges itself to find a new coherence, and hence, new capacities. Implicit is the need for the child to manipulate his own experiences to generate the input he needs to resolve this incoherence. Therefore, any individual child may need to go through a sequence of manipulations of its environment to eventually reach an inevitable inner incoherence and an inevitable resolution into a new inner equilibrium and new intellectual capacities. In Piaget's words:

> An individual learns to see the world as coherent, as structured, to the extent that he acts upon the world, transforms it, and succeeds in coordinating these actions and transformations. Good pedagogy [must allow the child to experiment] reconciling what he finds at one time with what he finds at another, and comparing his findings with those of other children. (Piaget, as cited in Duckworth, 1964, p. 172)

This internal drive to act upon the world for thought's sake was cited above from *The Origins of Intelligence* as "desirability," an internal experience of disequilibrium within the structures of the mind. It drives the individual experiencing it to act in a way to restore that cognitive equilibrium. Duckworth (1964) goes on to affirm the agency of the individual in his own learning:

> Good pedagogy must involve presenting the child with situations in which he himself experiments in the broadest sense of that term—trying things out, to see what happens, manipulating things, manipulating symbols, posing questions and seeking his own answers, reconciling what he finds at one time with what he finds at another, and comparing his findings with those of other children. (p. 173)

In more colloquial terms, this central notion present in Piaget's epistemology and developed by others into a constructivist pedagogy is that lasting and fundamental change in the thinking of individuals is built by individuals driven to resolve inconsistences in their own thinking when allowed to act on the world in those efforts. This forefronting of agency and cognitive conflict is formally stated in the next section.

Piagetian agency. The discussion above focuses on Piaget's view that teaching environments should "allow" and "instigate," in Bronfenbrenner's words cited above, a child's manipulation of her environment and her own thoughts to produce and resolve cognitive conflict. It is clear from the above that in Piaget such environments are the paths to human intellectual development and that manipulations and observation of the immediate physical world should be considered key sustained and regular reciprocal interactions in any Piagetian model of early-years development. Newer formulations of the idea of "rational constructivism" (Gopnik & Wellman, 2012) in the study of early-years cognitive development refute Piagetian stage theories and propose detailed and empirically validated mechanisms for learning, but present nothing in conflict with this core tenet of Piagetian constructivist psychology.

This study will refer to the agency of a developing human in resolving cognitive conflict as *Piagetian agency*. The theory of change behind the professional development model studied hypothesizes that Piagetian agency is important for development at any age and uses it (a) as the internal driver for adults' engagement with the representational tasks of the workshop when cultural norms of science in intersubjective contexts are used to maintain cognitive conflict and when this engagement is facilitated to maintain agency, and (b) as mediator between the work of the participants and the interest and utility value of the workshop tasks.

Vygotsky, Higher Thinking, and Opportunities for Cultural Transmission

Vygotsky's influence on education in the US has been increasing as the "taking science to school" movement was developing (Bruner, 1997). *Taking Science to School*, (National Research Council, 2007), the framing document behind the Next Generation Science Standards does not refer to Vygotsky directly, but his influence is apparent in *How People Learn* (National Research Council, 2004)*,* which discusses Vygotsky's zone of proximal development at length, and recommends one of the key reforms in the standard, "communities of scientific practice," based on ideas attributed to him (p. 184).

More recently, the shift in research reviewed in *How People Learn II* (National Academies of Sciences, Engineering, and Medicine, 2018) to a "sociocultural view of learning" (p. 22), is in part due to research built upon Vygotsky's work:

> Another body of work in psychology that explores the role of culture in shaping psychological processes has focused on learning as a dynamic system of social activity. Many of these researchers draw from a set of ideas about development advanced by Lev Vygotsky, Alexander

> Luria, and Aleksei Leontiev: the “troika” of pioneers in what is variously known as the sociocultural, social historical, or cultural-historical theory of development. (p. 26)

This section will briefly review Vygotsky’s thinking on how biological mechanisms within the human mind drive development by naturally cueing into the activity of others when it is salient to the development of competency in cultural tools. This mechanism can be made use of in schooling by engineering opportunities for proximal development that leads toward targeted, distal goals.

Humans are an unfinished species. Vygotsky compared human development to the limitations in thinking of other tool-using primates. What made humans a qualitatively different species was the way language facilitated the development of the intellect by incorporating cultural tools. Humans are an unfinished species, and acting in a social context, humans are able to make themselves instruments of their own minds:

> [F]rom the moment a child begins *to master the situation with the help of speech, after mastering his own behaviou*r, a radically new organization of behaviour appears, as well as new relations with the environment. We are witnessing the birth of those specifically human forms of behaviour that, breaking away from animal forms of behaviour, later create intellect and go on to become the base of labour: the specifically human form of the use of tools. (Vygotsky & Luria, 1994, p. 109)

In this he diverges radically from Piaget, not only on the way language develops, but in the way human intelligence itself develops. To Piaget, the intellect was driven by an engagement with the environment that demanded a coherent set of representations of the world and an agency that continually tries to coordinate itself with experience. To Piaget, others contribute to this naturally by destabilizing the inner world and by providing exemplars. However, with Vygotsky, a child’s activity in organized human society allows it to create what we recognize as human intellect:

> The child applies to itself the method of behaviour that it previously applied to another, thus organizing its own behaviour according to a social type. The source of intelligent action and control over his own behaviour in the solution of a complex practical problem is, consequently,

> not an invention of some purely logical act, but the application of a social attitude to itself, the transfer of a social form of behaviour into its own psychological organization. (Vygotsky & Luria, 1994, p. 119)

These “tools of the mind” (Bodrova & Leong, 2006) constitute the child as developing the capacities that he was genetically endowed with. They require a particular kind of environment, one organized and rich with cultural practices, symbols, and physical tools, all being used by others within the experience of the child.

Social history and social engagement. In *Tool and Symbol in Child Development* (Vygotsky & Luria, 1994), Vygotsky focuses on the child as developing within a culture. That culture has its own historical development, which feeds seamlessly into the processes determined by biological development. The language Vygotsky uses here to discuss his thinking is confusing and anachronistic. For example, “social history” can refer to the development of a culture over time or to the interactions of a child with his culture. For another, he borrows many technical terms from the biology and psychology of the time. Vygotsky, like Piaget, was interested in the *genesis* of mental function and uses the term “genetic” to refer to how something developed. Like Piaget, Vygotsky borrows language used in evolutionary biology, to distinguish the development of an individual human’s “higher mental functions” (1994, p. p. 132) into two parts: their “phylogenesis,” development which occurred prior to the birth of an individual, and their “ontogenesis,” development within the individual.

Vygotsky, like Piaget, looks for adaptive processes outside of the evolutionary development of the human species, but unlike Piaget, who imagined a metaphysical imperative for coherence (“equilibration”) of the intellect as an extension of biological adaptation solely within the ontogenesis of human intelligence, Vygotsky (1994) sees the development of human culture, its social history, *as part of the phylogenesis* of the human mind, and the engagement of a child with its culture, the child’s social history, *as part of the ontogenesis* of the human mind:

> Thus the higher functions form a psychological system, integral in its genetic character, although manifold in composition, built on foundations entirely different from those of the elementary

> psychological functions. The factors uniting the whole system, determining whether one or another individual psychological process should be attributed to it or not, is the common origin of their structure and function. Genetically they differ in that in their phylogenesis they are the product not of biological evolution, but of the historical development of behaviour, while in ontogenesis they have also a special social history. (p. 137)

In the above, the phylogenesis of higher elementary functions includes cultural ("historical development of behavior") and their ontogenesis requires social interaction of the child with the culture, i.e., its particular "social history."

Vygotsky (1994) invented his "genetic" methods of experimentation to separate, like Bronfenbrenner, environmental and biological factors. Otherwise, the unity of the two would be mistaken for biological development:

> [in phylogenesis] the biological and historical formation of all function are so sharply divided and so obviously belong to different types of evolution that both processes are evident in a pure and isolated form. In ontogenesis, however, both lines of development appear as an interwoven complex combination, and this has frequently misled the research worker who, perceiving these two lines as one integral entity, came to consider the higher processes as the simple continuation and development of the lower. (p. 139)

Social history determines "humanness." In *Tool and Symbol in Child Development* (Vygotsky & Luria, 1994), Vygotsky's thinking presses the cultural development of humanness further than the development of abstract thought. Vygotsky not only thinks of competence in language, logic, mathematics, and morality as determined by engagement with culture, but also aspects of the mind still often considered biologically determined. Here, Vygotsky also considered perception, complex motion, and self-conscious memory and purposeful action as developing solely within social experiences:

> Thus, however strange it may seem from the point of view of traditional doctrine, the higher functions of perception, memory, attention, movement and so on, prove to be internally connected with the development of the sign using activity of the child, and their comprehension is

> possible only on the basis of an analysis of their genetic roots and of that reconstruction which they underwent in the course of their cultural history (p. 118)

Another example is what is now called executive functioning:

> The source of intelligent action and control over his own behaviour in the solution of a complex practical problem is, consequently, not an invention of some purely logical act, but the application of a social attitude to itself, the transfer of a social form of behaviour into its own psychological organization. (p. 119)

The importance of interactions with adults, who represent holders of the results of phylogenesis, is illustrated by the way Vygotsky (1994) views speech. Language is not simply the means of communicating intention, needs, or thinking; it is what creates the human mind, and separates what we see as human from other primates. What are now called tools of the mind (Bodrova & Leong, 2006), or cognitive tools, Vygotsky (1994) called "intra-psychological functions:"

> The greatest change in child development occurs when this socialized speech, previously addressed to the adult, is turned to himself, when, instead of appealing to the experimentalist with a plan for the solution of the problem, the child appeals to himself. In this latter case the speech, participating in the solution, from an inter-psychological category, now becomes an intra-psychological function. (p. 119)

Though a child's development of its capacity for language was the clearest representation of this process, Vygotsky (1994) also extended his analysis to the incorporation of any culturally transmitted symbol system:

> ... a broader study of other forms of the symbolic activity of the child shows that not only speech, but all operations related to the use of signs, their differing concrete forms notwithstanding, are governed by the same laws of development... . (p. 119)

Internal drivers and the "zone of proximal development." Like Piaget, Vygotsky viewed the developing human as driven by an internal mechanism that responded to its environment. However, for

Vygotsky this driver is not cued by interactions with the material world, but like the proponents of "natural pedagogy" (Csibra & Gergely, 2009), Vygotsky believed that developing humans are cued biologically to the behaviors of others, especially adults, and adults can use this either informally or through formal instruction to direct the development along certain lines:

> Instruction is only useful when it moves ahead of development. When it does, it impels or wakens a whole series of functions that are in a stage of maturation lying in the zone of proximal development. This is the major role of instruction in development. ... Instruction would be completely unnecessary if it merely utilized what had already matured in the developmental process, if it were not itself a source of development." (Quoting Vygotsky, Bodrova & Leong, 2006, p. 212)

Thus, an "intersubjective" environment is necessary for children to develop their biological capacities. When this environment presents a chance for meaningful competence beyond what the child possess, the mechanism begins. In general, for Vygotsky, competence in a high-order cognitive tool is built by cultural transmission, in which an individual is in natural contact, especially when acting among peers, with others already adept in those tools.

Formal instruction and Vygotskian opportunities. Though Vygotsky's research was grounded in the early development of children, he was chiefly interested in developing methods for formal schooling (Bruner, 1984; Rogoff, 2003). This research lead him to model the development of mental tools in childhood as moving through four plateaus (Bodrova & Leong, 2006; Rogoff, 2003), from biologically natural behavior, to intersubjective behavior, to using external mediators, to using internalized cognitive tools, chiefly driven naturally by contact with those who are culturally more adept. Vygotsky thought these transitions could be aided by formal instruction, which should be guided by a desire to keep children internalizing external tools, and thus moving to "higher levels of functioning."

The role of the teacher in this instruction is to present what the model being studied refers to as *Vygotskian opportunities*: activities engineered by a cultural adept with the self-conscious goal of drawing a novice into tasks where cultural tools are apparent and can be practiced in intersubjective contexts in which the novice has access to expert guidance. The theory of change behind the professional development model studied hypothesizes that the combination of familiar representational tasks, intersubjective contexts that mimic those of working science, and facilitation practices that scaffold participants in following some of the imperatives of science culture create Vygotskian opportunities for the workshop participants. The reciprocal interactions between a participant and her group, the facilitator, the enacting materials, and the symbols used in representing thinking, if sustained and validated, should act as proximal processes that will help the individual develop her capacities in modeling the physical world in ways prototypical of scientific modeling.

Leading Children to Engagement with Science Work

It is an open question how to build an educational psychology of science work (Kind & Osborne, 2017; Lehrer et al., 2008; Lucas, Broderick, Lehrer, & Bohanan, 2005; Osborne et al., 2003b). Solomon (1992a) ends her discussion of the differences between an understanding of energy built up by common enculturation and that targeted by science education by drawing attention to the need to develop teaching practices that help young humans move between the cognitive tools of their “life-worlds” and the formal thinking of science work. She focused specifically on making sensible the abstract, context-free problems presented in science classes, the “crossing over between domains, from commonplace reality to distanced analogy and back again” (p. 114), historically challenging even to able students (Suppe, 1977) from backgrounds that predispose them to learning science, and arguably the main focus of Piaget’s attempt to find a genetic mechanism for the development of formal thought from experience.

Solomon (Solomon, 1992a) goes on to note the “considerable difficulties” in leading students between those worlds, as evident in the literature on science education, and concludes:

> Of one thing we may be sure, this movement between the two contrasting ways of thinking requires dedicated practice rather than athletic training. But if our pupils are to be allowed a glimpse of how science constructs its concepts and explanations, then such exercises may be the only way to achieve the necessary mental insight and flexibility. (p. 114)

It’s argued below that “how science constructs its concepts and explanations” is not natural, though parts of it seems like a systematization of natural thinking. It is cultural. Bronfenbrenner’s framework, introduced above, agrees with Solomon’s assessment that development of the cognitive tools targeted require sustained processes, but Bronfenbrenner (1994) includes an environment that would “allow and instigate the actualization” of whatever innate potentials humans do have for these culture-bound practices, given salience, visibly in “the beliefs and the behaviors of both self and others” (p. 583). Though the question about how much of the thinking and practices any one individual can develop is open, Bronfenbrenner’s (1994) insistence that research looks for the proximal causes of that development, the “progressively more complex reciprocal interaction[s]... on a fairly regular basis over extended periods of time” (p. 572), should focus science pedagogy, as in Vygotsky, on the role of the science adepts in leading individuals’ development within a classroom toward science practices.

This section first briefly reviews pertinent research on the cognitive engagement of young children with their environment and why this research should not lead to the view that children are natural scientists. It then develops the idea that Vygotskian opportunities making use of Piagetian agency is a way to think about engaging children with science that is consistent with current and historical notions of psychological constructivism. Finally, it discusses the approach the workshop model being studied uses to develop teachers’ competence in science work and their subjective value for science task.

Children Are Born to Think About Their Environment

Humans, it seems, typically are born with the fundamental cognitive and social capacities required to engage in modern scientific work. Indeed, developmental psychologists have long pointed out that preschoolers are driven internally to form, test, and revise their mental constructions about the physical world (Piaget, 1963), that they learn readily from well-conceived discourse and experiences challenging their personal theories (Forman & Hall, 2005), that they incorporate the cognitive and material tools of their culture to conceptualize the world (Vygotsky & Luria, 1994), and that they engage cultural communities to develop instrumental mastery over their immediate environment (Rogoff, 2003).

More recently, work in cognitive psychology (Gopnik, 2012) has overturned the simple stage theories of Piagetian constructivism, and instead affirms that young children—even toddlers—unselfconsciously are driven by cognitive resources that are core to the formal thinking of actual scientists. In one study, preschoolers and adults made inferences on the causes of physical phenomenon to find the most probable factors, but unlike adults, the children preferred explanations that had the fewest causes, a practice in science known as “Occam’s razor” (Bonawitz & Lombrozo, 2012). In another study, preschoolers recognized evidence that left different causes confounded and preferentially chose toys that let them resolve the ambiguous explanations, in essence intervening to provide evidence (Schulz & Bonawitz, 2007). Others show that children from infancy combine observed conditional probabilities with their own interventions to form intuitive theories about the world (Gopnik & Schulz, 2004) and that preschoolers conjectured unobservable causes to form abstract explanations that persisted in the face of counter-evidence, both behaviors similar to the ontology of modern science (Schulz, Goodman, Tenenbaum, & Jenkins, 2008).

These natural drives are easily conditioned by the behavior of others, especially adults. Children of this age are adept at social referencing (Rogoff, 2003) and their explorations are very responsive to intentional cues (Gopnik, 2012), especially cues that indicate knowledge about the world is intentionally being presented (Csibra & Gergely, 2009). In one study, preschool children were shown to constrain their free play to correspond with actions demonstrated by adults, while they explored more after no demonstration or when an adult demonstrated the same actions seemingly by accident (Bonawitz et al., 2009). Toddlers and preschoolers extend their causal explanations to indirect events when adults use cause-and-effect language to relate them or act as if a relationship was intentional, but otherwise the toddlers, at least, do not (Bonawitz et al., 2010). Question asking, the dominant form of speech in preschool-age children at home, reduces to near zero in classroom settings, and children who see the teacher show a single moment of curiosity about materials are seen to spontaneously explore them during free play, while otherwise they do not (Engel, 2011).

Children Are Not Little Scientists

There is a substantial literature stretching back decades that tries to frame children as prototypical science workers (Chaillé & Britain, 2002; Driver, 1983; Forman, 2010), much of it controversial at the time (Solomon, 2000). The result of the contention between children-as-scientists and children-as-not-scientists seems to have been a synthesis around “constructivism” as an active research program (Taber, 2006), starting from the core proposition that knowledge is not received directly by a learner, but actively constructed. This constructivist pedagogy keeps the child-as-scientist notion in the margins. Interpretations of recent research from cognitive psychology challenge that marginalization (Gopnik, 2012), making the case again that this is a central way to think of young children. This literature has informed the framework (National Research Council, 2007) undergirding the new STEM standards, a development criticized as unwarranted and counterproductive (Brewer, 2008).

This section will briefly review this controversy and then propose that extrapolating from current research on the mechanisms of child-learning to the notion of child-as-scientist is misguided and counterproductive and draws attention away from the crucial role of science and classroom culture in the teaching of science.

Academic war and the “child scientist” movement. Solomon (2000) reviews the “science wars” of the 1970s and 1980s around how schooling should confront the understanding children built about the physical world as enculturation into their natural culture, a review corroborated by Taber (2006).

In the early 1970’s, non-science academics found interest in children’s ideas as revealed by Piaget’s method of extended interviews. This literature presented children as having “alternative frameworks,” “their own rationality” “like a valid though unusual way of thinking.” New qualitative methods elucidated how children’s colloquial “world views” and “child paradigms” developed outside of schooling. Some presented students’ experiences of their teachers as authoritarian and arbitrary, simply demanding “their answers” to school questions. These studies started “a deliberate polemic designed to emphasize the coherent and theoretical nature of children’s explanations” (Solomon, 1992a, p. 23), and coined the term “child science,” opposed to “teacher science,” and framed children as “child scientists,” emphasizing that their views of the physical world were "coherent" and "sensible" and denouncing the view that they were somehow "misconceptions." Some of this critique found its way into discussions around science standards (Matthews, 1993).

Parallel research reviewed by Solomon (2000) and Taber (2006) characterized children's enculturated views on the physical world as far from coherent, and sought to help teachers anticipate and correct clear "misconceptions." Their studies showed typical colloquial explanations of things shifted with context, were inconsistent, and were not personally "constructed" but highly influenced by social context. The colloquial thinking of humans about the physical world appeared unsystematic and mistaken, and very difficult to adjust, and the knowledge they acquired through schooling was unintegrated and not functional (Schneps, Sadler, Woll, & Crouse, 1989).

Taber (2006) reviews the development of research into science education over that period and comes to the conclusion that those decades, controversial as they were, carved out an active and coherent and ongoing "constructivist" research program in science education. He identifies the "essence" of the constructivist position as "knowledge is constructed by the learner, not received" (p. 141) and that knowledge is structured as "concepts" which can be examined experimentally. The science wars around constructivism settled on broad agreement that students enter formal science education with their own ideas of natural phenomena that this education must address, and that these have serious consequences for their learning and that science education needs to understand and address these consequences. This consensus appears in the fairly weak concern in the early national science standards, mentioned above, that individual's prior knowledge needs to be addressed and folded into the subject matter.

Natural enculturation from "life culture." In her study on how people think about energy, Solomon (1992a) found that the children she worked with did not approach the physical world in any way prototypical of science work, for example, they did not think by "constructing tentative models" which they "evaluate against personal criteria," as claimed by "child-scientist" advocates (Pope & Watts, 1988). In general, she found that though children do have strong ideas about some of the physical phenomena they will be schooled on, these ideas are to a large extent common within their "life cultures" and were incorporated naturally without coercion and without the children being aware of, or critical of, the process. She found that though children enjoyed talking about their ideas and other's ideas—behaviors highly promoted in science culture—the ideas formed from common enculturation were often inconsistent, unexamined, and highly resistant to change. In fact, children—and adults—could not defend these life ideas with argument and often become angry when they are directly challenged.

Solomon (1992a) proposed that children in schooling, and adults afterwards, maintain two types of knowledge: life-world knowledge, which is general knowledge, commonsense knowledge, built in everyday exchanges; and formal "science" knowledge, taught in school, which is typically not useful except in abstract and familiar school exercises.

Confusing cognitive drivers with formal thought. Brewer (2008), in a review of more recent literature around "children as scientists," concluded that, though research in cognitive development clearly shows that young children think in more complex ways than was previously believed, it is a counterproductive simplification to say that children are natural scientists.

Being driven to engage the world unselfconsciously in ways that anticipate modern science work is one thing, but mastering the abstract "formal" reasoning that Piaget was fascinated by is a totally different question of cognitive development. Gopnik (2012), one of the proponents of a "new constructivism," illustrates this confusion when she urges policymakers and teachers to reconsider the nature of early childhood development and adjust to "scientific thinking of young children": "Anyone who has ever taught a [science] methods course knows that adults have a hard time explicitly understanding statistics. It may be surprising, then, that even very young infants can implicitly reason statistically" (p. 1625). What is crucial here are the differences between what the author means by "explicitly" and "implicitly." From context, these coinages indicate respectively (a) learning, by instruction, to manipulate formal systems of evidence and analysis, and (b) pursuing, unselfconsciously, an unjustified but compelling internal act of cognition.

Gopnik's line of thinking avoids the difficult problem that Piaget and Vygotsky faced head on: how do humans go from their internal cognitive and genetically founded mechanisms to systems of propositions that justify abstract and context-free knowledge? This transition is where Vygotsky drew the line between "lower" and "higher" mental functions: The former is natural human behavior and the latter is a cultural transfer (Vygotsky & Luria, 1994). It is where Bronfenbrenner's research paradigm pushes cognitive science to look: What are the detailed mechanisms which develop the potential for abstract thought. As possible answers, Rogoff (2003) offers "distinct patterns of guided participation" (p. 302) between adept's and learner's sustained participation in cultural communities.

A Small Illustration

In a brief article for practitioners, the early-years developmental psychologist George Forman (2010) uses video-clips of teachers and young children to illustrate how adults might reimagine some of the play of children as "legitimate forms of scientific thinking." Here, Forman argues that, as such, this play should be valued in school as driven by thinking that is highly valued by educational institutions and is in ways prototypical of the thinking fortified by science work.

Below is a close examination of Forman's analysis, intended to show where the natural behavior of children differs from the practices of science work, and to give light on the environmental processes that might lead from one to the other. All quotes are excerpts of his narrative (pp. 1–5), set as block quotes to emphasize the flow of his argument:

"Scientific thinking." In his exposition, Forman first introduces his thesis that special moments in children's natural play are examples of scientific thinking:

> we [do not] apply the adjective "scientific" to all of children's cause-and-effect thinking. Scientific thinking involves both a prediction and a method of testing the prediction; it comes about when a child both predicts and plays with an outcome.

Here, Forman distinguishes between normal human thinking about cause and effect and scientific thinking: the latter has a "method of testing" a prediction, which he identifies with play, internally driven not by goals but by the experience of the process itself.

Forman then illustrates his thesis with a detailed analysis of scenarios in which a child interacts with an adult during play. In one, a 3-year-old boy in a preschool class interacts freely with a setup involving pulleys:

> The child pulls on the bottom strand of a clothesline that stretches in a circuit between two pairs of pulleys on opposite walls of the room. A basket that is attached to the top strand moves away from the child as he pulls the bottom strand toward him. Surprised that pulling the line attached to the basket makes it go away, the child pauses.

In science education, this is a "discrepant event" (Hoover, 2016; Longfield, 2009; O'Brien, 2010). This event happens in the mind of the child, not in the physical world. Both Piagetian psychology and current developmental psychology predict that the child, given agency in her immediate environment, would act to reconcile her mind with the behavior of the physical world. However, in this illustration, we don't see what the child does next because the adult intervenes first. Forman continues his exposition:

> The teacher, in full view of the child, then attaches the basket to the bottom strand.

This adult's behavior would be clearly intentional to the child, and would change his thinking. This could be an example of "natural pedagogy" (Csibra & Gergely, 2009), but the point Forman is making here is that unless the adult is self-aware of the value of cognitive conflict and is targeting a particular kind of development, the adult would not take the opportunity to generate conflict and the child would not act "scientifically." After this intervention, the child acts in a way Forman identifies as scientific:

> This time, the child does not make a complete pull on the rope. Rather he holds the rope lightly and moves it back and forth slowly to see which way the basket moves.

This is a wonderful moment, in which the child's intellect seems to be formulating a problem in some sense. The adult is not directing the child to manipulate the material world. That drive is internal to the child. Forman is not clear on what he views the goal of the child is, but hypothesizes that he would not act of his own agency until this mental work was finished:

> Only after this confirmation—that pulling causes the basket to approach—does the boy make a full commitment to pulling the line toward himself.

Forman goes on to claim that the behavior does not indicate formal, mental operations, but a "method" of engaging the world, what Piagetian psychology would call sensorimotor intelligence acting to coordinate physical experience with mental structures:

> Where is the science in this behavior? Had the boy simply pulled the bottom rope again, I would not view this behavior as an indication of scientific thinking. I might call it a prediction or an expectation but not a method of testing a prediction. Causing an action is not the same as testing an expectation that an action will occur when a cause is fully implemented.

Forman's analysis above is also consistent with the "new constructivism" (Gopnik, 2012) that predicts young children act upon the world to build evidence for statistical hypotheses held in brain. To both views, the child's behavior can be taken as an indicator of unobservable mental work characteristic of thinking like a scientist.

"Another mind, older and equally curious." In the above, Forman (2010) interprets the behavior of the preschool child as a part of a "scientific method." It is not clear whether he thinks the behavior was self-conscious, that is, whether the child saw resolution as a goal. Did the child decide upon a course of action to achieve a goal? He writes that "science and play both represent a frame of mind, and attitude toward the events one observes," but then moves to discussing "thinking" and leaves open how this thinking develops:

> the child thinks like a scientist, trying to find the pattern, the structure, the cause, or the degree of the events that happen during ordinary moments of play. I will not say these mind-sets are inborn, but I will say that children do not need direct instruction on how to play. But they need the partnership of another mind, older and equally curious, with which to wonder out loud. (p. 5)

In his last comment, Forman moves toward the role of the adult in developing this child's capacity to think in a "scientific method." Piaget minimizes this role, instead focusing our attention on the few moments when the child was surprised and again when he manipulated physical materials to generate new experiences. Vygotsky emphasizes that the adult has an opportunity to move that child in his play past where he naturally would stay and toward a culture-bound competence. Bronfenbrenner insists that the adult's intervention into the child's play stays immediate, regular, reciprocal, and gives salience to the kind of behaviors that would build capacity for cause-and-effect manipulations as the child becomes more self-aware and self-regulating. Moving a growing child past this immediate desire for "Piagetian agency" to values and practices far past what is functional in a "life-world" will require a cultural community that makes those values and practices valuable to the developing individual.

Environments that Draw Children to Cultural Tools

Construing any human as "naturally" tending toward science is a misreading of science as constituted mostly by a particular kind of unselfconscious cognitive activity and misses the crucial aspect of the cultural demands and tools of modern science. As discussed above, the way of approaching and seeing the world that is actually practiced by working scientists is a cultural legacy of several hundreds of years of difficult, sustained effort by an extended community, a *cultural community* in Rogoff's (2003) words. Before that, those who worked professionally to construct trustable, abstract knowledge (*scientia*) did very different things for very different reasons, typically wrestling with language around theological questions. There were no "scientists" before the late middle-ages (Maier, 1982). So, were children little scientists before there *were* scientists?

Bronfenbrenner's framing of the ecology of human development asks us to characterize environments that promote the capacities utilized in science work and to look for the mechanisms that mediate between the environment and individual development. Vygotsky's reframing of higher thought in humans, and "scientific thinking" in particular, as cultural tools internalized through work with cultural adepts suggests that there is no reason to expect a human to incorporate these without sustained contact with a cultural community that presents them as interesting and functional.

Seeing the World Differently

The discussion above tries to make a few points: Children naturally think in ways that may be developed toward scientific practices and values. Children though, will not do this on their own, even though they find the moments of cognitive conflict and resolution deeply satisfying. Movement toward the abstract thinking, toward values and practices that are proximally dysfunctional, and toward an epistemology and ontology that took hundreds of years to develop, will take sustained and thoughtful contact with adepts who can move individuals lay to that culture into and through zones of proximal development with distal goals prototypical of science. And it will take an environment that gives salience to the target capacities.

The unselfconscious cognitive work and the social experiences characteristic of science work may be available, interesting, even compelling to children *on occasion* and *while developing*, but do children sustain these on their own? The line of thinking behind the workshop being studied leads to a clear answer: The work of science is not what most people expect or do. It is an unusual way of looking at the world developed over centuries, a cultural legacy similar to language and mathematics. Getting good at it involves a particular kind of work, work that teachers and their students can do and can enjoy. However, it is not natural.

On their own children—and most humans—do not *systematically and self-consciously* pursue theories of reality by gathering data about the physical world. They do not naturally *push the granularity* of their experiences to the point where measurement confronts their conceptions of what they know or what they believe is real. They do not *iteratively create and adjust* representations of the world based on how well they function. They do not *repeatedly question the obvious*. And they do not *participate in organized groups dedicated to challenging thinking* through presentation, argumentation, and skepticism among peers.

Drawing people who are inexperienced in science work toward using their native intelligence in these ways is the purpose of the *Seeing the World Differently* workshop model. Experience on representational tasks in contexts and under imperatives that are prototypical of actual science work will bring them closer to understanding and valuing the way physicists approach building knowledge of the physical world and will help make the findings and conventions of physics meaningful.

Exemplars with Young Children

The pedagogy behind the *Seeing the World Differently* model presents the problem of science education mainly as how to organize age-appropriate opportunities and environments for developing humans to reach for competency in their worlds by incorporating the cultural tools of science. The role of the adults in these environments needs to be highlighted, understood, and studied (Engel, 2011). This section looks at two situations that can serve to illustrate how these environments and the adults in them might function to move children beyond their natural engagements with the physical world and with each other and toward the values and beliefs, expectations, actions, and emotional responses that constitute science culture.

Being Asked to Draw What Is Really There

Broderick (2004) presents an example where the adult sees clearly that her interventions are leading young children (3.5 – 4.5 years old) beyond their typical interactions with the physical world toward distal developmental goals representative of science work. The author is trying to help a classroom become "constructivist," which she identified with the beliefs that "materials should be available for children to create with meaningfully in their own ways; teachers should not set out prescribed art activities; the curriculum should emerge from the interests of the children" (p. 1).

Below is a close examination of the author's discussion of the classroom activity and her own thinking as she engages the teachers and children. All quotes are excerpts of her narrative (pp. 19–23), with development of the story set as block quotes to emphasize the flow of her argument.

Drawing a real crab. Broderick begins by observing the activities of the classroom:

> The teachers wanted to learn more about what the children knew about hermit crabs so they invited the children to draw what they saw when looking at the hermit crab in his large fish tank.... They didn't really think that these young children had the skill to draw a hermit crab successfully and were entering this experience based on their trust in my suggestion that it would help them.

When one teacher asks the children, "Can you draw the hermit crab and tell us what you know about him?" the children make short statements about the crab and their experiences. The teacher then asks, "Can you draw him?" Though the crab was not visible,

> The children begin to draw but they seem to be making random marks unrelated to ideas about the hermit crab.

One child asks to see the crab. With the crab now visible, the children still seem to be making random marks. At this point, Broderick intervenes:

> "If I were going to draw a hermit crab I think I'd start by drawing the body." I draw a circle on my paper. Mary imitates me.... I place my pencil at the edge of this circle and say... "I may want to draw the legs next." Before I can say, "legs next" Mary has drawn a complete leg on her paper that extends out from the circle she has made. She continues to make four more lines down that almost touch the circular body.

Broderick now does the same. A boy then mentions "eye ringers" and the girl draws two lines up from the body. Broderick does the same, and the boy responds:

> Liam: See, eye ringers.
>
> Teacher 1: They help him to cry?
>
> Liam: Crawl.

Broderick relates her own thinking at the time, to model for teachers how to guide their own teaching to reimagine children's behavior, like Forman above, as indicating hypotheses about children's thinking:

> ... While sitting here drawing I think about [having] another drawing session in the future to revisit Mary's pictures and encourage other children to tell us how the eye ringers work. They may need to draw and act out a lot of thinking to discuss that idea. They may even choose other types of materials to support their thinking.

"Benefiting from suggestions." This adult intervened in the play of some toddlers expressly to guide them to represent their experiences with the physical world more carefully than is immediately necessary or of interest. Broderick (2004) goes on to note the essential role of the adult in moving children along the line of development:

> ... while children will explore available materials on their own, they also benefit from suggestions, particularly about materials they don't use frequently... that encourages children to develop a deeper understanding of their ideas by representing them in a variety of materials. ... In this manner the teacher's suggestions serve as the social conduit through which the children learn. (p. 8)

As typical in early-childhood constructivist approaches to working with children, she insists on the agency of children in resolving cognitive conflict, even when engineered self-consciously by adults:

> The key is for the teacher to present her suggestions in an open ended manner that encourages children to respond with their own ideas. The introduction of materials then becomes a first step in a dynamic dialogue with the children… . (p. 3)

Though Broderick presented above the activity as "visual arts experiences," she makes clear that they provide opportunities for adults to lead children into developing their capacities toward science work:

> The whole experience portrays children as researchers who know the importance of investigating real data (bring the real crab out for us to see it) and researching new sources of information (seeking out a book on hermit crabs) in the process of trying to communicate what they know and that their knowledge is not static, but developing along a continuum. (p. 19)

As with Forman above, it is unclear whether Broderick here is chiefly using the language of "Western science" to motivate teachers to reimagine the play of children as appropriate tasks, or whether she is modeling their activity as self-conscious, practices prototypical of science culture.

The *Young Scientist Series*

In their *Young Scientist Series,* Chalufour and Worth (2006) make explicit the difference between the unselfconscious drive to play and the cultural imperatives of science work. "The Young Scientist series makes science the work and play of exploring materials and phenomena, while providing opportunities for children to learn from that experience". (p. 2)

> Teachers' scaffolding provokes children to do other than they normally would, other than "playing with cars and blocks..." based on their "interest and curiosity..." with only the "potential for reflection, dialogue, and developing ideas about some interesting and critical physical science concept...". (p. 3)

For the 3 – 5-year-old children this curriculum is designed for, it is the teacher that must create a "building environment" and a "building culture" to bring children from self-absorbed and momentary play to the "discussion, expression, representation, reflection" that Chalufour and Worth (2006) recognize is the scientists work. They intend this curriculum to "draw forth" from children activity and thinking that children do not do in typical play: "observe closely," "raise questions" to "investigate," draw carefully to "represent things and ideas," and "analyze" their "findings" (p. 4).

As in the *Ramps and Pathways* (Zan & Geiken, 2010) activities, the *Young Scientist Series* keys into the natural social and cognitive interests and drives of young children. Here, the phrase "young scientist" stands for work that is developmentally appropriate but prototypical of actual science work: "[Children engaged as builders] spend a great deal of time representing and documenting what they do—using careful sketches and descriptive words to most accurately remember their experiences and share what they have noticed and learned..." (Chalufour & Worth, 2006, p. 6).

These authors do not confuse the natural drives of children with the values and beliefs, expectations, actions, and emotional responses familiar to insiders of science work. There are many references directly helping teachers connect the activities they are guiding the children into to the culture-bound practices of those who work in science. Since "scientists also communicate with words... children communicate their findings, participate, in discussions and represent their experiences... in multiple forms of expression." Since "scientists exchange ideas, build on one another's work... children need to work together... to suggest a bigger picture" (Chalufour & Worth, 2006, p. 7).

Motivation for Engaging Achievement Tasks

Expectancy-value theory (Eccles, 1983a; Eccles, 2007; Eccles, Barber, Updegraff, & O'Brien, 1998) is a well-developed framework for measuring the causal relations among personal and social factors mediating between experience and achievement behaviors. It was developed over several decades for exploring why adolescent females choose to take fewer mathematics courses even though females' performance in math courses was not significantly different from males'. Since it was formulated, the expectancy value model has been used as the theoretical framework behind hundreds of studies of achievement-related decisions and continues to be a popular conceptual tool.

Factors influencing choosing behaviors include individuals' own beliefs about their abilities, sense of identity, goals, and emotional reactions to the task. These factors are influenced over time by an individual's aptitudes, personality, temperament, perceptions of gender roles and of the work. Environmental influences include the behavior of socializing agents and more diffuse cultural factors like gender-role stereotypes and occupational stereotypes in society.

Mediators for Choosing to Engage in Academic Tasks

Despite its complexity, the model defines only two constructs that mediate the effects of developmental influences on choosing behaviors: the individual's *expectations for success* at each task option, and his *subjective value* for each task option (Eccles, 1983a).

Expectation for success is an individual's domain-specific belief about his personal efficacy to master a task. This belief is thought to be mediated by attributions for success and failure over many experiences with similar tasks. These interpretations are influenced by existing specific self-efficacy beliefs, which in turn are influenced by a history of social messages and by self-concepts, such as identity.

Subjective task value is an individual's composite view of the positive and negative experiences likely in choosing the task organized into four categories. *Interest-enjoyment value* includes how fun the work is, how interesting, and whether the experience of the work itself is immediately satisfying. *Utility value* includes whether the work is helpful in meeting a goal, either short-term or long-term. *Attainment value* is the extent the task agrees with one's sense of self or one's social identity. *Cost* captures all negative valuations of committing to the work, such as the loss of opportunities or the anticipated feelings of frustration or incompetence.

Lack of Attention to Intrinsic Value as a Driver for Choosing to Engage

The original presentation of the model defines intrinsic value of a task as “the inherent, immediate enjoyment one gets from engaging in an activity” (Eccles, 1983a, p. 89), but does not elaborate it further. In a two-year study using her model to explain engagement among high school students, Eccles (1983b) did not examine the impact of intrinsic value because she did not find any significant sex differences in this measure. In her review of the success of her model in helping to understand vocational differences between men and women, Eccles (2007) again gave little attention to how interest value affected choices in achievement tasks.

Attribution and Learners’ Interpretations of Events

Importantly for the current study, the expectancy-value model holds that the socializers around an individual’s experience with achievement tasks (authorities, judges) can strongly influence how a current experience with a task is interpreted. Eccles (2007) found, for example, that parents and math teachers attribute success in math differently for boys and girls, and consequently girls tend to believe the personal cost of doing math work is higher than boys and the utility value lower compared to other work. This highlights the importance of people’s attribution for their success and failures on later decisions to pursue different options in work and academic arenas.

Attributions influence achievement-related decisions (selecting work, engaging work, performing) indirectly both through the expectancy beliefs of the individual and the subjective value of the work to the individual in complex ways. Attributions can be communicated to learners in an achievement situation and are often negotiated unintentionally between a learner and authorities.

For this study, a sense that success in building competence in the tasks is attributable to external or uncontrollable causes (adept intervention, luck, easiness of task) could keep outcome expectancy low and not generate positive emotions around work in science. Affirmation of performance to distal developmental goals, such as competency in science (science is hard, teaching science is troublesome), or to differential abilities within peer groups (you are good at science thinking, you know science well) could affect the micro-decisions to engage or defer work within the workshop unpredictably. Attribution statements by adept should be back to the proximal task-at-hand, using cultural and cognitive tools to approach the task prompts (describe, explain, represent) and following science imperatives (get down carefully what you see).

As facilitator, the cultural adept should not attribute struggles to difficulty of canonical science or the ability of the teachers with canonical science. The adept can attribute struggles to difficulty in seeing what's going on or expressing what observations and thinking clearly enough for an audience or imagined others. Finally, as facilitator an adept should not mirror, extend, or refute participants' statements about adept's view of his own success or failures in the tasks.

Summary

This chapter developed the central thesis behind using this professional development model as an intervention into the way elementary-school teachers engage, parse, and explain the physical world: The problems of teaching science in ways that do not lead to assimilation, resistance, and resignation are not to be solved by thinking just about thinking. They require attention to the mechanisms through which people develop their competence in dealing with their own worlds, which in turn requires attention to culture.

That development looked to the academic literature to establish three main points: (a) National STEM standards have evolved over the last decade to require that elementary school education bring into the classroom work that is prototypical of actual science work, a change that will require different work for both students and teachers; (b) The tools of science work are more akin to a different way of being in the world, and they take sustained, culture-bound processes to develop; and (c) Small, regular interactions among people working through cognitive conflict within a familiar culture but organized around science cultural imperatives could draw people along the developmental paths leading to the cultural tools of science.

The intervention explored in this study is an attempt to meet this last challenge. It tasks adults to do work prototypical of scientific modeling within peer groups using familiar materials in contexts that simulate the contexts and imperatives of science work. The next chapter establishes the methods used to explore that model, the type of data the study generated, and the methods used to analyze that data to address the purpose and specific research questions of the study.

CHAPTER 3

METHOD

This is a non-experimental, exploratory study without comparison groups. The treatment was a workshop on scientific modeling based on the *Seeing the World Differently* model, delivered in two 1.5-hour sessions after school to elementary-school teachers recruited from local school districts. Following the model, participants worked in small groups and in one whole-group session on tasks revolving around describing and explaining everyday physical phenomena using pencil-and-paper representations. The work was facilitated by the researcher according to strict protocols.

Demographic data was collected on the participants prior to the workshop. Pre- and post-treatment data was compared for group effects on science teacher self-efficacy beliefs and outcome expectancy. In-treatment attitude data was analyzed to assess participants' subjective value of components of the intervention. Teacher behaviors during small-group work were coded from videotape to assess whether the workshop elicited prototypical scientific modeling. Post-treatment evaluation data was used to assess the social validity of the workshop as professional development. Facilitation checklists were used to help keep the facilitator on time and following protocols.

Research Questions

For the Seeing the World Differently workshop model:

1. Do workshop participants engage in prototypical scientific modeling behaviors?
   1.1. Do participants engage in arranging materials to create conditions for them to see and formulate questions about the physical phenomenon they are tasked to describe and explain?
   1.2. Do participants invent measures for characteristics of the physical phenomenon they are tasked to describe and explain?
   1.3. Do participants display representational competencies in externalizing their thinking about the physical phenomenon they are tasked to describe and explain?
   1.4. Do participants follow an epistemology of modeling while engaged in the prototypical scientific modeling tasks?

    1.5. Do participants' modeling behaviors differ between the research phase and the publication phase of the core treatment?

2. Do workshop participants find subjective task value in the activities of the workshop?
    2.1. Do participants find intrinsic task value in the activities of the workshop?
    2.2. Do participants find utility task value in the activities of the workshop?
    2.3. Do participants value the workshop phases (initial meeting, research phase, conference phase, publication phase, final meeting) differently?
3. Do workshop participants' expectancy for success in science tasks differ before and after the workshop?
    3.1. Do participants self-efficacy beliefs toward teaching science differ before and after the workshop?
    3.2. Do participants outcome-expectancy beliefs toward teaching science differ before and after the workshop?
4. Do workshop participants find social validity in the workshop as professional development?
    4.1. Do participants believe the workshop focused on science content and pedagogy appropriate for elementary classrooms?
    4.2. Do participants believe the workshop provided them with opportunities for active learning?
    4.3. Do participants believe the workshop was coherently aligned with their curricula, standards, and the ways they will be evaluated professionally?
    4.4. Do participants believe the workshop focused on science content and pedagogy that would be supported at their school or district level?
    4.5. Would participants pursue opportunities for follow-up activities to assist in incorporating either the physics content or the teaching methods they learned into their classrooms?

Population and Sample

The general population of interest is teachers of children aged 5 through 8 years. Of specific interest are those who are not experienced in the actual practice of science and have no special training in the physical sciences, but who are interested in bringing science into their classrooms.

Sample

Participants were recruited from elementary and preschool teachers working in an urban school district near the Appalachian mountains of northeast Tennessee. The district administration circulated the researcher's flyer advertising the workshop as part of their professional development offerings. As incentive, the district offered 3.5 hours of district professional learning credit for completing the workshop, and the researcher offered downloadable materials used in the workshop. This sample design is purposeful and convenient.

The study recruited seven participants. All were female. Six were established teachers and one was a student teacher. Three had bachelor's degrees, three had master's degrees, and one did not identify her educational level. Four were currently teaching 1st grade, one 2nd grade, and two 4th grade. Experience at current grade varied, with three at their current level for one year, two between four and six years, and 1 at 15 years. One person did not provide this information.

All participants completed both sessions of the workshop. However, pre/post measures of self-efficacy and outcome expectancy were not available for four people.

Ethical Treatment of Participants

The study was approved by ETSU's Institutional Review Board and the review board of the participating school district. The workshop flyer announced that teachers would be participating in a research effort to "understand how a popular professional development program on science education works" and offered, along with the professional learning credits, to help teachers become more at ease with the thinking behind science, see the importance of student representations and dialog, and develop teaching strategies for the Next Generation Science Standards while addressing ELA and math standards.

A week prior to the workshop recruits were given, via email, an explanation of the benefits of the study, the procedures, data collection and management procedures, and the likely outcomes of participating. They were informed that video clips of their activities might be used for teaching or public presentation but would have all names and school affiliations edited out, and if they did not wish video of their workshop activities used in this way they may opt out. All participants signed an informed consent agreement. They were reminded at workshop time that they could leave the study at any point and still have access to the workshop materials.

Participants were given a random ID prior to data collection and all data is identified by this ID only. Demographic and attitude data was collected using an online survey platform that did not collect IP information or other identifiable information from respondents. Physical artifacts of the workshop are identified only by ID. Video recordings of workshop activities were downloaded immediately to secured storage. Video used to analyze modeling behaviors was edited to identify participants by ID and was available only to research staff.

Treatment

The participating school district made a room available in one of their middle schools. The room had been a classroom but was being used to store furniture and house the desk of a content specialist. There were sturdy school work tables and chairs fit for adults that could be moved with some effort, and open space for videographers to reposition themselves freely and for teachers to move to if they wanted space to enact a phenomenon. There was a projection screen and projector with laptop connection suitable for the initial meeting presentation. There was a whiteboard at the end of an open space large enough for the teachers and presenters to discuss ideas during the conference phase. The room was cluttered but sufficient.

Planned Workshop Schedule

To keep down the time required after a full workday, the workshop model was compressed from 215 minutes (about 3.6 hrs) into a target time of 160 minutes (about 2.7 hrs), a little over an hour and a quarter per day (Figure 3). To accommodate this change, the initial and final meetings were each shortened by 10 minutes, each small-group session was shortened by 5 minutes, and the whole-group conference was shortened by 10 minutes. Break times between components were removed. The workshop was split to hold the initial meeting and research phase on the first day and the conference, publishing phase, and final meeting on day two. This allowed teachers to begin work on prototypical modeling immediately after the facilitator presented the key themes, but allowed no time for breaks or administrative work.

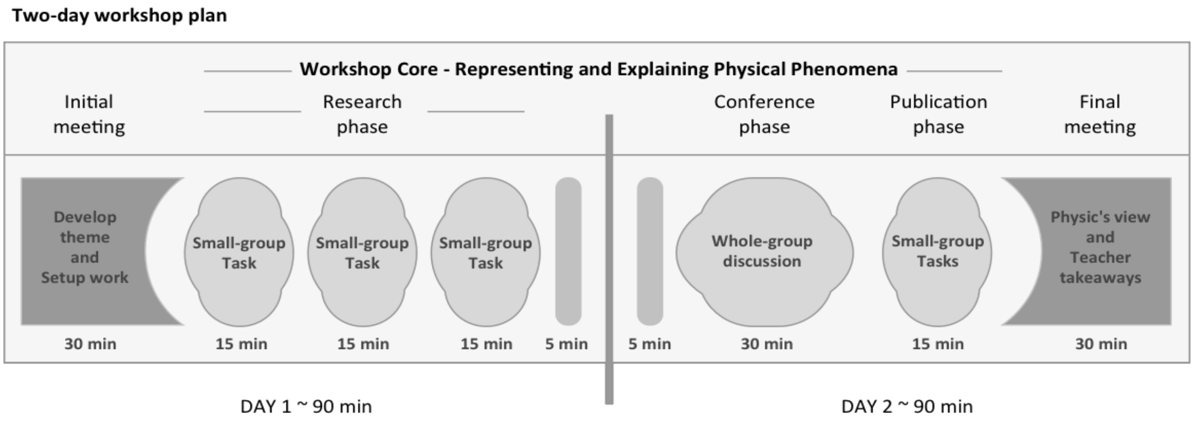


Figure 3. Planned delivery of the workshop model as a study treatment

Provocations for Representational Tasks

Three research phase rounds were planned. During each round, a group was presented a different prototypical modeling task as an educational provocation (Broderick & Hong, 2011; Jones & Nimmo, 1999) comprising a printed prompt establishing the task and a set of materials to enact the phenomenon. (See Appendix B: Provocations for Representational Tasks.)

In this study, the representational tasks have three fixed features: They are engagements with physical phenomena enacted with familiar, manipulable, physical materials. They stem from a uniform prompt to describe and explain a phenomena in isolation. They ask the participants to represent their thinking with pencil and paper in extendable, semi-structured booklets, referred to as “flipbooks.”

The physical phenomena and enacting materials. The physical phenomena were presented as three concrete situations enacted by simple materials. Each phenomenon had been used in representational tasks successfully in workshops with elementary teachers. The three physical phenomena are: (1) moving some ketchup stuck in a bottle to the top of the bottle; (2) accelerating a pickup truck with a loose bowling ball in the bed; and (3) swinging a stuffed toy in a circle by a string, then letting the string go. The ketchup and bear tasks present those objects directly to the groups as enacting materials. The truck task offers analogous materials to use as proxies for the ball and truck, adding a level of abstraction.

Task prompts. Task prompts begin with a brief text referring back to some of the content themes of the workshop, given below:

> The focus of day 1 will be teachers observing and representing their own descriptions and explanations of the how and why of movement in very simple situations.

> There is no right way to think about these provocations.

Each prompt then names one physical phenomenon, presents a question to explore, and reminds the teachers that their work is "observing and representing." The text of the prompt questions are given below:

> Ketchup: How do you get all the ketchup to go from the bottom to the top of the bottle and why does this work?
> Ball: Why does a bowling ball move the way it does when it is loose in the bed of a pickup truck while it's starting or stopping?
> Bear: If you swing a toy bear in a circle and let go, why does it do what it does?

Each prompt then presents "What to do" in five generic steps customized to describe the phenomenon being enacted and emphasizing the target scientific imperatives of the workshop: "looking very carefully at what happens and why it works," "represent what you saw... the best you can," "revisit the situation... revisit your drawing", "continue this until you are satisfied with your drawing."

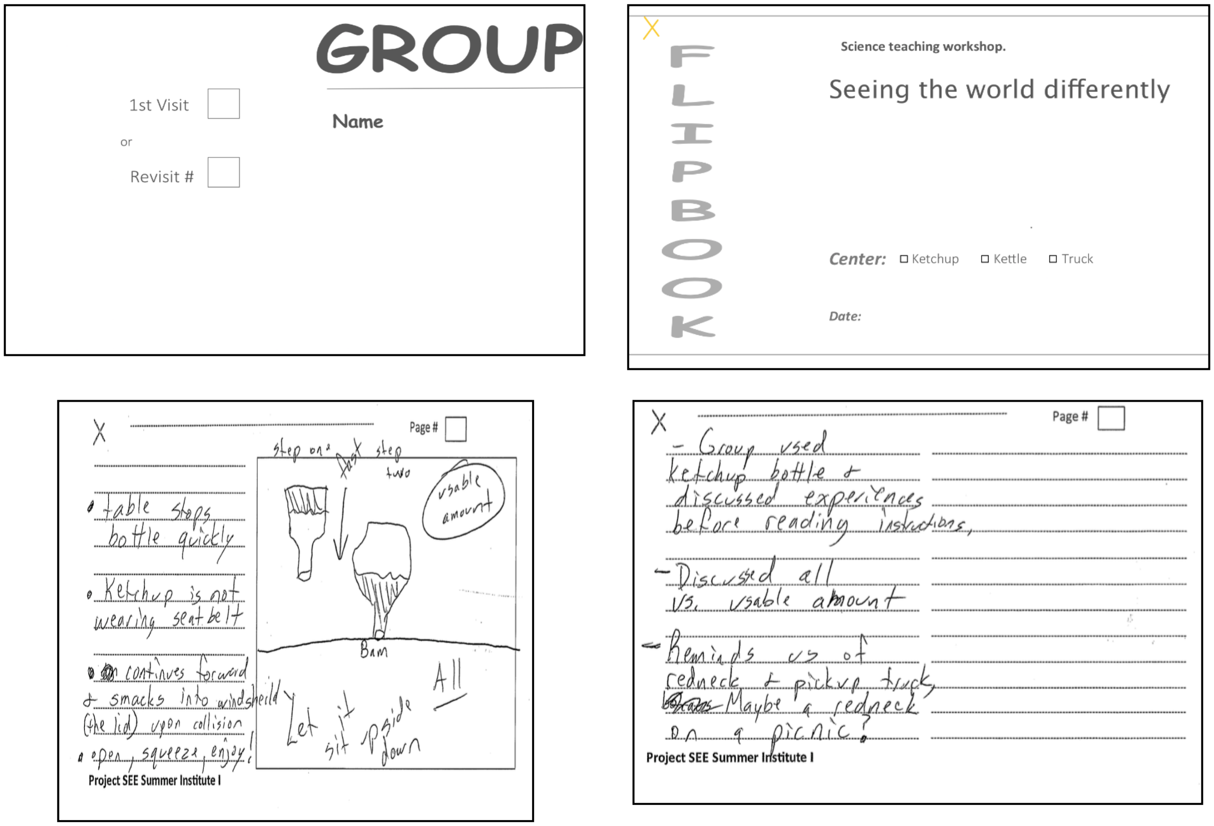
It is important that the representational tasks generate conversation around physical reality and work around representing reality, and that these conversations are in a context that bridges everyday experience with imperatives and dynamics of professional science. To this end, the tasks were varied along three dimensions: (a) the directness of the prompts, (b) the concreteness of the tasks, and (c) the social context and stated expectations for the groups.

The social context and expectations for tasks are implicit in the workshop structure itself. The research phase involves exploratory work in semi-public, during which a group can use the thinking and work of the others. The conference phase involves open, public discussions and argumentation about work. The publication phase is relatively isolated work to create a definitive version of a group's own thinking. The prompts themselves differ on the concreteness and directness. One prompt is worded to directly tell groups what to do with the materials ("How do you get the ketchup to…"), while the other two are more indirect and require some interpretation ("Why does it…"). Two prompts ask about the concrete objects in front of the groups (ketchup bottle, bear and string), while the third asks about a hypothetical situation and offers the materials as proxies (bowling ball in a pickup truck).

Representational materials. Teachers were asked to make their representations on semi-structured printed forms that the teachers draw and write on to build extendable booklets, referred to as flipbooks to emphasize that they can be "flipped through" to revisit a group's evolving thinking (see

Figure 4). Flipbook pages were 8.5 by 5.5 inches, printed on one side, and could be bound together into booklets using simple clips. They were somewhat structured—different pages had different purposes—and somewhat open—people could add pages as they liked in any order that seemed useful for capturing their thinking. The "group page " identified which group was building the booklet. A "task page" provided a cover page for the pages a group used to represent their thinking on a single task. A "sketch page" was for getting down a little diagram with annotations, and a "text page" was just for writing.

Flipbooks were extendable to capture the evolving thinking of a group of people. The drawing and writing space was made deliberately small to focus thinking and to encourage editing and structure. These booklets had been used in several situations with adults and adolescents performing similar tasks. They were easy to handle and drew no complaints. Previously, early-childhood teachers stated they could use these materials with literate and preliterate children and were interested in using them in their classes.



GROUP

1st Visit ☐
or
Revisit # ☐

Name

FLIPBOOK

Science teaching workshop.

Seeing the world differently

Center: ☐ Ketchup ☐ Kettle ☐ Truck

Date:

X

Page # ☐

- table stops bottle quickly
- Ketchup is not wearing seat belt
- continues forward & smacks into windsheild (the lid) upon collision
- open, squeeze, enjoy!

Project SEE Summer Institute I

X

Page # ☐

- Group used ketchup bottle & discussed experiences before reading instructions,

- Discussed all vs. usable amount

- Reminds us of redneck & pickup truck, Maybe a redneck on a picnic?

Project SEE Summer Institute I

Figure 4. Example of a group's representation of a phenomenon assembled into a flipbook

Facilitator and Facilitation Protocols

In this study, the researcher facilitated the workshop. He had previously facilitated a 3 half-day workshop using this model for early-years teachers and had worked with preservice teachers along the line of the model within their science methods course.

Qualifications of the facilitator. The facilitator was qualified both as an adept of science practices and was familiar with scaffolding and constructivist theory and practice. He had five years of experience working in an academic physical chemistry research setting and has eight years of experience teaching physics in secondary school and five years of tutoring physics in post-secondary school. He had finished his coursework in a PhD program in early childhood education and had several years' experience working with pre-service and inservice early childhood teachers. He was trained in constructivist and emergent approaches to teaching.

General standards for facilitation. The adept facilitated the workshop following general protocols for his choice of words, gestures, mannerisms, and tone-of-voice, and outlining the responsibilities and limitations of the treatment. Responsibilities: dialog with teachers about their ongoing work; focus teachers on the provocations, help frame confounding features of the situation and teachers' own representations, make clear that there is no targeted way to think about the phenomena, push the members of the group to be clear and to strive to capture what they see and think. Limitations: do not explain phenomenon or elaborate on teachers' thinking, do not tell the teachers that they have something right or wrong, do not relate or interpret one group's work to another, do not affirm the use of standard science formalisms. For example, if the group thought a representation did not succeed in capturing their own thinking, then the facilitator would prompt them to improve their representations, look again at the phenomena, or look at what others have done.

Measures

The study developed several measures of the fidelity of the workshop to the workshop model to help establish that the model itself was responsible for any treatment effects. These assess whether the workshop themes were introduced, whether the facilitator handled references to canonical science correctly, whether the facilitator managed causal attributions correctly. The study developed effect measures for participants' prototypical science behaviors, for the subjective task value of workshop components, and for the validity of the workshop as professional development. The study uses a well-established instrument to evaluate participants' self-efficacy and outcome expectancy beliefs.

Fidelity Measures

Since the purpose of the study is to explore a workshop model, measures of the fidelity of the implementation of the model were developed. The model calls for an initial and a final meeting, each with specific content, and for three distinct phases of participant work (research phase, conference phase, and publication phase). Facilitation protocol requires that during these core phases the facilitator uses scaffolding practices, does not use ideas and conventions from canonical physics, and should not attribute the difficulty or degree of success in teachers' work to science itself, though they are free to make attributions to the nature of the academic task at hand, that is, to enacting, observing, describing, explaining, and representing physical material systems. Fidelity to each of these features was measured.

Presentation of key workshop themes. Chapter 1 introduced six key content themes and six key process themes that the facilitator was to present at specified times in the model. Content themes are meant to draw teachers away from thinking about science work as scripted and toward it as a compelling human behavior that needs special but achievable conditions to develop. Process themes are meant to point teachers to a way of working that is intended to better model actual science work, built around provocations to engage with the physical world and around discussions and intersubjective standards of knowledge. The design of the workshop model stipulates that, in the initial meeting, "the facilitator presents the key content and process themes that the workshop is built upon", and that in the final meeting, "the facilitator… relates the work back to the themes of the workshop". Table 1 lists the 12 key themes and assigns to each a code to be used in coding video recordings of workshop components.

Table 1

Coding Table for Key Themes of the Workshop Model

Code	Theme
Content	
CAligns	The work aligns with teachers' work and can be taken into their classrooms with few resources
CSciencey	The work is "sciencey", not direct instruction in science content.
CDescExpl	Like physics, the work is to describe and explain simple physical phenomena.
CNewLook	The work is not the normal way people look at the world.
CDialRep	The work emphasizes representing your own thinking clearly and concisely and having conversations around those representations.
COpen	Because the work is about teachers' thinking, there is no one right way to represent their descriptions and explanations.
Process	
PPeers	Teachers will work in different ways, sometimes in small groups and sometimes altogether.
PProvoc	Teachers will work in centers around provocations about how they see and explain the physical world, and will transition between centers to engage different phenomenon.
PEnact	Teachers will use simple materials to enact everyday phenomenon in ways they can manipulate and modify.
PRepr	Teachers will use simple pencil and paper forms assembled into flipbooks to represent what they see and their explanations.
PDialRep	Teachers will have chances to dialog with each other and the facilitator on how they are representing their thinking.
PRevisit	Teachers will have a chance to revisit and modify their representations before the workshop ends.

Coding was done in four passes. In the first, the researcher viewed a video segment to make a two-level outline of the content of the meeting. This outline was not used directly for coding but to organize the flow of the component in the coder's mind. In the second pass, the researcher made an abridged transcription of facilitator talk, breaking the transcript into segments as seemed helpful (Appendix A: Coded Transcript of the Initial Meeting). This broke the 30-minute meeting into 61coding segments, ranging in length from 5 seconds to two minutes. The transcription is roughly verbatim, but talk that did not pertain to content or process themes was not transcribed and is indicated in the transcript with ellipses. In the third pass, the coder viewed the video and transcript simultaneously and marked transcript sections with the content codes. This was repeated in a fourth pass with process codes.

Facilitator reference to canonical science. The design of the workshop model stipulates that the facilitator should not introduce or affirm canonical science content. He should not offer technical explanations or introduce constructs, conceptualizations, or symbol systems that rely on expert knowledge from a scientific field or subject. He should be careful not to introduce technical versions of words that should be accessible within the population sampled in the study. If teachers ask specifically whether they are using such a term in a canonical sense, he should push the question back to the teachers by asking them to use it if it makes sense to them and to indicate in words or drawings how that word describes or explains what they see in the phenomena they are enacting.

To measure how faithfully the actual workshop was to this intention, video recordings of the research phase of the workshop were coded for facilitator statements.

Facilitator attribution statements. The design of the workshop model stipulates that the facilitator should not attribute difficulty or degree of success to science content, but that they can attribute these to the nature of the academic task, specifically to enacting, observing, describing, and explaining the phenomenon at hand, and to representing thinking. To measure how faithfully the actual workshop was to this intention, video recordings of the research phase of the workshop were coded for facilitator statements that implied attribution of performance levels to the ability of the participants or the difficulty of the task, two causal factors identified as particularly important for developing outcome expectancy in academic tasks. These two types of attribution are further divided by whether the statement is about the immediate task at hand or a more distant conception of science as work or an academic subject.

This scheme gives four attribution codes (Table 2): ability with science, difficulty of science, ability with academic task, and difficulty of academic task. The workshop model allows attributions of performance to both the agent's ability with the task at hand and to its perceived difficulty, but disallows any attributions to agent's ability with science as a subject or as work, or to their perceived difficulty.

Table 2

Coding Table for Facilitator Attribution Statements

Causal factor	Immediacy of factor	
	Canonical science	Representational work at hand
	Reference to science as work or as a school subject, or to the idiom of canonical science	Reference to the core academic task of the workshop model, “describing and explaining” a phenomenon
Agent ability	The facilitator comments on an individual’s or a group’s knowledge, ability, or performance in science or a science subject. For example: “You are good at science.” “That [what you said, drew, or wrote] is physics.” “That [what you said, drew, or wrote] is not quite right [as physics or or science].” “Yes, that is [as you say] momentum [velocity, torque, etc.].”	The facilitator comments on an individual’s or a group’s ability or performance enacting a phenomenon, describing and explaining the target physical phenomenon, or representing the thinking of the individuals or the group. For example: “That [what you just said about the phenomenon] is brilliant.” “Your drawing is great [as a representation].” “Your drawing doesn’t get across what you just said to me.” “That [what you just did] was a clever way of using the ball.”
Task difficulty	The facilitator refers directly to the ease or difficulty of science work or science as a school subject. For example: “Physics is hard.” “Science is complicated.” “This is science: It’s hard.”	The facilitator refers directly to the ease or difficulty of enacting, observing, describing, or explaining physical phenomenon or of representing thinking. For example: “This [describing, explaining, representing] is hard.” “Getting it [the words or drawings] down is not easy.” “Capturing your thoughts is difficult [takes trial-and error, is slow, etc.].”

Only the research phase work was coded for facilitator attribution statements. The study was not able to implement the publication phase of the workshop model, and the video recordings of the conference phase were not successful. A trained research assistant who was familiar with the content and intent of the workshop model coded all six of the research phase sessions using the coding scheme in Table 2. These are tabulated and presented in the results.

Prototypical Scientific Modeling Behaviors

Whether teachers' engagement with the core tasks elicited targeted protoscientific modeling behaviors were measured using a researcher-developed coding scheme (Table 3). These definitions are used to answer research questions 1.1 – 1.5 by coding video recordings of teachers' behaviors in the core workshop.

Constructs measured. The measure breaks prototypical modeling behaviors into four constructs: "Arranging for conditions of seeing," "Inventing measures," "Developing representational competence," "Developing an epistemology of modeling."

Table 3

Coding Table for Protoscientific Modeling Behaviors

Code	Behavior	Indicator
CS	Arranging for conditions of seeing	Arrange materials to isolate or observe the phenomenon Formulate questions to answer using materials Formulate conditions to allow questions to be answered using materials Adjust intentions to further study the behavior of materials Adjust understandings to accommodate the behavior of materials
IM	Inventing measures	Reconceptualize qualities to describe them by measures Invent, adapt, or adopt measures to describe qualities using counts or names Use measures to describe relationships between qualities Conventionalize measures to make them uniform across groups
RC	Developing representational competence	Invent, adapt, or adopt symbols to capture observable or unobservable qualities of the phenomenon, either on paper or in speech Simplify representations to ignore useless or distracting information, either on paper or in speech Evaluate a representation explicitly to qualify or back it as a stand-in for the phenomenon, either on paper or in speech
EP	Developing an epistemology of modeling	Evaluate descriptions or explanations to distinguish interpretations from observations Evaluate descriptions or explanations to qualify them as approximate or contingent Compare descriptions or explanations to observations or narratives to test them Compare descriptions or explanations to another description or explanation to test them Modify descriptions or explanations to make them fit observations or to generalize them Discuss conditions of seeing to establish a test of a description or explanation

Development of the instrument. Each construct is operationalized by behavioral indicators, written as an action with a purpose. The coding table above was developed from the extended discussion in Lehrer and Schauble (2010) of what students need to do to invent and revise scientific models of physical phenomena based on those authors' experience developing a pedagogy of scientific modeling for middle school. They present four broad categories of competence. The discussion below lists the categories as those authors named them, and for each, illustrates their thinking using key quotes and then conceptualize the category for this study. Key terms, in italics, are given meaning in the context of this study.

Arranging for the conditions of seeing. Lehrer and Schauble (2010) discuss this category on pages 13 – 14. Here they describe the “struggle that ensues when scientists try to wrestle the natural world into a position where they can effectively study.” “[W]hen one develops a material system for investigation, nature presses back in ways that investigators often find surprising and that result in adjustments of human intentions and understandings…” and that “[provoke] formulating the questions and conditions for inquiry.”

In this study, *the natural world* has been limited to the phenomenon each group is tasked to describe and explain. The *material system* is made of the enacting materials provided in the provocation, the work areas given to the teachers, and whatever supporting materials they choose to bring in. *Studying* implies manipulating materials with the intentions to pursue questions about the physical world and then adjusting thinking in response to observing the physical world. This conceptualization is summarized for this study as follows:

> *Group members arrange materials into a position where the phenomenon can be studied. They adjust their intentions and understandings based on materials reacting to their manipulations. They formulate questions about the phenomenon or about conditions for pursuing questions about the phenomenon.*

Competence in this type of modeling behavior relates to the science modeling imperative “to iteratively study the physical world via isolated phenomenon.” The prototypical scientific modeling behaviors for this competence are listed in Table 3.

Inventing measures. Lehrer and Schauble (2010) discuss this category on page 14. Here they relate how “[students’] questions inspired a menu of inventive measures, many of which were picked up by other student investigators and adopted as classroom conventions.” They relate this to scientific modeling, where “measures and qualities of a system are co-determined: inventing measures requires reconceptualizing the qualities being measured, and developing measures makes it possible to specify relationships among qualities”.

In this study the *questions* are group members' questions about how and why the phenomenon they are tasked to describe and explain behaves. The *system* is the materials they are using to enact the phenomenon and the process the students envision at work. *Measures* give answers to questions about qualities either as counts (quantitative) or as names (factorial). *Conventions* can be adopted within the small groups or across groups. This conceptualization is summarized for this study as follows:

> *Group members reconceptualize qualities of materials or processes so that they can be described by measures. They invent measures that are given as counts or names. They specify relationships among qualities using counts and names from measures. They combine measures into composite measures. They adopt or adapt measures from others, suggest measures for others, or work toward conventions on how qualities should be measured.*

Competencies in this type of modeling behavior relate to the science imperative "to refine the granularity of interrogations of the physical world". The prototypical scientific modeling behaviors for this competence are listed in Table 3.

Developing representational competence. Lehrer and Schauble (2010) discuss this category on pages 15 – 17. Here, they list skills students must build competence in when they "confront representational challenges". They must develop an "expanding representational repertoire" to "abstract attributes like height from their rich, personal [experiences with a phenomenon]" and to "notice", "focus on", "capture", "record" and "display" patterns in abstract qualities. They must learn to "leave information out [if it] is useless or distracting", "relinquishing the assumption that represent means copy". They must learn to evaluate representations "based on what one is trying to learn or communicate", to "recognize that all representations involve trade-offs", and to "critique and evaluate their own and their peers' representation with respect to what [they] show and hide", to "accept or communicate the representational validity of the model" and to evaluate it as "an adequate, persuasive, or informative stand-in" for the phenomenon.

In this study, the *representational challenge* is marking into flipbook pages words and drawings that capture the thinking of group members about the what and why of the behavior of the materials when the group enacted the phenomenon. The *developing an expanded repertoire* happens when group members invent, adapt, or adopt symbols to represent patterns, qualities, or attributes, either by marking them on paper or by discussing them in speech. The *learning to leave out information* happens when groups simplify symbols to ignore useless or distracting information, either on paper or in speech. The *learning to evaluate representations* happens when group members explicitly evaluate a representation, either on paper or in speech, to qualify or back the warrant for its claim as an informative stand-in for the phenomenon. This conceptualization is summarized for this study as follows:

> *Group members invent, adapt, or adopt symbols to capture observable or unobservable qualities of the phenomenon. They simplify representations to ignore useless or distracting information. They explicitly evaluate a representation to qualify or back it as a stand-in for the phenomenon.*

The competencies in this category of modeling behaviors cross boundaries drawn in this study: The group must coin symbols and use them to externalize members' thoughts about what happened and why. It must deprivatize individual thinking, making it an object of joint attention and creating an intersubjective milieu around the task of construct-building, that is, deciding what is real in the situation. It must evaluate, back, and qualify the warrant the group is trying to establish for the claim that it is describing and explaining the phenomenon. Finally, implicitly, the group must rely on mechanistic constructs for the patterns and qualities and the abstracted attributes to back its warrant that it's representation describes and explains the physical phenomenon. These competencies relate most clearly to the science imperatives "to communicate clearly" and "to use mechanistic explanations". The prototypical scientific modeling behaviors for this competence are listed in Table 3.

Developing an epistemology of modeling. Lehrer and Schauble (2010) discuss this category on pages 17 – 18. Here they list skills students must build competence in to "regard their own knowledge or ideas as potentially disconfirmable and as contingent upon evidence". Students must learn to "engage in a cycle of modeling" to "test models" and "invent and revise models". They must develop the habit of mind to "evaluate the relationship between belief and evidence" to "bracket theory or interpretation apart from evidence". They must learn to "justify their claims against other rival claims". They must learn to "evaluate model fit [and] misfit" with data, to "mathematicize, structure, and link complex forms of data" to questions of model fit, and to "include ideas about sampling, probability, and uncertainty". They must develop the habit of revising models to “build their power and scope” “to better fit the data or to encompass a wider array of situations”.

In this study, group members’ *knowledge or ideas* are manifest in their statements about the phenomenon, and *evidence* is the observed behavior of the phenomenon when the group enacts it. *Models* are descriptions and explanations of the phenomenon, either on paper or in speech, and the *claim* being justified is that a group’s representation describes and explains the phenomenon of interest. *Data* is any record of observations. *Evaluations of model fit* are comparisons between a representation and observations or between representations and data. This conceptualization is summarized for this study as follows:

> *Group members explicitly distinguish their ideas from their observations. They compare their description or explanation with a previous version or someone’ else’s. They evaluate how their model fits or doesn’t fit with their observations. They test or design tests of their descriptions and explanations. They indicate that parts of a representation are approximate or are contingent on events. They modify their description or explanation to make it fit their observations better or to make it more general.*

These competencies relate most clearly to the science imperative “to warrant claims in specific statements about observations, models, theories, and established fact”. The prototypical scientific modeling behaviors for this competence are listed above in Table 3.

Subjective Task Value

Whether the tasks in the workshop had subjective value to the teachers was measured using the researcher-developed “Component Value Measure” (CVM). The CVM (Table 4) give two bi-directional measures of intrinsic task value on an 11-point scale from -5 to +5 with a score of 0 indicating that the participant “didn’t feel strongly either way”. It gives two uni-directional measures of utility task value on a 5-point scale from 0 to +5, with 0 indicating not useful and 5 indicating very useful. The CVM included three questions asking for textual responses. CVM questions will be used to answer research questions 2.1 – 2.3.

Constructs measured. This study was interested in two components of Eccles (1983a) expectancy/value model for choosing-behaviors in achievement settings. The intrinsic task value of the task to the subject while engaged in the work is conceptualized in this study as "how interesting or enjoyable" the work is. This relates directly to the study hypothesis that adults can find scientific modeling work intellectually fun and compelling. The utility task value of the task to the subject is conceptualized as "how useful mastering these tasks might be". This relates to how participants feel the work of the workshop might help them to understand something they will need.

Table 4

Component Value Measure (CVM)

Question ID	Type	Question Text	Range	Construct
CVM1	Scale	How enjoyable was this part of the workshop?	-5 – +5	Intrinsic value
CVM2	Scale	How interesting was this part of the workshop?	-5 – +5	Intrinsic value
CVM3	Scale	How useful do you think this part of the workshop was for helping you understand the way science works?	0 – +5	Utility value
CVM4	Scale	How useful do you think this part of the workshop was for helping you understand how to teach science?	0 – +5	Utility value
CVM5	Text	Did you find parts of this work fun or interesting?	NA	Intrinsic value
CVM6	Text	Do you think parts of this work could be useful in helping you understand science itself or helping you teach science?	NA	Utility value
CVM7	Text	Anything else you'd like to get down about this work? Write on the back if you need to.	NA	NA

Development of the instrument. This instrument was developed *prima facie* without appeal to an authority. Questions CVM1 and 2 are simple restatements of the vernacular definition of the construct in question form. CVM3 and 4 separate "utility" into usefulness personally ("helpful in understanding") and usefulness directly pertaining to work ("helpful in teaching"). Given the literature on elementary teachers negative self-concepts and attitudes around science, and physics particularly, it seemed good to separate these. The free-response questions were included to illicit illustrative quotes giving depth to the measure and to allow the teachers to feel that their voices were being heard.

Expectancy for Success

A modified version of the Science Teaching Efficacy Belief Inventory (Appendix D: Modified Science Teaching Efficacy Belief Inventory) was used to gauge whether the treatment changed teachers' expectancy for success in future work related to science teaching. The STEBI provides two scales: The Personal Science Teaching Efficacy Belief scale (PSTE) measures an individual's belief in her ability to teach science, and The Science Teaching Outcome Expectancy Scale (STOE) measures an individual's belief that teaching science has the desired effect on children. The range of possible scores on the PSTE is 13 - 65, and on the STOE is 10 - 50. These measures address research questions 3.1 and 3.2.

Constructs measured. Riggs and Enochs (1989) designed the STEBI to help answer why inservice elementary teachers were averse to teach science and their teaching was often ineffective. Their measurement framework probes individuals' beliefs about their own teaching. Here, a belief is what an individual accepts as true about her science teaching, as distinct from her attitudes or general feelings about teaching science. They then applied Bandura's (1977) social learning theory to target two constructs: self-efficacy beliefs and outcome expectancy beliefs. In Bandura's theory, a person enacts some behavior in a context if she think both that she can do it and that doing it makes a difference. The instrument, therefore, was designed to measure what an inservice elementary science teacher thinks is true about her ability to do what science teachers are expected to do (self-efficacy belief) and to measure the likely effects that successfully doing so would have on her students' science learning (outcome expectancy).

Development of the instrument. The STEBI as first presented (Riggs & Enochs, 1989) uses 25 forced-choice questions to define two scales, Personal Science Teaching Efficacy Belief scale (PSTE) and the Science Teaching Outcome Expectancy scale(STOE). Questions were constructed using vernacular language typical of inservice elementary science teaching with five responses ranging from "strongly disagree" to "strongly agree." The middle response is labeled "uncertain". Factor analysis suggested a two-factor model, which accounted for 36% of accumulated sample variance on all items. The two scales correlated weakly, consistent with the separate but interrelated constructs. Correlations between an item and the full scale on the PSTE were at 0.53 or above, and internal reliability was high (Cronbach's $\alpha =$ 0.92). The STOE presented a weaker scale, with the individual correlations with full scale measures as low as 0.34 and internal reliability slightly lower ($\alpha = 0.77$). Measures on both scales correlated well with external criteria (self-report on effectiveness in science teaching, years of experience, time spent teaching science, etc.). Population means were zero ($\alpha = 5\%$) on all teacher demographic characteristics except gender. In the literature, this instrument is referred to as the STEBI.

The STEBI-B. Enochs and Riggs (1990) revised their instrument to make it appropriate for preservice elementary teachers by slightly adjusting the language for those items that referred to a teacher's current practice to instead refer to expected practice. Factor analysis confirmed the two-factor model remained valid, with moderate correlations between subscales. Two questions, 13 for the self-efficacy scale and 10 for the outcome expectancy scale, were dropped because the correlated poorly with the full subscales, leaving 23 questions. Measures on both scales correlated moderately with external criteria (a standardized Science Preference Inventory, use of activity-based science teaching, etc.) but poorly with the number of science classes taken voluntarily by the students. In the literature, this preservice measure with two questions dropped is referred to as the STEBI-B.

Bleicher (2004) reevaluated the preservice version (STEBI-B) using several samples of mostly female students enrolled in elementary science teacher methods courses at the University of Florida. This study upheld the overall validity of the STEBI-B and offered a slight modification that improved its psychometric properties. Two items from the outcome expectancy scale (10 and 13) loaded ambiguously across the two factors. Bleicher identified that the word "some" ("some students") had been confusing to respondents in his sample. Removing this word on these items resolved the ambiguous loadings on a second sample. Factor loadings were consistent with the original analysis of the STEBI-B; the two factors accounted for 36% of the variance in item responses for the sample, and were moderately correlated ($r = 0.12$) consistent with the theory behind the instrument.

The STEBI as modified for this study. This study omits from the original STEBI the two questions dropped by Riggs and Enochs in the STEBI-B and adopts the modifications by Bleicher to questions 10 and 13. This modification builds in the improvements to psychometric properties but retains language appropriate for inservice teachers. This leaves 23 questions, with 13 items for the PSTE self-efficacy scale (2, 3, 5, 6, 8, 12, 17, 18, 19, 20, 21, 22, 23) and 10 items for the STOE outcome expectancy scale (1, 4, 7, 9, 10, 11, 13, 14, 15, 16). As in the validation studies, items will be coded on a 5-point scale with “Strongly agree” as 5, “Strongly disagree” as 1, and “Uncertain” as the middle score. Following instructions for the STEBI-B (Bleicher, 2004), items 3, 6, 8, 10, 13, 17, 19, 20, 21, and 23 are reverse coded. The range of possible scores on the PSTE is 13 - 65, and on the STOE is 10 - 50. This modified instrument, called in this study the STEBI, STEBI-A or modified STEBI-A as needed. The form is given in Appendix D: Modified Science Teaching Efficacy Belief Inventory.

Social Validity of Workshop as Professional Development

Whether the workshop is considered valid professional development by the participants is gauged by the researcher-defined Workshop Evaluation Questionnaire (Table 5). Questions WEQ1-15 are bidirectional, 11-point, forced-choice items organized into 5 subscales. Items were direct statements about the workshop. Some were positive assertions and some were negative. A response of -5 means strong disagreement, +5 means strong agreement, and 0 indicates “no opinion”. Negative assertions were reverse coded before scoring. Answers were averaged to produce a range of possible subscale values from -5 to +5. A negative subscale score means the teacher did not think the workshop as valid professional development on that dimension. Questions WEQ16-19 are open-ended questions allow participants to comment on the workshop in their own terms. The WEQ will address research questions 4.1 – 4.5.

Constructs measured. The WEQ is designed to probe the five dimensions of the evaluation rubric developed by the Council of Chief State School Officers (CCSSO) for a cross-state study of science and mathematics professional development programs (Blank & de las Alas, 2009). The dimensions are: (1) content focus, (2) active learning, (3) coherence, (4) collective participation, and (5) sufficient time. The CCSSO identified these five constructs as crucial for professional development programs to successfully move inservice teachers to be more proficient in science and mathematics teaching.

Table 5

Dimensions of the Workshop Evaluation Questionnaire (WEQ)

Dimension	CCSSO descriptions of rubric dimension (Blank & de las Alas, 2009)	Positive assertion about the workshop as professional development	WEQ item
Content focus	“the extent to which the professional development program or activity focuses on the subject content of mathematics or science” “emphasis on pedagogical content knowledge—understanding how to teach subject content to students in the classroom” “the degree to which professional development is specifically designed to address the identified content weaknesses or needs of teachers in the target population”	The subject matter of the workshop fits with science content.	1
		The workshop helps me understand how to teach science content to students in my classroom.	2
		I can relate what I did in the workshop to things I need or will need when I teach.	13 N
		The workshop helped address weaknesses I feel I have in my teaching.	14
Active learning	“provide teachers opportunities to talk, think, try out and hone new practices”	This workshop let me talk and think about the subject of the workshop.	9
		This workshop let me try out and hone new practices.	6 N
		I am able to work with other teachers on new practices built around this workshop.	15
		I am able to observe other teachers working with the content of the workshop.	5
Coherence	“how the program and its implementation are aligned to the curriculum being implemented in classrooms, the standards of learning that define expectations for students, and the needs of teachers”	The workshop is aligned with my school curriculum or learning goals for students.	11
		The content of the workshop is aligned with my state or district standards for the learning or performance of my students.	3 N
Collective participation of teachers	“carry-out the program with teachers that will support and encourage the movement from teacher learning to more effective practices”	I am able to work with teachers who teach in the same grade as me.	10 N
		I am able to work with teachers who support and encourage me to move what I did in the workshop into my classroom.	8 N
		The workshop gave me a way of thinking and talking about science	4

		that I can use when talking to the other teachers.	
Sufficient Time	“provide participant teachers with more contact hours in professional development courses or activities and support the teachers through follow-up activities or assistance with implementation over a prolonged period”	The workshop offers sufficient follow-through and support to bring workshop activities into my classroom.	12
		I would like to see opportunities to continue working on this way of thinking about science.	7

Items marked with an “N” are negatively worded and will require recoding to create a score that increases with a positive affirmation of the respondent.

Development of the instrument. The CCSSO working group was created to provide a uniform assessment to evaluate large-scale development programs as implemented in the field, based upon current research on best practices in the professional development of teachers. They identified five dimensions that characterized the quality of professional development, and created a complex evaluation rubric around these features (Blank & de las Alas, 2009). The WEQ uses the working groups descriptions of these program dimensions to develop a list of positive assertions about a single professional development workshop. These statements were used for the WEQ items. Items 3, 6, 8, 10, and 13 are reworded as negative assertions in the WEQ and were reverse coded.

Data Collection

Basic demographics were collected prior to the workshop and teachers were assessed for their self-efficacy beliefs. The activities of the teachers were video-recorded. The facilitator was audio-recorded and he filled out protocol checklists after each workshop component. Teachers’ pencil-and-paper representations (their flipbooks) were collected. Teachers were surveyed immediately after the workshop for their view of the workshop as valid professional development. Teachers were surveyed one week after the workshop for their self-efficacy beliefs.

Pre-treatment Survey

Both the demographic data and the initial STEBI assessment were collected using an online survey platform. Teachers who agreed to participate were sent a link for the survey via email. The first page of the survey informed teachers of the purpose of the survey and asked for consent. The next section collected demographic information: current grade and years teaching that grade, other grades taught, level of formal training, type of professional licensure, number of science courses taken since high school and the number of years since the last one, and gender.

The third section introduced the modified STEBI-A as “a questionnaire on your attitude toward teaching science”, and presented the instrument preface and questions verbatim one screen at a time. Teachers could move back and forth among the questions at this point until they clicked the final submit button. At that point, teachers were given a text-entry box and asked to leave a comment if they wanted.

After all participating teachers finished the survey, the researcher downloaded the results to secured storage as a Microsoft EXCEL workbook file. One teacher joined the study the day of the workshop and finished the STEBI on paper at a quiet place on location before the workshop began. However, this data was misplaced and not added to the workbook file. Recoding and analysis was done using the R programming language (R Core Team, 2013).

Video Recording

Each component of the workshop was video-recorded using Flip-brand, handheld camcorders. Each camcorder could capture 120 minutes of HD 720p (1280 x 720) video at 30 frames per second. The cameras had a 2-inch LCD screen to monitor recording real-time. Video was downloaded to secure storage on location after the workshop as H.264 video in MP4 files. Audio-recoding was only somewhat directional and picked up troublesome background sounds, which caused problems in transcription.

Personnel. Five research assistants were trained by the researcher a week prior to the workshop. Assistants were briefed on the purpose and methods of the workshop and went through several role-playing exercises to become familiar with the equipment and to learn how to focus on the teachers’ work without being intrusive. All five assistants attended the first day of the workshop, but only four were needed: one for each small group and one to help the facilitator with materials if needed. On the second day, only four assistants attended. During the workshop, research assistants had no trouble managing the equipment. Teachers seemed unhindered by the attention of the video-recording staff. In all six sessions, teachers made eye contact with the camera just a few times and directly acknowledged the staff once when one moved a chair a teacher had been using.

Extent and quality. The initial meeting was recorded completely by a single assistant. Video and audio quality were good for this entire workshop phase. In small-group sessions (research phase rounds 1 and 2) each group had an assigned assistant to record teachers' work. Video recordings were adequate to follow the hand, eye, and body movements of the teachers and facilitator while they worked on the research-phase tasks, but often were not able to capture details of markings the teachers made on the representation materials. Audio quality was largely adequate but at times speech was unintelligible. The conference phase had an assistant assigned as a videographer, but for reasons unclear only an 8-minute segment of the facilitator introducing the phase and a later a 10-minute segment of teachers presenting their work survived downloading. The final meeting also had an assigned videographer, but no video recordings survived downloading.

Transcription. All small-group sessions were transcribed from video using a modified CHAT format (MacWhinney, 2000). The researcher and one assistant trained on this format using video clips from another workshop. They then simultaneously recorded two sessions, compared notes, and isolated problems. The research then produced a definitive transcription manual. The researcher and assistant divided the six videos amongst themselves to transcribe using the manual. Transcriptions are saved as standard CHAT files.

Participant Journals

When teachers arrived at the first workshop, each was given a "participant journal" identified by their study ID, comprising a Component Value Measure (CVM) instrument for each workshop component (initial meeting, research phases 1 – 3, conference phase, publishing phase, and final meeting) and one Workshop Evaluation Questionnaire (WEQ). All journals were collected at the end of each workshop day. Scale values for each question were recorded into EXCEL worksheets. Recoding and analysis was done using the R programming language (R Core Team, 2013).

Teacher reactions to workshop components. When the facilitator called an end to a component, he asked the teachers to take time to think about the work they had been doing and to fill in the CVM and to include their written comments. Facilitator checklists show this was done each time. Several video recordings document this transition. These suggest that even though teachers may not have wanted to end their representational work, they put aside their flipbook pages and picked up their participant journal. All CVM measures were filled in.

Evaluation of the workshop as professional development. When the facilitator signaled that the final meeting was ending, he asked the teachers to pick up their participant journal and fill in a final questionnaire. From the video recordings, it is clear that at this point, teachers were fatigued, and several had to leave for elsewhere. However, all filled in the WEQ and most left some comments.

Artifacts of Small-Group Work

Teachers were encouraged to use as many flipbook pages as they wished. Several times during the video recordings, the facilitator is seen encouraging individual groups to use new pages to refine their representations and not to erase their earlier work. No teacher is seen destroying or discarding a flipbook page. Several times they are seen getting up to get additional pages. At the end of the representational sessions (research phase 1 and 2), the facilitator asked teaches to assemble their pages into a booklet. These were collected at the end of the session. They were not revisited or revised after that.

Post-Treatment Survey

Post-treatment collection of the teachers' self-efficacy beliefs was purposefully delayed to allow teachers time to reflect on their experience so they were more likely to evaluate their stable feelings and not the feelings while in the middle of the work. Teachers were sent an email about one week after the workshop asking them to take a follow-up survey online and providing a link to a new form on the online survey platform. This form first thanked them for their participation and asked for their study ID. If they did not remember that, the form asked them to exit the survey and contact the researcher. The next section presented the modified STEBI-A preface and questions verbatim, as in the pretest. Again, teachers could move back and forth among the questions until they clicked the final submit button, at which point they were given a text-entry box to leave a comment. Six teachers entered their data within a few days. However, two apparently entered their IDs incorrectly. One did not take the post-test.

After another week, the researcher downloaded the results to secured storage as a Microsoft EXCEL workbook file. Recoding and analysis was done using the R programming language (R Core Team, 2013).

Data Analysis

RQ1. Prototypical Scientific Modeling Behaviors

For this study, the six small-group sessions of the research phase of the workshop are identified by a 3-letter prefix, “Res”, a 1-digit indicator of which round of the research phase the session was in (1 or 2), and a 1-letter group ID (A, B, or C). For example, “Res1A” indicates the research-phase session took place in the first round and follows group A. Data coded from video recordings of research-phase sessions was used to answer questions about whether the constructivist engagements with prototypical scientific modeling tasks elicited targeted modeling behaviors (RQ1.1-4). Whether participants’ modeling behavior differed between the research-phase and the publishing-phase modeling tasks (RQ1.5) could not be answered because the study workshop did not implement the publishing-phase of the model.

Each session is analyzed using a standard interval-coding technique by two independent coders for indicators of each of four prototypical scientific modeling behaviors (PSMBs), “Arranging for the conditions of seeing,” “Inventing measures,” “Developing representational competence,” and “Developing an epistemology of modeling,” developed from Lehrer’s and Schauble’s (2010) experience developing a pedagogy of scientific modeling for middle school. Each construct is operationalized by behavioral indicators (Table 3) written as an action with a purpose.

Though the actions are visible behaviors, the coder must establish a purpose to trigger the indicator. For example, “Formulate questions to answer using materials” is one indicator for the behavior “Arranging for the conditions of seeing.” To apply this code, the coder must hear speech by a group member that asks a question about the phenomenon, but must also judge from context whether the questioner intends to pursue an answer using enacting or supporting materials during the session. Two indicators for the behavior “Developing an epistemology of modeling” are based on the action “Evaluate descriptions or explanations” but have different purposes, “to distinguish interpretations from observations” and “to qualify them as approximate or contingent.” If the coder decides a speech act is an evaluation of the group’s description or explanation of the phenomenon given in the provocation, they must also identify the purpose as one of these two to apply the code. Another purpose, for example to critique its wordiness or its length, would not indicate a code for this behavior. If an action evaluates a written representation explicitly and the coder judges its purpose as “to qualify or back it” as a representation of the phenomenon, the act would also indicate the behavior “Developing representational competence.”

The researcher is considered the primary (1°) coder for this analysis. The secondary (2°) coder is a research assistant who also helped transcribe the video recordings and was very familiar with them from a separate analysis looking for how the groups focused their work on the materials provided in the provocations. The assistant was trained on the PSMB coding using a brief initial segment of the video for Res1A, and then left to code each video independently. The decisions of the primary coder are used to analyze group behavior. The secondary coder is used to test the construct validity of the PSMBs.

For this analysis, if the facilitator engaged the group, he was temporarily included as a group member. To describe groups’ modeling behaviors in the research sessions, each video recording is divided into 10-second intervals. If a coder decides any group member’s visible actions matched one of the indicators for a behavior, he flags that the group exhibited that PSMB during that interval. Total counts of intervals coded for each PSMB for a session are used to establish whether groups acted during the session in ways prototypical of scientific modeling.

RQ2. Subjective Task Value

Data from the Component Value Measure (CVM) are used to answer questions about teachers’ perceived value of workshop components (RQ2.1-2). Plots and summary statistics for distributions in individuals’ evaluations of the interest (CVM1), enjoyment (CVM2), usefulness for understanding science (CVM4) and usefulness for teaching science (CVM5) for each component are given. Average evaluations and variability for this sample are analyzed visually and using distribution means. Teachers’ experiences with each component will be illustrated with sample comments from the CVM (CVM3, CVM5, and CVM6).

Generalizations to ideal populations (“inference”) are tested for each measure and each component with single-sample *t*-tests against a null hypothesis of no strong feelings. This study did not use contrasting groups, so treatment effects must be compared to a reference criteria. A natural inference is to answer whether a larger population of similar elementary-school teachers would have strong feelings either way about the individual workshop components, given the valuations of this sample. Since there is no reference criteria for acceptable levels of subjective task value, statistical significance is calculated using a null hypothesis of "component evaluation is zero" (mean score equals zero) with a family significance level of 5%. Confidence intervals for mean evaluations are at the 95% family-confidence level.

To judge whether the participants reacted differently to different phases (RQ2.3), trends in individuals' evaluations across components are plotted for this sample. Generalizations to ideal populations are tested using a MANOVA using phase as the independent factor and construct-level measures of intrinsic task value and utility task value as dependent variables, run at the 5% significance level, with follow-up ANOVA on individual measures and post-hoc comparisons between factor-level means as needed.

RQ3. Expectancy for Success

Data from the PSTE subscale of the modified STEBI-A is used to answer questions about teacher self-efficacy (RQ3.1) and data from the STOE subscale is used to answer questions about teaching outcome expectancy beliefs (RQ3.2). Plots of individual scores and summary statistics are given for both before and after treatment. Average evaluations and variability for this sample are analyzed visually and using distribution means.

Generalizations to ideal populations ("inference") were not attempted because there were only three individuals with both pre- and post-test scores. Survey responses for the one individual who filled out the modified STEBI-A questionnaire by hand at the day of the workshop was lost, and three individuals mistyped their study ID number when taking the online post-treatment questionnaire.

RQ4. Social Validity of the Workshop as Professional Development

To answer questions about the social validity of the workshop as professional development (RQ4.1-5), plots and summary statistics for distributions in individuals' evaluations are given, and generalizations to ideal populations are tested with one-sided *t*-tests against a null hypothesis of no strong feelings. Average evaluations and variability for this sample are analyzed visually and using distribution means.

Generalizations to ideal populations (“inference”) are tested for each measure and each component with two-sided, “single-sample”, *t*-tests against a null hypothesis of no strong feelings. This study did not use contrasting groups, so treatment effects must be compared to a reference criteria. A natural inference is to answer whether a larger population of similar elementary-school teachers would have strong feelings about the worth of this workshop as professional development in science teaching, given the valuations of this sample. Since there is no reference criteria for acceptable levels on these evaluations, statistical significance is calculated using a null hypothesis of “no opinion about the workshop as professional development” (mean score equals zero) on a two-sided *t*-test. Confidence intervals for mean evaluations are at the 95% confidence level.

CHAPTER 4

RESULTS

The purpose of this study was to explore a professional development workshop model. To make inferences about the model, the study will first assess whether the implementation was faithful to the stipulations of the model. Once that is assessed, the specific aims and research questions will be addressed.

Fidelity of Implementation of the Workshop Model

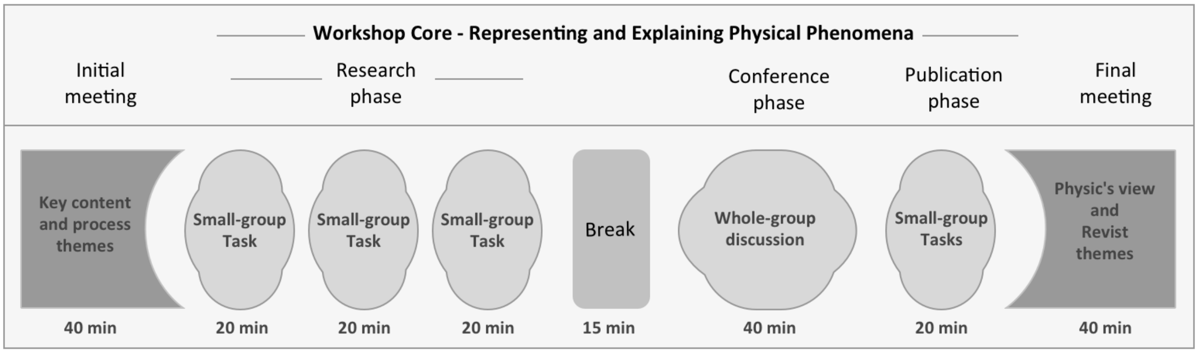
The model calls for an initial and a final meeting and for three distinct phases of participant work (research phase, conference phase, and publication phase). Each phase has a specified purpose and is to have specific content and facilitation protocols. The duration and pace of components are flexible, as long as the phases can be implemented effectively.

Workshop Schedule

The workshop was held on a Tuesday and Thursday during late August, after the teachers' school day was over, about three weeks into their school calendar. The workshop flowed smoothly. Administrative and organizational tasks such as setting out materials were handled efficiently, thanks to an assistant dedicated to helping with this part of the workshop. The teachers were prepared to work each day and stayed focused on their work until time was called.

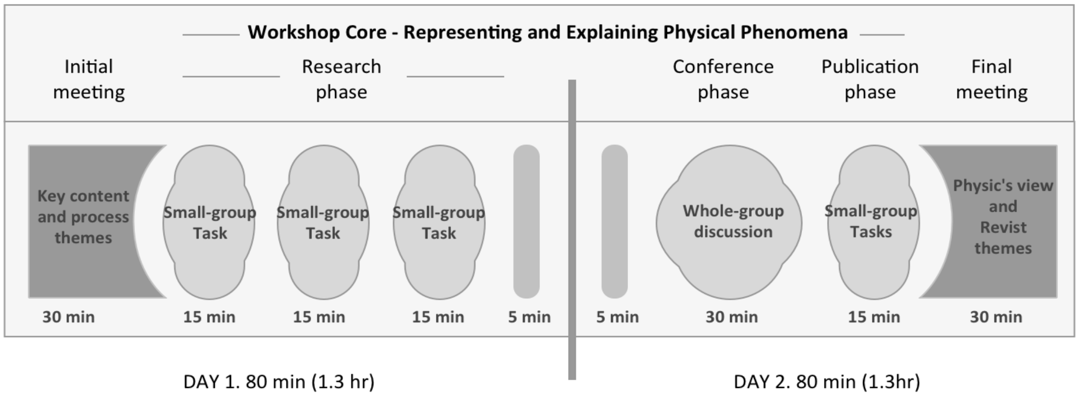
At the school district's request, the workshop was broken into two afterschool sessions. To keep down the time required after a full work day, the workshop model had been compressed from 215 minutes (about 3.6 hr) into a target time of 160 minutes (about 2.7 hr), a little over an hour and a quarter per day. These changes proved to be problematic. Some teachers could not get to the central location quickly enough to start on schedule, which pushed the start time later into the afternoon. The shorter time did not allow time for breaks or socializing between components. Teachers became fatigued by their engagements before the 80-minute time allotted, and the facilitator decided to stop each day after about 70 minutes. As a result, the study did not present the full workshop as planned (Figure 5).

Workshop model plan



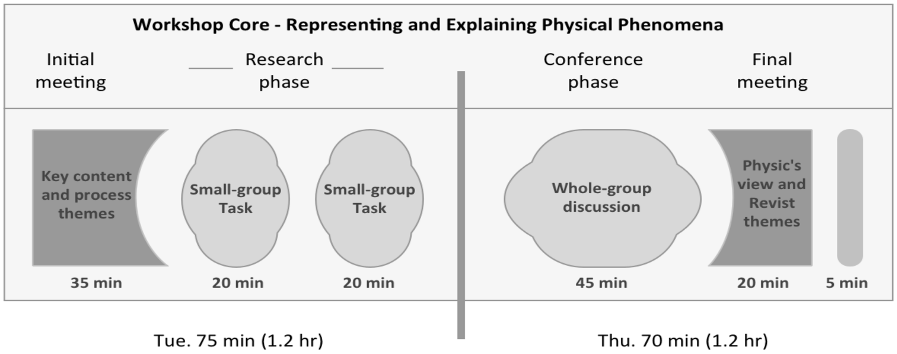
Half Day. 215 min (3.6hr)

Two-day workshop plan



DAY 1. 80 min (1.3 hr) DAY 2. 80 min (1.3hr)

Actual study workshop schedule



Tue. 75 min (1.2 hr) Thu. 70 min (1.2 hr)

Figure 5. Comparison of workshop model, treatment plan, and workshop as implemented

On the first day, the facilitator allowed each small group session to go longer, but decided to not begin the third engagement. On the second day, he allowed the whole-group discussion to continue longer and decided to forgo the small-group revisiting of the phenomena to give time for closure of the workshop in the final meeting. In sum, in 145 min (about 2.4 hr) over two days, the study successfully implemented the initial meeting, two of the three small-group sessions (research phase), the whole-group discussion (conference phase), and an abbreviated final meeting, but did not implement the small-group revisiting of the physical phenomenon (publishing phase).

Day one. On the first day, verifying IDs, informed consent, and pre-treatment surveys took less than the 5 minutes allotted from the initial meeting. Then, for about 30 minutes the facilitator, as planned, walked through a handout outlining the style, aims, and schedule of the workshop, gave a PowerPoint presentation on the key themes of the workshop, and introduced the participant journal and the enacting and representational materials. The room was sufficient to let teachers work at independent tables, and to create larger spaces for enacting the target phenomenon, but didn't allow centers to be isolated from the meeting space, so the materials were brought to the tables the teachers were sitting at. Teachers quickly formed groups and began reading the instructions for the provocation at their table. The facilitator circulated among the groups. After 17 minutes, he called for an end to that round and asked teachers to assemble their pages into flipbooks, fill out their journals, and transition to another provocation. After another 20 minutes, the facilitator called time for the second round. At this point, the facilitator felt that the teachers would be pushing themselves to start a third modeling engagement round. Several had made good-natured comments that the thinking being required at the end of their work day was taxing. The staff collected the participant journals, which were not looked at between workshop days.

Day two. On the second day, teachers again had trouble getting to the location at the scheduled time. Teachers picked up their journals and the flipbooks they had made on day one, and then sat in a half circle of tables facing a whiteboard. The enacting materials were available. For about 10 minutes, the facilitator reviewed the purpose of each phase of the workshop, and then invited groups to present their work from the first day. One group quickly volunteered and discussed how they had viewed the "Bear" phenomenon (swinging a stuffed toy by a string in a circle and letting it go). The facilitator asked the other group who had worked on this phenomenon to then give their views. All groups discussed their thinking and each phenomenon was touched upon. These discussions did not reach a natural ending, but the facilitator called time after the conference phase discussion had proceeded for about 35 minutes and asked the teachers to fill in their journals. Again, the teachers seemed fatigued by the work and the facilitator decided not to revisit the task of representing their thinking (publication phase) but to move on to the final meeting. He presented for about 15 minutes some canonical views of physics on each phenomenon, relating the Bear to centripetal force, the Ball to frames of reference, and each one to inertia. The facilitator asked the teachers to fill in their journals and to complete the WEQ questionnaire evaluating the workshop as a whole. All flipbook pages and participant journals were collected.

Implementation of the Initial Meeting

The purpose of this meeting is to present the key content and process themes of the workshop, intended to draw teachers away from the view that science work is scripted and orient them toward the view that those who do science learn to approach the world in an unusual way. This will include discussing the norms of science culture, its difficulty for those not used to it, and how it can look in the classroom, but should not include discussing technical terms from canonical science.

Timing and schedule. The initial meeting took about the time targeted in the treatment plan (35 minutes instead of 30), which was close to what the model called for (40 minutes). In the video recordings, the facilitator is seen referring on occasion to protocol notes. The facilitation checklist he filled out at the end of the meeting indicates that he believed he attended to all targets. Transition to the provocations was smooth.

Content and process themes. The design of the workshop model stipulates that in the initial meeting “the facilitator presents the key content and process themes that the workshop is built upon”. To measure how faithfully the actual workshop was to this intention, the researcher coded the video recording of the meeting to indicate which content and process themes appeared as the meeting progressed. Content themes focus workshop participants on what their engagement with workshop activities will bring to their teaching, and process themes focus them on how they will work in the workshop and how they could work with their own students. The analysis of the initial meeting is summarized in Table 6. The coded transcript is included in Appendix A: Coded Transcript of the Initial Meeting.

Each content theme was addressed within the first five minutes and were revisited evenly throughout the meeting, variously brought up between 4 and 19 times in the 30 minutes dedicated to introducing the workshop. The heaviest emphasis was on the usefulness of the workshop activities in addressing standards practically. Least emphasis was on the similarity of the tasks to describing and explaining the physical world like physics.

Each content theme was also addressed repeatedly in the meeting, but with less frequency and these themes were introduced somewhat later, initially within the first 10 minutes, and then revisited in the last 10 minutes. The heaviest emphasis was on the teachers using pencil and paper materials to represent their thinking and the least was on teacher's having a chance to revisit their representations during the workshop.

Table 6

Key Workshop Themes Appearing in the Workshop's Initial Meeting

Theme	Ending of count interval (minutes)							Total
	5	10	15	20	25	30	35	
Content								
The work aligns with teachers' work and can be taken into their classrooms with few resources.	xxx	x	xxx xx	xxx	xxx xxx	x		19
The work is "sciencey", not direct instruction in science content.	xxx x	x	xx	x	xx			10
Like physics, the work is to describe and explain simple physical phenomena.	xx	x			x			4
The work is not the normal way people look at the world.	x	x	x	xx		x		6
The work emphasizes representing your own thinking clearly and concisely and having conversations around those representations.	x	xx	x		xxx x	xxx x	x	13
Because the work is about teachers' thinking, there is no one right way to represent their descriptions and explanations.	x	xxx	x	xxx	x	x	x	11
Totals for content themes	12	9	10	9	14	7	2	63
Process								
Teachers will work in different ways, sometimes in small groups and sometimes altogether.		xxx					x	4
Teachers will work in centers around provocations about how they see and explain the physical world, and will transition between centers to engage different phenomenon.		xxx				xx	x	6
Teachers will use simple materials to enact everyday phenomenon in ways they can manipulate and modify.	x	xx				x		4
Teachers will use simple pencil and paper forms assembled into flipbooks to represent what they see and their explanations.	x	x	x		xx	xxx xx	x	11
Teachers will have chances to dialog with each other and the facilitator on how they are representing their thinking.		xx					x	3
Teachers will have a chance to revisit and modify their representations before the workshop ends.		x					x	2
Totals for process themes	2	12	1	0	2	8	5	30

Each "x" indicates the appearance of the theme in that time interval.

Reference to canonical science. The design of the workshop model stipulates that in the initial meeting the facilitator should talk about science in the context of the key themes: the norms of science culture, its difficulty for those not used to it, how it can look in the classroom, etc., but should not introduce technical terms from canonical science or extend discussions of these. To gauge whether facilitation was faithful to this intent, the researcher reviewed the video recordings of the entire initial meeting for references to “science” or technical terms from science subjects. The results are given in Table 7.

Table 7

Facilitator’s Initial-Meeting References to Science

Stamp	Facilitator reference	Context of usage	On protocol
Administrative tasks and introducing the study			
02:10	“I look at the way you think about science before and after [the workshop] .”	Administrative	Yes
Walking through a handout about the workshop			
02:55	“the purpose of the workshop… bring science thinking into the classroom .”	Key theme	Yes
03:01	“this science thinking works towards a number of goals (..) the Next Generation Science Standards…”	Key theme	Yes
03:15	“I want to bring science thinking into the classroom…”	Key theme	Yes
03:30	“… workshop gets all those [standards] done (.) plus it gets science thinking into the classroom .”	Key theme	Yes
03:40	“I use what you call physics because you can do physics with anything”	Key theme	Yes
03:50	“so (.) I’m using physics… “	Key theme	Yes
03:53	“anyone have a physics course… ?”	Administrative	Yes
04:00	“a lot of folks are unnerved by it [physics]…”	Key theme	Yes
04:23	“physics is not … a natural way to think…”	Key theme	Yes
04:33	“to get people to do it [physics thinking] is a bit of a trial .”	Key theme	Yes
04:45	“those [why does it work?] are science questions… not fancy (.) it’s hard…”	Key theme	Yes
05:20	“I want to generate thinking… not sciencey answers .”	Key theme	Yes
06:20	“this [to represent their own minds…] is what scientist do…”	Key theme	Yes
06:30	“it lets you build sciencey ways of looking at the world…”	Key theme	Yes
06:50	“nobody is going to tell you what momentum is in this workshop…”	Key theme	No
08:24	“this [asking about moving ketchup in a bottle] is the kind of thing scientists do…”	Key theme	Yes
Slide Presentation			
12:43	“how do you get physics into the heads of a little kid : Well you don’t”	Key theme	Yes
12:56	“we all learn about physics … through our bodies…”	Key theme	Yes
13:15	“I’m introducing the idea of force and inertia .”	Introduced technical terms	No
13:56	“this is the way people build physics experiences… science experience… through engaging the world .”	Key theme	Yes
16:00	“… just teach them to use equations… fairly useless knowledge…”	Key theme	Yes
16:37	“what happened in science, 300 years ago… people came up with a method of figuring things out .”	Key theme	Yes
18:45	“[these feelings] are one thing that drives scientists to do the things they do…”	Key theme	Yes
19:05	“… story about a kid who thought a pendulum goes the fastest at the end…”	Key theme	Yes

19:35	“had a movie of a pendulum going back and forth…”	Key theme	Yes
20:25	“run through of what physics looks like… Sullivan central…”	Key theme	Yes
20:38	“not good enough if you’re a physics guy…”	Key theme	Yes
20:53	“here’s another bit of physics… [HS class] measure the weight of something by throwing it…”	Key theme	Yes
21:15	“[he figured how] using a few equations… of predicting the mass of something…”	Key theme	Yes
21:37	“that’s physics… here’s a physics thing…”	Key theme	Yes
22:15	“that’s what physicist do [build evidence by a model] (..) that’s exactly what physicists do .”	Key theme	Yes
22:24	“Nobel prize winner’s lab… coldest fridge in the world .”	Key theme	Yes
20:20	“[a drawing a pretty ketchup bottle] is not what a physicist wants .”	Key theme	Yes
Introducing the workshop process			
	No references to science were made in this period	_	_

In the 30 minutes of the initial meeting, science was referred to repeatedly in the first two thirds of the meeting time. Technical terms from physics were mentioned 3 times. Two were references to canonical physics constructs (force and inertia) in the context of exemplary work with young children. One (momentum) was in the context of what the teaches would be doing.

Fidelity of the initial meeting. The initial meeting gave attention to both what the workshop model intended the teachers to think about during their engagements with the prototypical scientific modeling tasks (content) and to the manner in which they, and eventually their students, would work (process). The workshop model does not specify how to emphasize the themes. This initial meeting emphasized content, as these themes are addressed twice as much as the process themes. Content themes are meant to draw teachers away from thinking about science work as scripted and toward it as a compelling human behavior that needs special but achievable conditions to develop. Process themes are meant to point teachers to a way of working that is intended to better model actual science work, built around provocations to engage with the physical world and around discussions and intersubjective standards of knowledge. In this meeting, the facilitator drew more attention directly, through content themes, to these new ways of thinking about science work, rather than indirectly, through process themes. This is entirely consistent with the workshop model. The facilitator made few passing references to constructs or tools of canonical science. The majority of the meeting talked about science in the context of the content themes.

Implementation of the Research Phase Engagements

In the research phase, teachers should work in small groups and transition through a sequence of provocations. Each provocation should task the teachers to explore one simple, familiar phenomenon, but not tell them how. The provocation presents simple, familiar materials to enact the phenomenon, and prompts teachers to describe and explain what they are seeing using semi-structured pencil-and-paper representations, as clearly and completely as they can. The facilitator should use scaffolding practices to press teachers to increase their competence in following the targeted science imperatives. The facilitator should not refer to canonical science content and should not attribute difficulty or degree of success to teachers' ability in science or to the difficulty of science work, but should attribute these to the nature of the task at hand, enacting, describing, and explaining the phenomenon and representing thinking.

Timing and schedule. The planned workshop called for three research-phase rounds of about 15 minutes each. This study implemented two complete rounds of about 20 minutes each. After about 12 minutes, the facilitator was to announce the session was about over, and after a few minutes more, direct the teachers to assemble their flipbooks, fill out their journal for this component, and transition to the next provocation. Video recordings show the teachers stayed engaged in the tasks for the entire 20 minutes and typically felt interrupted in their work when the facilitator called time. Teachers had time to assemble their flipbooks and quickly fill out the journals for each session, though there was not down time between rounds.

Scaffolding practices. Facilitation protocol requires an initial visit within three minutes and then a return at least twice before the session ended. The workshop model stipulates that the facilitator employ an "intrude and withdraw" strategy when joining groups engaged in the prototypical scientific modeling tasks. This requires that the facilitator briefly orient the group toward the task at hand, as defined in the provocations at the centers, and to involve themselves in the group work in brief intervals as needed to refocus work on the academic task, in this case, describing and explaining a simple physical phenomenon under some of the modeling imperatives of working science.

Figure 6 shows the pattern of facilitation for the two rounds of the research phase and for each group. Facilitator involvement with the group is coded in black. Independent group work is white.

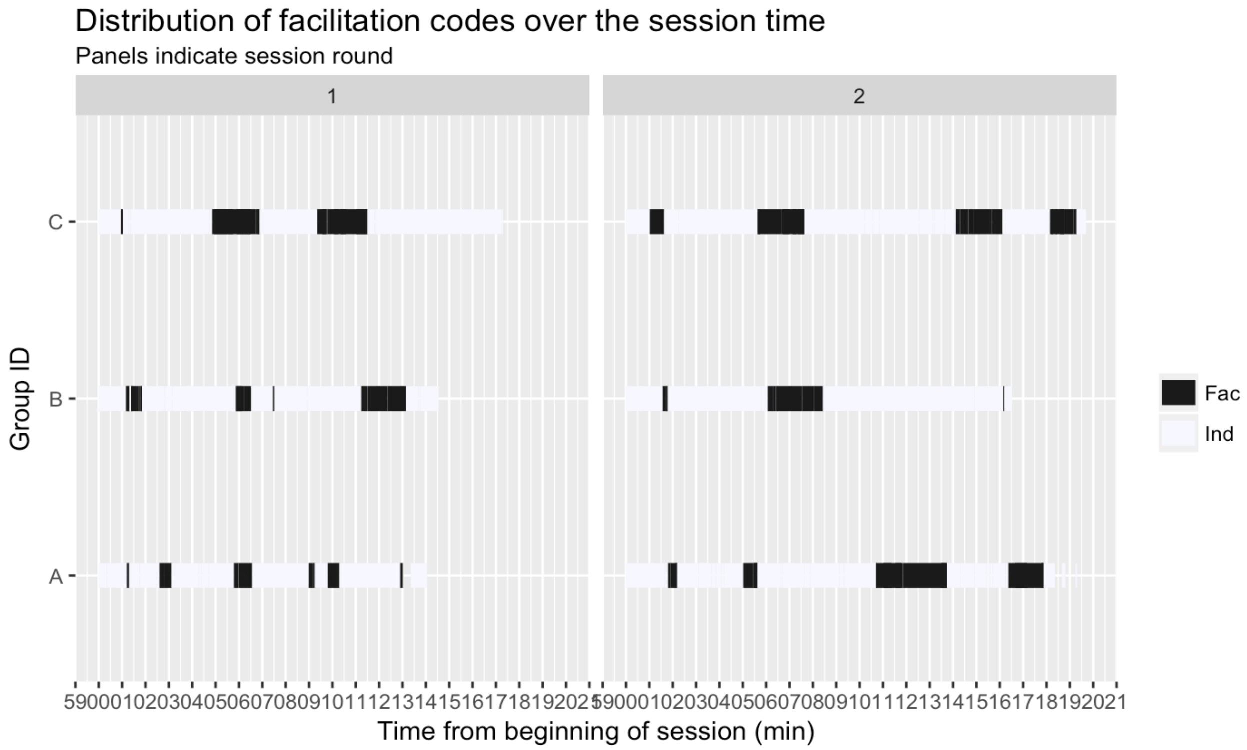


Figure 6. Pattern of facilitation in the workshop as implemented

There were 24 facilitation engagements in the 6 sessions, between 3 and 6 times per session. The facilitator engaged each group in both rounds within the first two minutes of the session typically for less than a minute. Engagements ranged from 20 to 180 seconds, with an average engagement of about 60 seconds. The analysis shows a reasonable intrude-and-withdraw pattern of facilitation, consistent with scaffolding.

However, group B had a somewhat different pattern from the other two. The initial engagement in round one (from 1:09 to 1:55) was sustained for about a minute, much longer than for any other session. In round two, the facilitator engaged the group initially briefly, according to protocol and only revisited them once at any length for the rest of the session. Analysis of causal attributions for each group below shows that this group received no attributions of progress to ability or task difficulty for this round, suggesting that facilitation behaviors depend on the individual teachers.

Reference to canonical science. The workshop model stipulates that the facilitator does not introduce or extend discussion around technical terms or symbols used in canonical science while the teachers are engaged in enacting, describing, and explaining the physical world or in representing their own thinking. To gauge whether facilitation was faithful to this intent, the researcher reviewed the video recordings of all six research phase sessions (three groups x two rounds) for references to "science" or technical terms from science subjects. The results are given in Table 8. In the roughly 40 minutes of facilitation in the research phase, the facilitator made 7 references to canonical science. In six of those, the intent was to ask a teacher to clarify or illustrate her use of a term, which is part of the facilitator's scaffolding practices. Only one usage was off protocol: the teacher extended a discussion about her engagement into teaching science.

Table 8

Facilitator's Research-Phase References to Science

Stamp	Reference	Intent	On protocol
Group A round 1			
09:00	"so where is the orbit, where is he in orbit?... let's get that captured ."	Asks teacher to represent a term on paper	Yes
13:05	"that's when, that's when you can start teaching physics… I need words… you can say, like 'momentum'…"	Extends discussion of language to science teaching	No
Group A round 2			
10:28	"so when you say accelerating (.) what does that mean ?"	Asks teacher to clarify use of a term	Yes
10:38	"So in your mind you are seeing 'truck accelerates' ."	Asks teacher to clarify her meaning	Yes
Group B round 1			
	No references	—	
Group B round 2			
	No references	—	
Group C round 1			
09:50	"so it's the truck that's accelerating? Is starting… accelerating… same thing ?"	Asks teacher to clarify her thinking	Yes
10:06	"… when you say starts and accelerating (.) do you mean the same thing ?"	Asks teacher to distinguish between two terms	Yes
Group C round 2			
16:00	"try to explain that (..) if you think gravity is involved…"	Presses teacher to explain technical term	Yes

Causal attributions. The workshop model stipulates that during participants' engagements with the representational tasks, the facilitator should avoid attributing performance levels either to an individual's *adeptness with canonical science* or to the *difficulty of canonical science* as work or as a subject. Such causal attributions are known to have complex interactions with an individual's outcome expectancy beliefs, academic self-concept, and the affective reaction to the task at hand. The theory of change (Figure 1) behind the workshop suggests that avoiding such attributions is likely to allow those lay to science work to find subjective task value in modeling tasks and to build a positive expectancy for success in academic work around science subjects.

However, the workshop model does encourage scaffolding practices that attribute performance to the *individual's competence in representational work*, in this case enacting, observing, describing, explaining, and representing simple, everyday physical phenomenon and that acknowledges the *inherent difficulty of representational work*. The theory of change suggests that using such attributions is likely to encourage engagement with cognitive conflict in a way that is subjectively valuable and that promotes a positive academic self-concept.

To gauge whether facilitation was faithful to this stipulation, the researcher reviewed the video recordings of all six small-group engagements for causal attribution statements made by the facilitator. The results are given in Table 9. The table identifies the statements that attribute struggle or success either to the *abilities* of teachers with canonical science or to *nature of science tasks* themselves, or to their abilities at the representational tasks at hand or those tasks themselves.

Table 9

Facilitator's Research-Phase Causal Attributions

Stamp	Statement	Attribution type				Context
		Canonical science		Representational work		
		Ability	Task	Ability	Task	
Group A. Round 1 "Bear"						
2:36	"... you did something // you guys did something that was very interesting. You made up something : follow-through…"			x		Group's use of language to describe phenomenon
6:12	"you guys are thinking great ."			x		Group's description of task
6:19	"that really is the hard part ."				x	Teacher's comment about describing phenomenon
9:19	"interesting / interesting (..) I mean your choice of words there ."			x		Group representation
9:49	"you're doing great ."			x		Group representation
10:16	"those [words used in describing the phenomenon] were pretty darn clear to me ."			x		Teacher's verbal description of phenomenon
12:45	"brilliant // that's brilliant what you just said ."			x		Teacher's comment about needing language
12:58	"that's when you can start teaching physics [i.e., about teaching science] ."	x				Teacher's comment about needing language

Group A. Round 2 “Ball”						
5:31	“It’s hard : it’s very hard .”				x	Teacher’s comment about describing
10:43	“oh that’s beautiful”!			x		Teacher’s representation
11:48	““‘cause you’re explaining it well .”			x		Group’s explanation of phenomenon
12:45	“it’s not clear ‘cause you’ve got two things .”			x		Teacher’s representation
13:31	“No [it’s not easy] : … it makes me appreciate how hard some of the tasks that we give little kids are [i.e., about teaching science] .”		x		x	Teacher’s comment about representing being difficult.
17:23	“You’re using ‘it’ and I get lost .”			x		Teacher’s description of phenomenon
20:21	“It’s surprising how the mistakes really help you understand the world .”			x		Teacher’s question about including draft representations
Totals for group A		1	1	11	3	
Group B. Round 1 “Ketchup”						
11:25	“that [taking a different approach] is brilliant .”			x		Group enacting different procedures to perform task
12:58	“let’s let go of [focusing on getting all the ketchup to go down] … and let’s see if we can figure out why it’s doing what it is doing : the simple part .”				x	Group trying many ways to get the ketchup to the top
12:58	“… and that’s another xxx of hard thinking .”				x	Teacher’s comment explaining/ representing the phenomenon
Group B. Round 2 “Bear”						
	No attribution statements					
Totals for group B		0	0	1	2	
Group C. Round 1 “Ball”						
5:30	“there are some things that I can’t follow… when you say ‘it is going in the opposite direction’ I am not sure what ‘it’ was (.) and the opposite direction of what .”			x		Teacher’s use of the word “it” in describing the phenomenon
10:45	“that’s very clear .”			x		Teacher’s language in describing the phenomenon
11:03	“nice [about teaching science] .”	x				Teacher comments she tells students “Now don’t erase.”
11:25	“you’re not alone : that’s hard : this is hard enough, right ?”				x	Teacher’s comment about representing task
Group C. Round 2 “Ketchup”						
6:44	“you are taking this in a different way than I had thought : it’s interesting… it’s hard // I think what you’re doing is hard .”				x	Group’s enacting phenomenon
15:34	“and those are good words (.) so label them .”			x		Teacher’s verbal description
Totals for group C		1	0	3	2	
Grand totals		2	1	15	8	

Table 9 shows that the facilitator faithfully held to this protocol. The facilitator made 26 statements implying causal attributions of performance on the modeling tasks to various factors during the six small-group sessions. Of these, 23 (88%) referred to the immediate task at hand (enacting, describing, or explaining phenomenon or representing thinking). Total contact time between the facilitator and the teachers during this phase was about 40 minutes, which gives an average of 1 of on-target attribution statement about every 100 seconds. The three off-target attributions refer to teaching science as a subject, not to learning or knowing canonical science. These occurred when the facilitator moved off protocol and talked about the difficulty in teaching science in the classroom.

It is interesting to note that these on-target attributions are not evenly spread among the groups. Facilitation with group A accounts for about half. This suggests that facilitator behavior may depend heavily on individual teachers. For example, when working with the "Bear" (swinging a toy in a circle and letting it go), the performance of group A was attributed to ability or task difficulty 14 times, while no such attributions were made for group B working on the same phenomenon. It would be interesting to look at other factors that distinguished these two groups.

Implementation of the Conference Phase

In this whole-group meeting, the facilitator should organize a discussion of the small-group work by asking the teachers to present and discuss their thinking about the phenomena they had worked with. In the workshop model, this phase acts as an analogy to scientific conferences, in which teachers present as experts to peers to increase their competence in following the targeted imperatives of science work. Due to video-recording problems, only an 8-minute segment of the facilitator introducing the phase and a later a 10-minute segment of teachers presenting their work survived downloading. These are used below to sample facilitator behavior during the conference phase.

Reference to canonical science. The workshop model stipulates that during the conference phase the facilitator should not refer to canonical physics content and should not attribute difficulty or degree of success to canonical science content, but can attribute these to the nature of enacting, observing, describing and explaining a phenomenon at hand and to the work of representing thinking. To gauge whether facilitation was faithful to this stipulation, the researcher reviewed the two segments of the conference phase for references to “science” or technical terms from science subjects. One segment samples from the facilitator’s introduction to the conference and one from the exchange between a group presenting their thinking on a phenomenon and an audience made of the facilitator and the other teacher groups. The results are given in Table 10.

Table 10

Sample of Facilitator’s Conference-Phase References to Science

Stamp	Reference	Intent	On protocol	Key theme[1]
Introducing conference				
01:43	“When science workers do their bit (..) they do something different than we do normally .”	Refers to cultural norm of science work	No	CNewLook
	“[what they do] is a method … sometimes difficult to figure what they did .”	Refers to cultural norm of science work	No	
02:14	“trying to get the kind of thinking that science people do into normal people’s heads…”	Refers to science practices and cultural norms	No	CNewLook
02:59	“how do scientist really work (..) confused … trying to figure out what’s important .”	Refers to science practices	No	
03:30	“research conferences… experts presenting… talking about what they do in their lab .”	Refers to science practices	No	PPeers
04:30	“sit privately in their room… write up the best description…”	Refers to science practices	No	CDescExpl
05:50	“[presenting what you know and talking] is a good structure for science activity .”	Refers to teaching science	No	CAligns
07:09	“Here’s the way it works … science conference… experts on bear and ketchup…”	Refers to science practices	No	PPeers
Expert presentations				
08:20	“do you understand what all these little symbols mean… this is part of what scientist do… invent all these little symbols…”	Refers to science practices	No	

Due to video recording problems, this table represents 18 minutes (about 40%) of the conference time.
1. “Key themes” are part of the workshop model and are listed in Table 1.

In the 18 minutes sampled, the facilitator made eight references that were off the protocol as stipulated in the model. None were references to specific technical terms or symbols, but all were to canonical science culture (practices or norms). The pattern of the references is significant. The facilitator’s checklist (Appendix C: Research-Phase Facilitation Checklist) has no specific guidelines on how to introduce the conference phase. The researcher decided to introduce the meeting by asking teachers to revisit key workshop themes and to connect what they would be doing that day to canonical science work. In the remainder of the conference phase, teachers presented their thinking as “experts” on the phenomenon they had studied while the facilitator intervened to scaffold the targeted proto-scientific norms. Seven of the off-protocol references were in the orientation segment, and one was during the teachers' discussions of their expertise with phenomena they had studied. This suggests consideration of a change to the facilitation protocol for the conference phase to have the facilitator revisit the overall purposes of the workshop as introduced in the initial meeting and to relate teacher's whole-group discussions to the culture of science work.

Causal attributions. The workshop model stipulates that during participants' whole-group discussions of the representational tasks, the facilitator should avoid attributing performance levels either to an individual's *adeptness with canonical science* or to the *difficulty of canonical science* as work or as a subject. Such causal attributions are known to have complex interactions with an individual's outcome expectancy beliefs, academic self-concept, and the affective reaction to the task at hand. The theory of change (Figure 1) behind the workshop suggests that avoiding such attributions is likely to allow those lay to science work to find subjective task value in modeling tasks and to build a positive expectancy for success in academic work around science subjects

However, the workshop model does encourage scaffolding practices that attribute performance to the *individual's competence in representational work*, in this case enacting, observing, describing, explaining, and representing simple, everyday physical phenomenon and that acknowledges the *inherent difficulty of representational work*. The theory of change suggests that using such attributions is likely to encourage engagement with cognitive conflict in a way that is subjectively valuable and that promotes a positive academic self-concept.

To gauge whether facilitation was faithful to this stipulation, the researcher reviewed the two segments of the conference phase for causal attribution statements made by the facilitator. One segment samples from the facilitator's introduction to the conference and one from the exchange between a group presenting their thinking on a phenomenon and an audience made of the facilitator and the other teacher groups. The results are given in Table 11. The table identifies the statements that attribute struggle or success either to the *abilities* of teachers with canonical science or to *nature of science tasks* themselves, or to their abilities at the representational tasks at hand or those tasks themselves.

Table 11

Sample of Facilitator’s Conference-Phase Causal Attributions

Stamp	Statement	Attribution type				Context
		Canonical science		Representational work		
		Ability	Task	Ability	Task	
During introduction to the role of conferences in science culture						
0:25	“so (.) you fooled around (..) very detailed .”			x		Responding to a teacher describing what her group did in the research phase
0:57	“now (.) as I walked around there was a lot of interesting and clever thinking going on .”			x		Responding to general talk about what groups did in the research phase
1:37	“when science workers do their bit (.) they do something different than what we do in normal life .”		x			Referring to the goal of the workshop
1:47	“… and sometimes it’s really hard to figure out what they’re [science workers] doing and why .”		x			Referring to the difficulty of doing science work
3:12	“these are some of the weird things science folks have to live under : a lot of mucking around in confusion .”		x			Referring to the unique aspects of science work
4:55	“so you’re [group 2] really kind of clueless about the ketchup .”				x	Commenting on group 2 not having done the ketchup task
8:02	“does that [getting up to present what you think] sound intimidating to anybody ?”				x	Referring to presenting thinking to the whole group
8:16	“it’s a little intimidating to think ‘I gotta tell them what I think and I don’t even know !”				x	Referring to presenting thinking to the whole group
8:26	`”that’s fine : you know more than these people !”			x		Referring to presenting thinking to the whole group
Totals for segment from introducing the conference		0	3	3	3	
During groups’ presentations of their own thinking about a phenomenon						
3:16	“that’s very graceful .”			x		Referring light-heartedly to enacting the phenomenon
4:03	“what about the other group : did you get anything weird like that ?”			x	x	Responding to teacher introducing the importance of “follow-through”
4:20	“notice you’re moving into explanation again (.) which is very cool : it’s not a bad thing : it’s so easy to do .”			x		Responding to presenting teacher talking about a phenomenon
4:32	“you’re building a little theory that the fingers are doing something… ”			x		Responding to presenting teacher talking about a phenomenon
6:09	“yeah (.) there’s some kind of weirdness going on .”				x	Responding to audience teacher commenting on presenter’s idea
7:57	“interesting (.) yeah : it might make it more (.) weird because they don’t have as much control .”			x	x	Responding to audience teacher giving a counter-idea
8:21	“this is part of what scientists have to do : to invent ways to describe stuff .”	x				Commenting on the work of a presenting group
Totals for segment from groups’ presentations		1	0	5	3	
Grand totals		1	3	8	6	

Due to video recording problems, this table represents 18 minutes (about 40%) of the conference time.

Table 11 shows that the facilitator held fairly well to this protocol. In the 16 minutes sampled, the facilitator made 18 statements implying causal attributions of performance on the modeling tasks to various factors during the six small-group sessions. Of these, 14 (78%) referred to the immediate task at hand (enacting, describing, or explaining phenomenon or representing thinking), which gives an average of 1 on-target attribution statement about every 69 seconds. The four off-target attributions refer to the cultural norms of canonical science, mostly during the improvised revisiting and orientation period.

Implementation of the Final Meeting

In the final meeting, the facilitator should present to the whole group how canonical physics would describe and explain the phenomena that the teachers had worked with. They should encourage the teachers to interrupt with their own thoughts about how these compare with their thinking and representations. The facilitator should relate the work of the teachers back to the key content and process themes of the workshop model. The facilitator should lead the teachers to discuss and list any key insights they would like to capture from the workshop. In closing, the facilitator should emphasize the overarching theme that science work asks people to see the world in a different way from how people normally function, that is not scripted work, and that it involves group dialog around representations of thinking about the physical world.

Research Questions

Table 12 summarizes the data used to address the research questions (RQ) at each stage of the workshop: one week before the workshop, during the five phases of the workshop (initial meeting, research phase, conference phase, and final meeting), at the end of the workshop, and one week after.

Table 12

Review of the Data Collection Schedule

Source	Timing							
	Pre	Initial meeting	Research phase		Conference phase	Final meeting	End	Post
		Presentation	Small-group 1	Small-group 2	Whole-group discussion	Presentation		
Video	—	Full	Full	Full	Partial	None	—	—
Measures	STEBI	CVM	CVM	CVM	CVM	CVM	WEQ	STEBI

The core academic task of the workshop, constructivist engagements with prototypical scientific modeling, was presented in two rounds of the research phase. In some analyses, data from these two rounds are averaged to give an overall evaluation of the research phase.

Teachers' modeling behaviors were coded from video recorded by an assistant dedicated to a single group during the research-phase sessions. This data is used to answer RQ1. Component Value Measures (CVM) were part of the participant journal given to each teacher at the beginning of the workshop, and were filled out at the end of each workshop component. They asked teachers to rate how enjoyable, interesting, and potentially useful they found the work they had just finished. CVM data is used to answer RQ2. Pre- and post-measures of the Science Teaching Efficacy Belief Inventory (modified STEBI-A) were done online a week before and after the workshop. One person took the pre-workshop assessment onsite before the initial meeting. Modified STEBI-A data is used to answer RQ3. The Workshop Evaluation Questionnaire (WEQ) asked teachers to evaluate the entire workshop, and was given at the end of the final meeting, also as part of the participant journal. WEQ data is used to answer RQ4.

RQ1. Prototypical Scientific Modeling Behaviors

RQ1. *For the Seeing the World Differently workshop model, do workshop participants engage in prototypical scientific modeling behaviors?*

Each group's work and their interactions with the facilitator were video-recorded by an assistant dedicated to that group during each of the two research-phase rounds. Teachers' modeling behaviors were coded from the video recordings of these sessions. Each session, Res1A, Res1B, etc., is analyzed using a standard interval-coding technique by two independent coders for indicators of each of four prototypical scientific modeling behaviors (PSMBs). The researcher is considered the primary (1°) coder for this analysis. The secondary (2°) coder is a research assistant who was very familiar with the video recordings from a separate analysis. Total counts of intervals coded for each PSMB for a session are used to establish whether groups acted during the session in ways prototypical of scientific modeling. Conceptualizations of the four constructs are summarized below. Behavioral indicators are in Table 3. The coding method is described under *Data Analysis*. The four PSMB constructs are:

- *Arranging for the conditions of seeing*. Group members arrange materials into a position where the phenomenon can be studied. They adjust their intentions and understandings based on materials reacting to their manipulations. They formulate questions about the phenomenon or about conditions for pursuing questions about the phenomenon.
- *Inventing measures*. Group members reconceptualize qualities of materials or processes so that they can be described by measures. They invent measures that are given as counts or names. They specify relationships among qualities using counts and names from measures. They combine measures into composite measures. They adopt or adapt measures from others, suggest measures for others, or work toward conventions on how qualities should be measured.
- *Developing representational competence*. Group members invent, adapt, or adopt symbols to capture observable or unobservable qualities of the phenomenon. They simplify representations to ignore useless or distracting information. They explicitly evaluate a representation to qualify or back it as a stand-in for the phenomenon.
- *Developing an epistemology of modeling*. Group members explicitly distinguish their ideas from their observations. They compare their description or explanation with a previous version or someone else's. They evaluate how their model fits or doesn't fit with their observations. They test or design tests of their descriptions and explanations. They indicate that parts of a representation are approximate or are contingent on events. They modify their description or explanation to make it fit their observations better or to make it more general.

Table 13 presents for each session the percentage of intervals that the primary coder judged contained indicators of each behavior ("1°") and the percentage of those that the secondary coder agreed were present ("agreed").

Table 13

Percent of Intervals in Research-Phase Sessions with Prototypical Scientific Modeling Behaviors

Indicator present	Conditions of seeing		Inventing measures		Representational competence		Epistemology of modeling	
	1°	agreed	1°	agreed	1°	agreed	1°	agreed
Res1A								
Yes	21%	88%	8%	17%	51%	98%	14%	9%
No	79%	97%	92%	97%	49%	68%	86%	97%
Res1B								
Yes	64%	84%	0%	100%	29%	88%	6%	20%
No	36%	91%	100%	97%	71%	95%	94%	88%
Res1C								
Yes	29%	60%	1%	0%	50%	81%	20%	43%
No	71%	84%	99%	100%	50%	63%	80%	79%
Res2A								
Yes	23%	81%	3%	0%	37%	82%	16%	29%
No	77%	88%	97%	100%	63%	69%	84%	95%
Res2B								
Yes	26%	73%	4%	25%	39%	95%	24%	42%
No	74%	89%	96%	95%	61%	82%	76%	85%
Res2C								
Yes	41%	55%	2%	0%	46%	91%	18%	38%
No	59%	96%	98%	100%	54%	61%	82%	90%

This table gives the percentages of intervals in which the primary coder (1°) judged an indicator of one of the PSMBs was present ("Yes") and not present, ("No") followed by the percentage of those intervals for which the secondary coder (2°) was in agreement.

Construct validity. As can be seen, the agreement between the coders varies considerably. This indicates the difficulty in establishing the purposes of various actions, which requires considerable expertise in judging the thinking behind the visible actions in a complex engagement with an academic task. This difficulty challenges the validity of the constructs as operationalized in this study. This is explored in detail under each research question.

RQ1.1. *Do participants engage in arranging materials to create conditions for them to see and formulate questions about the physical phenomenon they are tasked to describe and explain?*

The primary coder found this behavior in between 24% to 64% of the intervals in these six sessions, and typically the secondary coder largely agreed (60% to 88% agreement). For example, in

Res1B, the session with the highest count on this construct, the primary coder found indications of this behavior in 64% of the intervals, and the secondary coder agreed on 84% of these decisions. Agreement was even more likely on decisions that there were no indications (84% to 97%). This means the secondary coder did not see the indications of the primary coder (lower agreement) more often than she flagged behaviors as indicators which the primary coder did not see (higher agreement).

One reason this behavior was common and easy to see was that any purposeful effort to enact the phenomenon described in the provocations should be coded in this category. As an example, consider this excerpt from session Res1B, the engagement with the largest proportion of behaviors coded as "Arranging for the conditions of seeing," in which three teachers are tasked with describing and explaining how to get ketchup to the top of a ketchup bottle:

Time	Behavioral description
3:22	34 turns bottle, looks at bottom of bottle, taps bottom of bottle; 76 looks at bottle;
:32	34 lifts bottle, shakes bottle, looks at bottle; 76 looks at bottle;
:42	76 turns bottle, looks at bottle;
:52	34 holds bottle, says re repr "xxx some arrows", points to FB, shakes bottle; 76 marks-on FB;
4:02	34 looks at FB, shakes bottle, says re thinking "can you see xxx"; 76 marks-on FB;
:12	76 marks-on FB;
:22	34 says re phenom "more goes down if you hit it"; 76 marks-on FB;

Here, one teacher repeatedly manipulates the bottle while watching it with the clear purpose to study how it behaves as a "material system," while a second teacher looks at the bottle and describes it in the group's flipbook page (FB). All of these intervals except the last two were coded by both coders as indicating "Arranging for the conditions of seeing." This group interacted with the materials this way repeatedly, and so they demonstrated that they are not simply speculating about how the world works, but using a material system to study it.

Not all indicators of this PSMB were this obvious. Later, in the same session, the group for some reason thinks of a different tack:

Time	Behavioral description
8:21	36 hits bottle on table, looks at bottle; 76 marks-on FB;

:31	36 hits bottle on table, looks at bottle, says re phenom “I’m actually making it worse : why ?”;
	76 marks-on FB;
:41	36 hits bottle on table, looks at bottle;
	76 marks-on FB;
:51	36 hits bottle on table, looks at bottle;
	76 marks-on FB;
9:01	36 hits bottle on table, looks at bottle;
	76 marks-on FB;
:11	34 squeezes bottle, looks at bottle;
	76 looks at bottle;
:21	34 says re process “xxx squeeze on it”;

In the interval ending at 8:31, the teacher manipulating the enacting materials (bottle) notices that the ketchup is bouncing back to the bottom of the upturned bottle when she hits it, and then asks a question that is pursued for study. This should be coded as “Arranging conditions for seeing: Formulate questions to answer using materials.” At about 09:21, a third teacher gets the idea to squeeze the bottle and prompts the other teacher to try. If this were just in fun, the coder should ignore it, but it is clear from context that the purpose of the action is to see if the system behaves a certain way under certain conditions. This should be coded as indicating “Arranging conditions for seeing: Formulate conditions to allow questions to be answered using materials.”

Later, this same group illustrated in a short sequence how a question leads to an intention to study which leads to formulation of conditions for answering question and then on to a manipulation of the material system to answer a question:

Time	**Behavioral description**
14:50	76 off-camera says re phenom to form question “xxx height might make a difference too”
	34 resp re thinking “I know”;
	36 off-camera resp re thinking “I thought about that too : I wondered too”;
15:00	76 off-camera says re process to form conditions “you [34] want to try it ? cause C [36] and I are about the same height”;
	36 takes bear, says re process “now I’m right handed…”
:10	76 stands, says re process “left-handed vs right-handed : now that’s something too”;
	36 walks to enacting area, swings bear to enact phenom;

All three of these intervals should be coded as “Arranging for conditions of seeing”, even though the teachers manipulate the enacting materials to study only in the last interval. The first should be coded for the indicator “Formulate questions to answer using materials” and the second for “Adjust intentions to further study the behavior of materials" and "Formulate conditions to allow questions to be answered using materials". Though it is easy to see that *something* is going on in this brief 20 seconds, to tease apart the indicators to describe the sequence of thinking that moves from a wondering about to purposeful action is demanding. It is more subtle indicators like this that cause the disagreements between the coders.

Arranging materials to create conditions for the conditions to see and to formulate questions takes in many actions that lead from a thought about the phenomenon through formulating a question, deciding to pursue it, deciding on conditions needed to answer it well, and then manipulating a material model of the phenomenon to answer the question. Though all of these should be considered functional in any culture, even those lay to science work, it is the chaining together as sustained sequences past what is typically considered necessary, simply as a means of satisfying an internal drive, that is what this study considers prototypical of science.

Given the strong agreement of the secondary coder with the primary across all sessions, it seems that arranging materials to formulate and answer questions about the physical world was a fairly common behavior in engagements at this level. It is a more open question how common were the more subtle actions under this construct.

Overall assessment of RQ1.1. Despite disagreement of the secondary coder with the primary, the level of agreement seems sufficient to declare that the teachers in this study did manipulate the materials at hand to allow them to formulate and pursue questions about the how and why of the target phenomenon. That is, they used a material system to engage the task of describing and explaining the physical world. This was one of the most common modeling behaviors of group members during the small-group engagements with prototypical scientific modeling tasks.

RQ1.2. *Do participants invent measures for characteristics of the physical phenomenon they are tasked to describe and explain?*

The primary coder found little behavior indicating that group members invented or used measures in their engagements with the tasks. For example, in Res1A, the session with the highest count on this construct, the primary coder decided 92% of the intervals had no such behavior, and the secondary coder agreed on 97% of these decisions. This is typical of the analysis for this PSMB. However, where the primary did see indications (all sessions except Res1B), the secondary coder largely did not. This testifies to the subtly of nascent quantification of physical properties, especially when ordinal factors (names with an implied ordering) are allowed as measures.

To illustrate, consider the following excerpt from session Res1C in which two teachers were asked to describe and explain the behavior of a loose bowling ball in the bed of a pickup truck, using a box and a marble as the material system under study:

Time	**Behavioral description**
00:10	68 moves box FrR to mimic phenom;
	41 looks at box;
:30	41 looks at enacting materials, says re phenom “it rolls back (.)”;
:40	41 cont looking at enacting materials, says re phenom “almost back to its original position”;
:50	41 points within box says re phenom “it has a back a middle and a front”;
1:10	68 moves box FrL to estab conditions, sets marble inside box;
:15	68 moves box FrR to enact phenom;
	41 says re phenom “so when it xxx back (.) it moves up to the top and back to the middle”;
:25	68 moves box FrL to enact phenom;

The action by participant 41 at 00:50 should be coded as “Inventing measures: Invent, adapt, or adopt measures to describe qualities using counts or names” because the person created an ordinal factor to establish the position of the ball in the box. This subtle behavior is easily missed but is very significant for understanding how people lay to science work think about organizing their experience when pressed to a finer granularity than is typically functional. This teacher used her invention 15 seconds later to sort out a perception she had been stuck on: She is now able to articulate the motion of the marble succinctly as “it moves up to the top and back to the middle.” Tracking the microgenetic evolution of such thinking is difficult but would help to establish how behavior may be influenced by facilitation of the norms of science work. This is one of the indicators that the second coder did not mark.

An example of where the second coder agreed with a primary decision are these three excerpts from session Res1A, in which two teachers were grappling with the same provocation. Here, the middle excerpt is during an engagement with the facilitator (FA):

Time	Behavioral description
14:25	91 points within box, says re phenom to descr phenom “… it would continue to stay in the back”;
	25 says re phenom to descr phenom “until it hit the back”;
:35	25 manip box to enact phenom, says re conditions “we need a bigger table”;
…	(Group asks the facilitator to join them)
17:11	25 moves box FrR to enact phenom, says re process to form cond “if I put my pencil right here”, sets pencil center box;
:21	25 moves box FrR to enact phenom slowly, says re phenom to desc phenom “the ball doesn’t really // well (.) never mind”;
:41	FA says re proc to form conditions “why don’t you really punch on it”;
	25 moves box FrR to enact phenom;
:51	25 points to marble, gestures to mimic phenom, says re phenom to desc phenom “it appears as if is rolling (.) and it does roll …”;
…	(Facilitator leaves group)
18:18	25 sets pencil center box to measure;
	91 points to box, says re phenom to desc phenom “the ball is staying xxx : it’s the truck that’s moving // the ball xxx”;
:38	25 writes-on FB;
	91 writes-on FB;
	91 says re phenom to desc phenom “it appears to // we would say it appears to”;
:48	25 points to box, moves box FrR to enact phenom, says re phenom to desc phenom “it’s rolling : it has to move”;
:58	91 looks at 25, says re repr “how do you say that”, writes-on FB;
	25 looks at box, resp re repr “I don’t know”;

In the first excerpt, the teachers are trying to understand what the marble does as it moves from the front to the back and hits the back of the box. As they try to explain their confusion to the facilitator, at time 17:11 participant 25 uses her pencil to mark the position of the ball. Both the primary and secondary coders identified this as a use of a measure. In effect, when pushed to formulate her perceptions, the teacher set up a coordinate system to allow her to describe the position of the marble without referencing the box, but then loses her thought. After the facilitator leaves, the teachers try to articulate their new perceptions and rely again on their invented measure. Both coders identified this action as “Inventing measures: Use measures to describe relationships between qualities”.

In essence, these teachers here discovered a canonical physics construct, “motion relative to a frame of reference”, though the facilitator correctly did not point this out. This is the key to understanding this phenomenon in the way it is taught in a physics class. This moment would eventually allow a facilitator to help these teachers bridge to science norms.

Overall assessment of RQ1.2. Inventing and using measures seem to be uncommon at this level of engagement with prototypical scientific modeling tasks. Taking the primary coder's decisions at face value, they are the least common modeling behavior among the six sessions studied, but they are there. They are subtle and easy to miss but may be important responses to being pressed to perceive the physical world at a granularity beyond what is typically functional. They may allow people to form and articulate perceptions to create finer representations of the physical world.

RQ1.3. *Do participants display representational competencies in externalizing their thinking about the physical phenomenon they are tasked to describe and explain?*

The primary coder identified this behavior as the most common of the four prototypical scientific modeling behaviors (from 63% to 98% of intervals), and the second coder typically agreed (81% to 98% agreement). However, unlike for the other constructs, the second coder disagreed more on decisions that this behavior was *absent* from an interval (61% to 95% agreement, with four sessions' agreement in the 60% range). This shows that the secondary coder flagged actions as indications of representational competence more often than the primary. As an example, for the session Res1C, in which a different pair of teachers worked to describe and explain the bowling ball in the pickup truck, the primary coder did not see indications of representational competence in half the intervals, but the secondary coder flagged 32% of those with indicators (that is, 68% agreement).

Even though the second coder saw more representational work, both coders identified this area of prototypical scientific modeling behaviors as the most common of the four and as a regular practice in these engagements. The main reason this behavior is so prevalent is that any writing or drawing on the representational materials provided to the groups that was not clearly administrative should be marked as an indicator of representational competence. For example, in Res2C, in which two teachers were exploring the ketchup bottle, the group continued to write and draw on flipbook pages from 2:30 to 5:40 when the facilitator entered the group. All but one of the 20 intervals were coded by the primary as "Representational competence. Invent, adapt, adopt symbols", the common indicator for capturing thinking on a flipbook page, and the secondary coder agreed. It was clear to both coders that this group was inventing, adapting, or adopting symbols to capture observable or unobservable qualities of the phenomenon, and the actual work of the group had more of the character of an exploration than just writing a description. For example,

Time	**Behavioral description**
4:10	41 writes-on FB to capture thinking;
	68 asks re proc “what is it we’re doing: are we drawing what we did ?”;
:20	41 resp re proc “we are drawing like a before and after”;
	68 looks at instr, reads instr;
:30	41 touches FB, looks at FB;
	68 draws-on FB to repr bottle;
:40	41 cont touching FB, looking at FB;
	68 cont drawing-on FB;
:50	68 looks at bottle, turns bottle, says re bottle to unclear “xxx”, draws-on FB;
	41 touches bottle, points to bottle, says re phenom “I’d say about here”;

At the interval 4:10, teacher 41 was continuing to put her thoughts onto a flipbook page when the other teacher changed from talking about the phenomenon to asking about the process they were following. She then referred to the instructions for the provocation, while the drawing teacher explained her method. Then, the page changes hands and the second teacher begins to draw while she and the first teacher explore the details of the ketchup in the bottle.

The exchanges around representations can be very productive, but sometimes it is difficult to decide between competence in representational work and competence in regarding knowledge as tentative and contingent. For example, in this brief discussion in Res2B, where the facilitator and three teachers are talking about their thinking about how a stuffed toy acts they let go of a string they’ve been using to swing it in a circle:

Time	**Behavioral description**
6:34	FA asks re phenom to form question “how does he fly out ? that’s one thing I am interested in”
:44	FA asks re phenom “so where did she let go ?”
	34 points to FB, says re phenom “hmm (..) she (.) I don’t know : it doesn’t show…”
:54	34 says re process to adjust intent “so (.) we’ll do it again”;
	FA asks re thinking “well (.) do you know where she let go ?”
	34 points with FB, says re repr “it was right around (.) here somewhere”;
07:04	FA says re repr to warrant “I’m going to call you on this : if it was here (.) how come…”
	34 points within FB, says re repr “no (.) it was here”;
	76 looks at FB, points within FB, says re repr “no (.) it had to be here”;

Are the group members qualifying the warrant for a claim that a description is good (representational competence) or are evaluating how well the model fits their observations (epistemology of modeling)? It should be clear to a coder that some type of modeling behavior is demonstrated here, but which type is not easy to agree upon.

Overall assessment of RQ1.3. Representing thinking about the physical phenomenon seems to be the most common prototypical modeling behavior in the small-group engagements, and the easiest to agree upon. Some groups fell into these tasks easily, while others resisted the work of capturing thinking and perceptions on paper and at times complained mildly that that work was uncomfortably difficult. Though the straight-forward actions of putting words and drawings on paper were common and easy to agree upon, more subtle types of competence, such as evaluating a representation and qualifying its warrant as a stand-in for the phenomenon, are difficult to distinguish from modeling behaviors around assessing the fit of the representation to reality. Typically, conversations around representations, whether evaluating its usefulness and clarity or its fit to reality were some of the most change-producing short exchanges in the engagements.

RQ1.4. *Do participants follow an epistemology of modeling while engaged in the prototypical scientific modeling tasks?*

Like inventing measures, conversations around epistemology were not as common and agreement on them between the coders was not as good as for the more physical actions, arranging materials and making representations. The primary coder found indications of this behavior in between 6% and 20% of the intervals, and the secondary coder agreed as little as 9% of the time and only 42% of the time at best. Unlike inventing measures, the secondary coder agreed highly on the primary's decisions that this behavior was *not* indicated. This means, the primary coder saw this behavior more often than the secondary.

The most common indicator selected for this behavior was “Modify descriptions or explanations to make them fit observations or to generalize them”. The primary used this to tag speech in which a group member was describing or explaining what she thought was happening. For example, in this sequence from Res2A, in which two teachers are trying to describe and explain the bowling ball in the truck bed:

Time	Behavioral description
2:24	25 sets marble front box, moves box FrL to enact phenom;
:34	25 says re phenom to desc phenom “it starts to roll backwards (..)”;
:44	25 sets marble front box, moves box FrR to enact phenom;
	25 says re phenom to desc phenom “it spins really fast (..) and then (.) it spins slow”;
:54	25 says re phenom “it spins fast going backwards (..) and then it slows down (..) when it comes forward”;
3:04	25 sets marble FrR box, moves box FrR to enact phenom;

Here, the teacher slides the box to the right, watches as the marble moves, and then vocalizes to the other teacher what she sees happening. She repeats this sequence several times. The intervals ending at 2:34, :44, and :54 were coded by the primary and the secondary as “Developing epistemological competence: Modifying descriptions … to make them fit”. This was clear because the teacher is observed looking at the material system and working to articulate her description of what is happening.

However, more subtle comparisons between observations and models can be difficult to identify and agree upon. For example, later in this session, the facilitator joins the group and presses the teachers to consider how well their representations would communicate their thinking to another person:

Time	Behavioral description
12:09	FA points within 25 FB, says re repr “so (.) the arrows stand for direction”;
:19	FA asks re repr “is that different from what you got ?”;
	91 points to own FB, says re repr “… this stands for the distance of the truck”, marks-on FB;
:29	FA points within 91 FB, says re repr “and so (.) this is xxx”;
	91 looks at FB;
:39	FA points within FB, asks re repr to clarify “… you say acceleration : what does that mean ?”;
	91 gestures to mimic phenom, resp re phenom “the truck goes vroom (.) and he’s going forward”;
	25 says re repr “xxx stomped down on the xxx”;
:49	FA says re thinking “so what you’re meaning // in your mind you’re seeing ‘truck’ accelerates”;
	25 resp re thinking “right”;
	FA says re repr “so (.) it’s not clear cause you got two things”;
:59	FA says re repr “so just label it cause it’s not clear”;
	91 writes-on FB;
	25 looks at own FB, reads own FB “when the truck is moving…”;

In this sequence, the interval at 2:19, the facilitator is asking one teacher to compare her representation to the other’s, which should be coded as “Developing an epistemology of modeling. Compare descriptions or explanations to another description or explanation to test them”. The exchange between the facilitator and the teachers about their meaning for "accelerate" and the symbols they are using were coded by the primary coder as "Developing an epistemology of modeling. Modify descriptions or explanations to make them fit observations… ." In general, speech about the meaning of words or symbols should be coded this way. The facilitator's final push to get the teachers to label their symbols to make clear their thinking is no longer about fitting descriptions to the phenomenon but about producing a clear representation. This should be coded as "Invent, adapt, or adopt symbols to capture observable or unobservable qualities of the phenomenon, either on paper or in speech." These are very subtle and difficult distinctions and cause disagreement between the coders.

Overall assessment of RQ1.4. Actions indicating that groups were developing their epistemological competence were not commonly identified, though they were coded more often than were groups inventing measures. They were also harder to agree upon. The second coder did not see many of the indicators that the primary identified.

Indicators of this behavior were most often speech in which group members were articulating their descriptions of what they saw, often tentatively. Speech about the meaning of words and symbols may have been indicators that the groups were trying to make their descriptions and explanations better match the phenomenon, and these would indicate development of epistemological competence. However, those actions are difficult to distinguish from speech trying to make representations more clearly communicate their thinking, which would indicate a different behavior. As in other cases, it was clear that *something* around carefully describing and explaining was going on, but it was difficult to agree upon what.

Taken at face value, the primary coder's analysis suggests that groups did work on developing their epistemological competence, though this behavior was not prevalent. When indicated, this behavior was typically in conversations in which group members worked to verbally but carefully articulate their descriptions and explanations of the phenomenon they had observed. In the engagements with prototypical scientific modeling tasks, teachers did take care to make their words and symbols match what they had observed, and did cycle between representing and re-visiting a phenomenon to improve their representations. This study considers these behaviors prototypical of scientific modeling.

Less common were direct statements about holding representations as tentative or about formulating tests of them, but these were observed. These behaviors move closer to the norms of science work.

RQ1.5. *Do teachers' modeling behaviors differ between the research phase and the publication phase of the core treatment?*

This question could not be addressed because the publication phase was not implemented in the study workshop. At the school district's request, the workshop was broken into two afterschool sessions. To keep down the time required after a full work day, the workshop model had been compressed from about 3.6 hr to about 2.7 hr, or a little over an hour and a quarter per day. These changes proved to be problematic. Some teachers could not get to the central location quickly enough to start on schedule, which pushed the start time later into the afternoon. The shorter time did not allow time for breaks or socializing between components. Teachers became fatigued by their engagements before the 80-minute time allotted, and the facilitator decided to stop each day after about 70 minutes. As a result, the study did not present the full workshop as planned. On the second day, the facilitator allowed the whole-group discussion to continue longer and decided to forgo the small-group revisiting of the phenomena (publishing phase) to give time for closure of the workshop in the final meeting.

RQ2. Subjective Task Value

RQ2. *For the Seeing the World Differently workshop model, do workshop participants find subjective task value in the activities of the workshop?*

Prototypical scientific modeling tasks are the engagements of teachers with the provocations to "describe and explain" in the two rounds of the research phase of the workshop. The subjective value of workshop components is measured by the Component Value Measure (CVM), part of the teacher's participant journal, filled out after each workshop component. On some CVM measures, distributions of teacher evaluations differed markedly between the two rounds of the research phase, so for RQ2.1 and RQ2.2, the data is kept separate (Research 1 and Research 2). RQ3 asks if teachers valued the phases of the workshop differently (initial meeting, research phase, conference phase, and final meeting). For this question, the CVM measures for the two research phase components are averaged to give an overall measure for that phase.

Constructs measured. This study defines subjective task value as in the expectancy-value theory on motivation in academic tasks, as “the value of an achievement task for the individual” (Eccles, 1983a, p. 89). The model breaks subjective task value into four components: intrinsic task value, utility task value, attainment task value, and task cost. This study follows two constructs: intrinsic task value and utility task value. Four questions of the CVM gave quantitative measures on these two constructs and three questions asked for teachers’ written comments.

Intrinsic task value is “the inherent, immediate enjoyment one gets from engaging in an activity” (Eccles, 1983a, p. 89). Following the literature on achievement choices, this construct comprises both enjoyment and interest. CVM1 asked “How enjoyable was this part of the workshop?” CVM2 asked “How interesting was this part of the workshop?” Utility task value is “the importance of the task for some goal that might itself be somewhat unrelated to the process nature of the task” (Eccles, 1983a, p. 89). Because teacher’s academic self-concept around science is separate from their self-efficacy beliefs around teaching science, the measures include questions that probe the value of the workshop both for improving their sense of their own science knowledge and for improving their abilities to teach science. CVM3 asked “How useful do you think this part of the workshop was for helping you understand the way science works?” and CVM4 asked “How useful do you think this part of the workshop was for helping you understand how to teach science?”

RQ2.1. *Do workshop participants find intrinsic task value in the activities of the workshop?*

To allow for strong feelings of both enjoyment and displeasure and strong feelings of both interest and boredom as well as no strong feelings at all, these measures are on a bi-directional scale, with -5 a very negative valuation, +5 a very positive valuation, and 0 indicating “didn’t feel strongly either way”.

For each workshop component, distributions of CVM1, CVM2, and an intrinsic task value construct-level measure averaging the two are pictured in Figure 7. Dots show individual scores and the boxplots show the 5-number summary (minimum, Q1, median, Q2, and maximum) for each distribution.

Descriptive sample statistics (mean, standard deviation, median, and inter-quartile range) are given in Table 14.

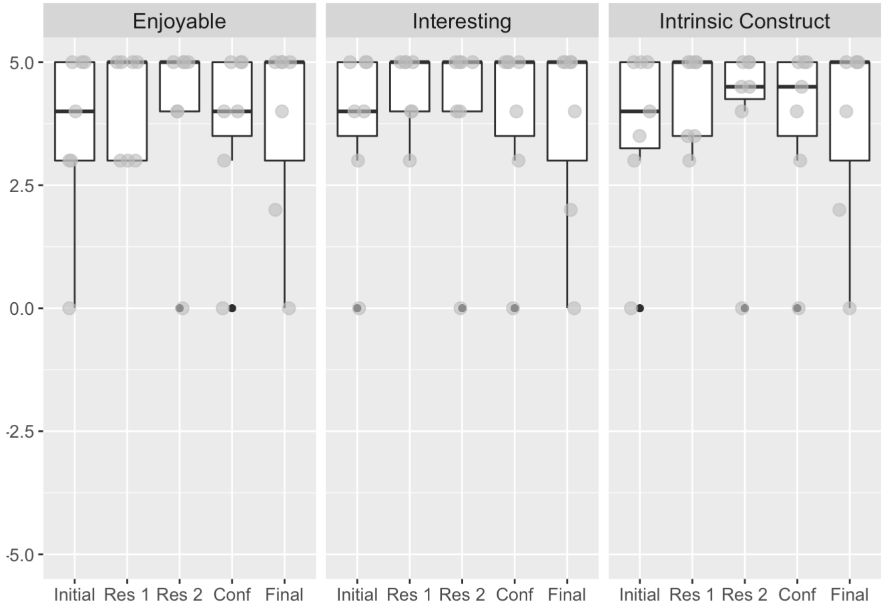


Figure 7. Distribution of intrinsic task value measures for each workshop component

Table 14

Descriptive Statistics of Intrinsic Task Value of all Workshop Components

Component	Enjoyable (CVM1)		Interesting (CVM2)		Construct-level (Average)	
	M(*S*)	*Median*(*IQR*)	*M*(*S*)	*Median*(*IQR*)	*M*(*S*)	*Median*(*IQR*)
Initial meeting	3.6(1.8)	4(1.5)	3.7(1.8)	4(1.5)	3.6(1.8)	4(1.8)
Research 1	4.1(1.1)	5(1.0)	4.4(0.8)	5(1.0)	4.3(0.9)	5(1.5)
Research 2	4.0(1.8)	5(1.0)	4.0(1.8)	5(1.0)	4.0(1.8)	4.5(0.8)
Conference	3.7(1.8)	5(1.5)	3.9(1.9)	5(1.5)	3.8(1.8)	4.5(1.5)
Final meeting	3.7(1.8)	5(2.0)	3.7(2.0)	5(2.0)	3.7(2.0)	5(2.0)

All measures are on an 11 point bi-directional scale centered at 0 (“not strongly”), ranging from -5 (“very unenjoyable/uninteresting”) to +5 (“very enjoyable/interesting”).

Mean and median scores on all measures for each component are in the high positive range (3 to 5), and over half of the individual evaluations of interest and enjoyment were above 3 (medians from 3.6 to 5). No teachers evaluated a workshop component negatively. Outlying this positive pattern, for the initial meeting, the second research round, the conference phase, and the final meeting one individual indicated she had "no strong feelings" about the work. For the three components in which teachers took on the core prototypical scientific modeling tasks (research phase rounds and the conference phase), the evaluations were mostly uniformly high.

Overall, the data shows that this sample found, on average, all components both enjoyable and interesting. In particular, the core components which represent teachers' engagements with the modeling tasks all, on average, had high intrinsic task value for these teachers. This gives support to the model's hypothesis that such cognitive work can be intrinsically valuable to adults who are lay to science culture.

RQ2.1 asks about the intrinsic task value of engagements with prototypical scientific modeling tasks. These are directly measured by evaluations of the research phase. A natural statistical inference is to answer whether, given the valuations of this sample, a larger population of similar teachers might have strong feelings either way about these components. Since there is no reference criteria for acceptable levels of intrinsic task value, the sample effect size is how far the sample mean is from a rating of zero ("no strong feelings") and statistical significance is calculated using a single-sample, two-sided t-test with a null hypothesis of mean population score equals zero.

Distributions of intrinsic task value on the two research phase components differed markedly, so inferences were made for each round. The two t-tests are run against the same research question, so to keep the chance of erroneously inferring population effects using these sample data below the 5% significance level, each test will be compared to the Bonferroni-corrected level of 5% / 2 = 2.5% and confidence intervals are at the 97.5% level. Test statistics are given in Table 15.

Table 15

Population Effect Sizes and Statistical Significance for Intrinsic Task Value Construct

Component	Estimate of population effects		Statistical significance of point estimate	
	97.5% t-confidence interval	Point estimate (sample mean)	t (df)	p
Research 1	(3.3 – 5+)	4.3	12.5 (6)	< 0.001
Research 2	(2.0 – 5+)	4.0	5.8 (6)	0.001

Both t-tests were statistically significant at the 2.5% level (Res1 $t(6) = 12.5, p < 0.001$; Res2 $t(6) = 5.8, p = 0.001$), indicating that these teachers, considered as a random sample of an ideal population of similar teachers, would be an unlikely sample if the population mean evaluation were zero. The null model distribution should be rejected and the confidence intervals can be taken as statistically significant effects for the intrinsic value of the two research components. However, since the sample was voluntary and not approximating a random sampling of a real population, inference to any group is speculative.

Overall assessment of RQ2.1. The teachers in this sample did find strong intrinsic task value in their constructivist engagements with prototypical scientific modeling tasks. Most teachers found them both enjoyable and interesting. The distribution of overall intrinsic task value differed between the first and second tasks. Evaluations were higher and less variable for the second task, though one outlying teacher had no strong opinions on that session. Further, though the sample was small, evaluations were high enough with low enough variability to suggest that a larger population of similar regional elementary-school teachers who enjoy science-like activities and who believe in their abilities to teach science would also find intrinsic task value in these engagements.

RQ2.2. *Do workshop participants find utility task value in the activities of the workshop?*

Unlike the enjoyment/interest measures for intrinsic task value, which had to allow for strong feelings of both enjoyment and displeasure and strong feelings of both interest and boredom, as well as no strong feelings at all, the range of utility evaluations are from no strong feeling of utility to strong feelings of utility. Therefore, these measures are on a uni-directional scale, with 0 as the lowest valuation ("not useful") and +5 a very positive valuation ("very useful"). A construct-level measure for utility task value was created by averaging individuals' CVM3 and CVM4 scores.

For each workshop component, distributions of CVM3, CVM4, and a utility task value construct-level measure averaging the two are pictured in Figure 8. Dots show individual scores and the boxplots show the 5-number summary (minimum, Q1, median, Q2, and maximum) for each distribution. Descriptive sample statistics (mean, standard deviation, median, and inter-quartile range) are given in Table 16

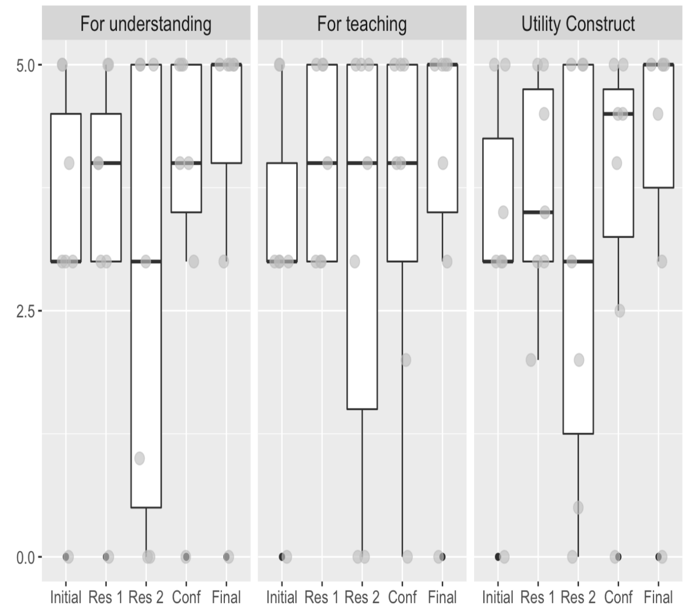


Figure 8. Distribution of utility task value measures for each workshop component

Table 16

Descriptive Statistics of Utility Task Value of Workshop Components

Component	For understanding (CVM4)		For teaching (CVM5)		Construct-level (Average)	
	M(*S*)	*Median*(*IQR*)	*M*(*S*)	*Median*(*IQR*)	*M*(*S*)	*Median*(*IQR*)
Initial meeting	3.3(1.7)	3(1.5)	3.1(1.7)	3(1.0)	3.2(1.7)	3(1.2)
Research 1	3.4(1.7)	4(1.5)	4.0(1.0)	4(2.0)	3.7(1.2)	3.5(1.8)
Research 2	2.7(2.4)	3(4.5)	3.1(2.3)	4(3.5)	2.9(2.2)	3(3.8)
Conference	3.7(1.8)	4(1.5)	3.6(1.9)	4(2.0)	3.6(1.8)	4.5(1.5)
Final meeting	4.0(1.9)	5(1.0)	3.9(1.9)	5(1.5)	3.9(1.9)	5(1.2)

All measures are on a 5-point unidirectional scale from 0 (“not useful”) to 5 (“very useful”).

Mean and median scores on all measures for each component are positive (2.7 – 5), though not quite as high as those for intrinsic task value. Over half of individual evaluations on most measures of utility were 3 or above (medians 2.9 – 5). For each component, one or more teachers found the work “not useful” for understanding science, and for all but the first small-group engagement, one or more found the work “not useful” for teaching science. Reversing the trend in intrinsic task value, teachers rate on average the initial and final meetings and the conference phase more useful than the research phase components both for understanding science and for teaching it.

Construct-level evaluations of utility task value, though mostly positive, are consistently lower than for the intrinsic task value on each component (means 2.9 – 3.9, vs. 3.6 – 4.3 for intrinsic task value). Evaluations of utility were generally lower for the small-group research phase components compared to the whole-group conference and final meeting (2.9 – 3.7 vs. 3.2 – 3.9). Several more people evaluated the second research phase round lower than the first for utility but not for intrinsic value.

Overall, the data shows that this sample found, on average, all components somewhat useful for both their own understanding of science and for understanding how to teach science, though to a lesser extent than they found it intrinsically valuable. This suggests that, though these teachers found the work interesting and enjoyable personally, they were not as sure how it could be used to help them understand and teach science. In particular, the components with whole-group work may seem more useful for understanding and teaching science than the small-group work. The utility of the second small-group engagement in the research phase was more variable than the first and stretched lower. This is hard to interpret for such a small sample but, it could suggest that the teachers were becoming more interested in questions about how to make use of what they were doing.

RQ2.2 asks about the utility task value of engagements with prototypical scientific modeling tasks. These are directly measured by evaluations of the research phase. A natural statistical inference is to answer whether, given the valuations of this sample, a larger population of similar teachers might have, on average, strong feelings about these components. Since there is no reference criteria for acceptable levels of utility task value, the sample effect size is how far the sample mean is from a rating of zero ("component has no value") and statistical significance is calculated using a single-sample, one-sided *t*-test with a null hypothesis of mean population score equals zero.

The distributions of utility task value on the two research phase components differed markedly, so inferences were made on each round. The two *t*-tests are run against the same research question, so to keep the chance of erroneously inferring population effects using these sample data below the 5% significance level, each test will be compared to the Bonferroni-corrected level of 5% / 2 = 2.5% and confidence intervals are at the 97.5% level. Test statistics are given in Table 17.

Table 17

Population Effect Sizes and Statistical Significance for Utility Task Value Construct

Component	Estimate of population effects		Statistical significance of point estimate	
	97.5% *t*-confidence interval	Point estimate (sample mean)	*t* (df)	*p*
Research 1	(2.4 – 5.0)	3.7	8.5 (6)	< 0.001
Research 2	(0.5 – 5+)	2.9	3.6 (6)	0.012

Both *t*-tests were statistically significant at the 2.5% level (Res1 $t(6) = 8.5, p < 0.001$; Res2 $t(6) = 3.6, p = 0.001$), indicating that these teachers, considered as a random sample of an ideal population of similar teachers, would be an unlikely sample if the population mean evaluation were zero. The null model distribution should be rejected and the confidence intervals can be taken as a statistically significant effect for the intrinsic value of the two research components. However, since the sample was voluntary and not approximating a random sampling of a real population, inference to any group is speculative.

Overall assessment of RQ2.2. The teachers in this sample did find utility task value in their constructivist engagements with prototypical scientific modeling tasks, however they seemed to feel they were less useful than they were intrinsically valuable. Most teachers found them more useful for understanding science themselves than for teaching science. There is some evidence suggesting that these teachers found the whole-group work more useful than the small-group work for both understanding science and how to teach it and that they may have become more interested in finding use for it as they progressed through their engagements. Though the sample was small, evaluations were high enough with low enough variability to give good evidence that a larger population of similar regional elementary-school teachers who enjoy science-like activities and who believe in their abilities to teach science would also find utility task value in these engagements.

RQ2.3. *Do participants value the workshop phases (initial meeting, research phase, conference phase, publication phase, final meeting) differently?*

To answer this question, the construct-level scores for intrinsic task value and utility task value were compared across the four phases of the workshop. For this analysis, the two research-phase engagements were averaged. Distributions of intrinsic task value and utility task value for each phase of the workshop are plotted in Figure 9. Dots show individual scores and the boxplots show the 5-number summary (minimum, Q1, median, Q2, and maximum) for each distribution. Descriptive sample statistics (mean, standard deviation, median, and inter-quartile range) are given in Table 18.

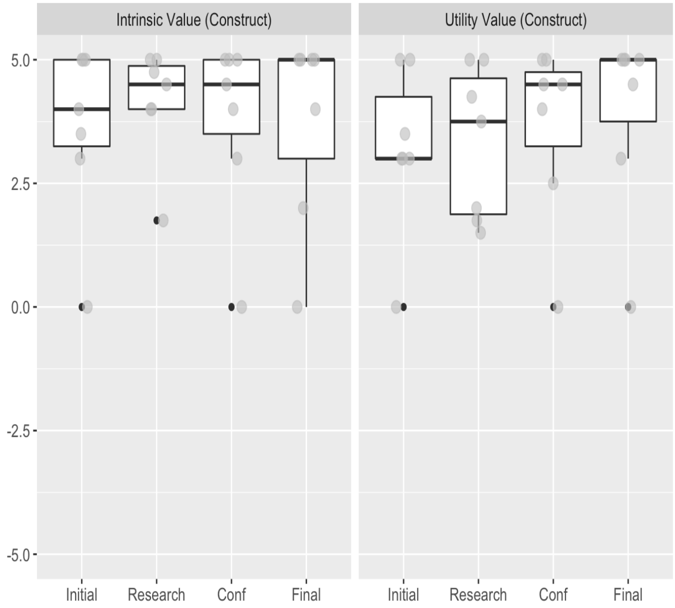


Figure 9. Distributions of subjective task value measures for each workshop phase

Table 18

Descriptive Statistics of Subjective Task Value Measures by Workshop Phase

Phase	Intrinsic Task Value		Utility Task Value	
	M(*S*)	*Median*(*IQR*)	*M*(*S*)	*Median*(*IQR*)
Initial meeting	3.6(1.8)	4.0(1.8)	3.2(1.7)	3.0(1.2)
Research phase	4.1(1.1)	4.5(.9)	3.3(1.5)	3.8(2.8)
Conference phase	3.8(1.8)	4.5(1.5)	3.6(1.8)	4.8(1.5)
Final meeting	3.7(2.0)	5.0(2.0)	3.9(1.9)	5.0(1.2)

This data corroborates the trends seen in the component level assessments. Mean and median evaluations were largely positive for both the intrinsic task value (means 3.6 – 4.1, medians 4.0 – 5.0) and the utility task value (means 3.2 – 4.9, medians 3.0 – 5.0) for all workshop phases, but mean scores for intrinsic value were typically higher than for the utility value. This was true especially for the research phase. However, mean and median evaluations of the intrinsic task value are about the same across phases. Mean and median evaluations of day-2 phases (conference and final meeting) are somewhat higher than for day-1 phases (initial meeting and final meeting).

Plots of individual teachers CVM scores across all workshop components are displayed in Figure 10. There is no one pattern of individual evaluations. One teacher evaluated all phases as very interesting and enjoyable but made distinctions on the utility values (14968), while another did the opposite (12025). Generally, teachers tended to answer questions of the same type similarly.

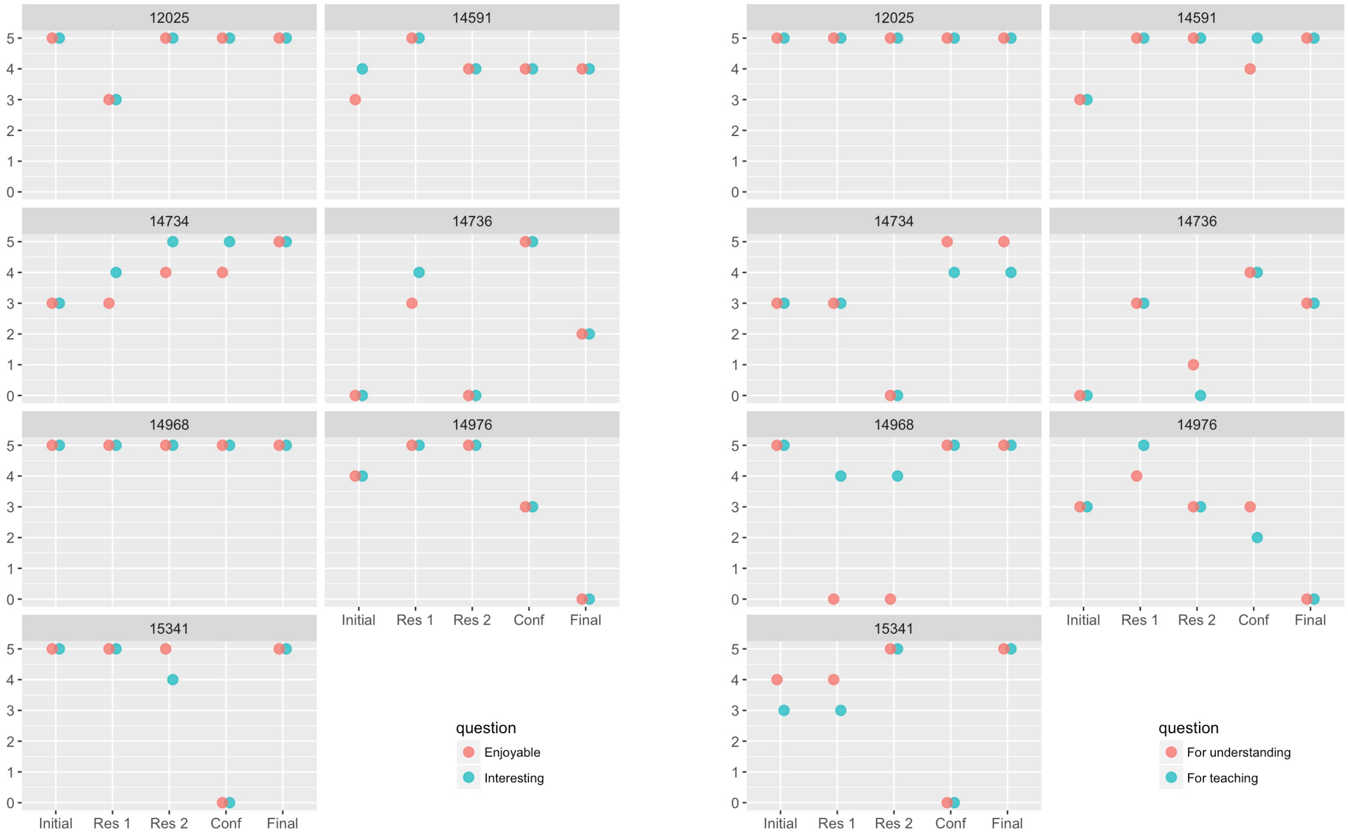


Figure 10. Individual CVM scores across workshop components, paneled by participant

RQ2.3 asks whether evaluations were similar across workshop phases. A natural statistical inference is to answer whether, given the valuations of this sample, a larger population of similar teachers would find constant utility or intrinsic value across workshop phases. To answer this, statistical significance for factor level means are calculated using a MANOVA procedure at the 5% group significance level with a Bonferroni correction for multiple comparisons. The workshop phase is treated as a 4-level factor (initial meeting, research phase, conference phase, final meeting) and the individual intrinsic task value scores and individual utility task value scores are viewed as dependent measures. The MANOVA test showed no evidence from this sample for factor-level differences in the two construct-level measures ($F(6, 48) = 0.80$, $p = 0.57$). Because the complete MANOVA model showed no statistical significance, no further analysis of factor-level effects were carried out.

Overall assessment of RQ2.3. The data suggests that these teachers valued all workshop phases on average about the same, but that they seem to value the utility of the last two phases more than the first. There is no evidence that, when generalized to an idea sample of similar teachers, the mean differences in either the intrinsic task value or the utility task value would differ across phases.

RQ3. Expectancy for Success

RQ3. *For the Seeing the World Differently workshop model, do workshop participants' expectancy for success in science tasks differ before and after the workshop?*

Teachers' responses to the modified Science Teaching Efficacy Belief Inventory (modified STEBI-A) is used to answer RQ3.1 and RQ3.2. The modified STEBI-A was administered via an online survey portal one week before the workshop and again one week after. However, due to administrative problems, of the seven participating teachers, only six have pre-treatment data, four have post-treatment data, and three have pre-post differences.

Constructs measured. Following Eccles (1983a), task outcome expectancy is divided into (a) individuals' self-concepts of their ability and (b) their estimates of the difficulty of future tasks. This study uses the Personal Science Teaching Efficacy Belief scale (PSTE) of the modified STEBI-A to measure teachers' self-concept of their ability to teach science (a scale of 13 – 65), and uses the Science Teaching Outcome Expectancy (STOE) subscale of the modified STEBI-A to measure teachers' beliefs about the difficulty of successfully teaching science (a scale of 10 – 50). The distinction here is based upon Bandura's model of agency: teachers may believe they are competent in teaching science but that the ultimate outcome is influenced by factors outside of their abilities.

Distributions of the modified STEBI-A subscales are pictured in Figure 11. Dots show individual scores and the lines connect pre- and post-treatment assessments. Descriptive sample statistics (mean, standard deviation, median, and inter-quartile range) are given in Table 19.

This data is sufficient to suggest a picture of some individual effects of the treatment for these teachers, but is insufficient to convincingly argue for population effects. No inferences about populations are made.

Table 19

Descriptive Statistics of Teacher Outcome Expectancy Measures (Modified STEBI-A)

Phase	Pre		Post	
	M(*S*)	*Median*(*IQR*)	*M*(*S*)	*Median*(*IQR*)
PSTE (full scale 13 – 65)	31.5(7.1)	30(9.8)	25.5(3.0)	25(4.5)
STOE (full scale 10 – 50)	31.3(3.0)	31(0.9)	31.8(3.3)	32(4.8)

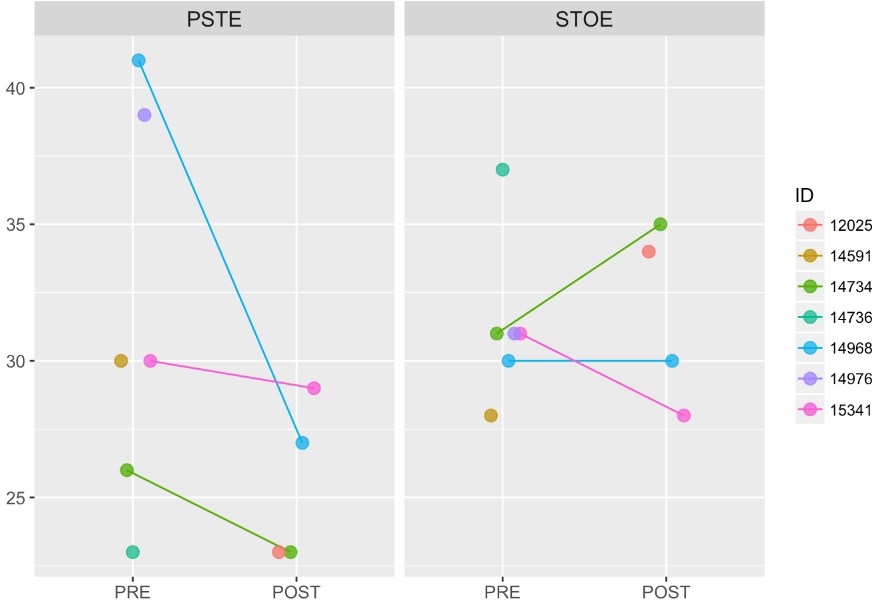


Figure 11. Distributions of pre- and post-treatment outcome expectancy measures (modified STEBI-A)

RQ3.1. *Do participants self-efficacy beliefs toward teaching science differ before and after the workshop?*

The PSTE scores of the three individuals with pre- and post-treatment assessments dropped over the period of the workshop. No information is published on the test/retest reliability of the STEBI-A, so the likelihood of these results happening from random fluctuation in within-subject variations can't be judged. At face value, this data suggests these teachers beliefs in their own ability to teach science dropped over the workshop. This is unexpected, but it could be that these teachers have been brought to think differently about science and science teaching and are now unsure of their current practice.

RQ3.2. *Do participants outcome-expectancy beliefs toward teaching science differ before and after the workshop?*

The STOE scores of the three individuals with pre- and post-treatment assessments varied differently over the period of the workshop, and one did not change. No information is published on the test/retest reliability of the STEBI-A, so the likelihood of these results happening from random fluctuation in within-subject variations can’t be judged. At face value, this data suggests little, except that individuals’ beliefs in the success of future science-teaching efforts react variably to their experience in the workshop.

RQ4. Social Validity of the Workshop as Professional Development

RQ4. *For the Seeing the World Differently workshop model, do workshop participants find social validity in the workshop as professional development?*

The workshop’s social validity as professional development is gauged by teacher responses to the Workshop Evaluation Questionnaire (WEQ). All teachers completed the WEQ as part of the participant journal on workshop day 2, after the final meeting.

Constructs measured. The WEQ has five subscales modeled after the evaluation rubric developed by the Council of Chief State School Officers (CCSSO) for a cross-state study of science and mathematics professional development programs (Blank & de las Alas, 2009). Subscales use an 11-point, bidirectional scale, with -5 indicating the teacher did not think the workshop was valid professional development. A zero indicates no strong opinion.

- *Content*. This subscale had four items that probed whether the workshop content (1) fit with science as a subject, (2) helped to understand how to teach science, (3) was relatable to their own teaching, and (4) helped address what they see as their weaknesses in their teaching.
- *Active*. This subscale had four items that probed whether the workshop processes let participants (1) talk about science, (2) try out or hone new practices, and (3) work with and (4) watch other teachers working with the workshop content.

- *Coherent*. This subscale had two items that probed whether the workshop (1) content and (2) processes aligned with teachers' school, district, and state curriculum, goals, and standards.
- *Collective*. This subscale had three items that probed whether the workshop content and processes might help them (1) talk about science to other teachers, (2) promoted work with other teachers who taught at their grade level, and (3) promoted work with other teachers who might help them use what they learn in their classrooms.
- *Sufficient*. This subscale had one item that probed whether the teachers wanted to continue working with the facilitator to continue their development as science teachers.

Distributions of the five WEQ subscales are pictured in Figure 12. Dots show individual scores and the boxplots show the 5-number summary (minimum, Q1, median, Q2, and maximum) for each distribution. Descriptive sample statistics (mean, standard deviation, median, and inter-quartile range) and descriptive sample statistics are given in Table 20. Results for each subscale are discussed under RQ4.1 – 4.5.

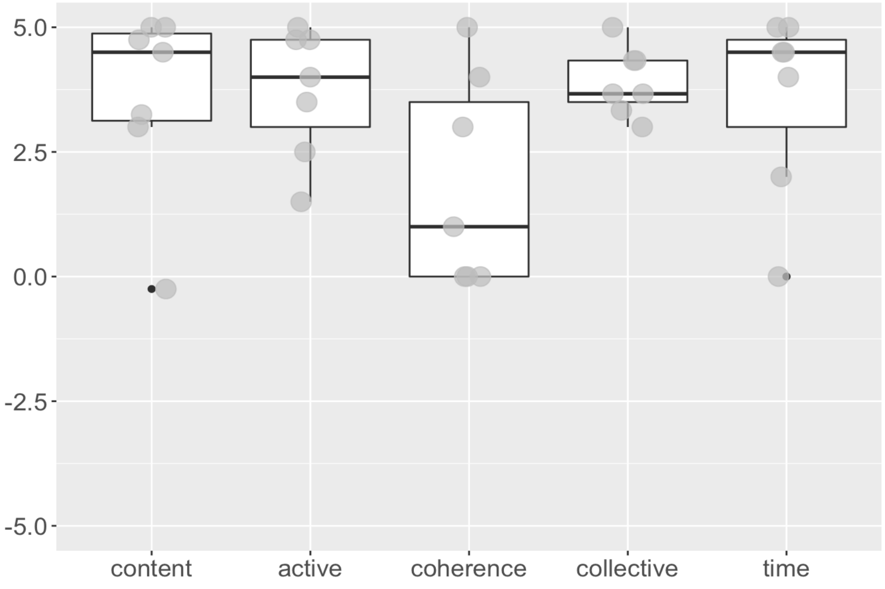


Figure 12. Distributions on social validity measures (WEQ)

Table 20

Descriptive Statistics of Social Validity Measures (WEQ)

Dimension	*M*(*S*)	*Median*(*IQR*)
Content	3.6 (1.9)	4.5 (1.8)
Active	3.7 (1.3)	4.0 (1.8)
Coherent	1.9 (2.1)	1.0 (3.5)
Collective	3.9 (0.7)	3.7 (0.8)
Sufficient	3.6 (1.9)	4.5 (1.8)

All measures are on an 11-point bi-directional scale centered at 0 (“no opinion”), ranging from -5 (“strongly disagree it was valuable”) to +5 (“strongly agree it was valuable”).

RQ4.1 – 4.5 asks about evaluations of the workshop as valid professional development for science teaching. A natural statistical inference is to answer whether, given the valuations of this sample, a large population of similar teachers might have, on average, strong opinions either way about the validity of this workshop along the five dimensions of the WEQ. Since there is no reference criteria for acceptable levels of social validity on these measures, the sample effect size is how far the sample mean on each measure is from a rating of zero (“no opinion”) and statistical significance will be calculated using single sample, two-sided *t*-tests with a null hypothesis of mean population score equals zero. Test statistics are given in Table 21. Since the five *t*-tests are run against the same research question, to keep the chances of erroneously inferring population effects using these sample data below the 5% significance level, each test will be compared to the Bonferroni-corrected level of 5% / 5 = 1.0%.

Table 21

Population Effect Sizes and Statistical Significance for Social Validity Measures (WEQ)

Dimension	Estimate of population effects		Statistical significance of point estimate	
	97.5% *t*-confidence interval	Point estimate (sample mean)	*t* (df)	*p*
Content	(1.9 – 5+)	3.6	5.1 (6)	0.002
Active	(2.5 – 4.9)	3.7	7.5 (6)	<0.001
Coherent	(-0.1 – 3.8)	1.9	2.3 (6)	0.059
Collective	(3.3 – 3.8)	3.9	15.1 (6)	<0.001
Sufficient	(1.8 – 5+)	3.6	5.0 (6)	0.002

RQ4.1. *Do participants believe the workshop focused on science content and pedagogy appropriate for elementary classrooms?*

On average, teachers evaluated the workshop highly for science content and pedagogy ($M = 3.6$, $SD = 1.9$). One teacher did not have a strong opinion on this dimension, but the others were uniformly high (range 3 – 5). Inference to an ideal population of similar teachers was significant at the 1% level ($t(6) = 5.1$, $p = 0.002$). However, since the sample was voluntary, inference to any group is speculative.

RQ4.2. *Do participants believe the workshop provided them with opportunities for active learning?*

On average, teachers evaluated the workshop highly for active learning opportunities ($M = 3.7$, $SD = 1.3$). All teachers expressed a positive opinion on this dimension, and most others were uniformly high (range 3 – 5). Inference to an ideal population of similar teachers was significant at the 1% level ($t(6) = 7.6$, $p < 0.001$). However, since the sample was voluntary, inference to any group is speculative.

RQ4.3. *Do participants believe the workshop was coherently aligned with their curricula, standards, and the ways they will be evaluated professionally?*

On average, teachers evaluated the workshop toward neutral for coherence with the standards and professional evaluations they work under, though variability was greater than for the other social validity measures ($M = 1.9$, $SD = 2.1$). Half of the teachers rated it at 1 or below (median = 1), though none evaluated it negatively. Inference to an ideal population of similar teachers was not significant at the 1% level ($t(6) = 2.3$, $p = 0.059$).

RQ4.4. *Do participants believe the workshop focused on science content and pedagogy that would be supported at their school or district level?*

On average, teachers evaluated the workshop highly for the potential for working collectively within their schools and were more in agreement on this dimension than the others ($M = 3.9$, $SD = 0.7$). All teachers expressed a high positive opinion on this dimension (range 3 – 5). Inference to an ideal population of similar teachers was significant at the 1% level ($t(6) = 15.1$, $p < 0.001$). However, since the sample was voluntary, inference to any group is speculative.

RQ4.5. *Would participants pursue opportunities for follow-up activities to assist in incorporating either the physics content or the teaching methods they learned into their classrooms?*

On average, teachers evaluated the workshop highly for interest in pursuing this as professional development ($M = 3.6$, $SD = 1.9$). All teachers expressed a positive opinion on this dimension, and most others were uniformly high (range 3 – 5), though one teacher did not have a strong opinion. Inference to an ideal population of similar teachers was significant at the 1% level ($t(6) = 5.0$, $p = 0.002$). However, since the sample was voluntary, inference to any group is speculative.

Overall evaluation of RQ4. The data suggests that these teachers considered this workshop as valid professional development for science teaching in all dimensions except coherence with state and local standards for curriculum and teacher evaluation. They rated it highly for science content and pedagogy, for opportunities to discuss and explore new practices with other teachers, and for opportunities such work might provide for working in this way with other teachers at their grade level at their schools. They also rated it as something they would like to pursue further as professional development.

CHAPTER 5

DISCUSSION

The purpose of this study was to explore the *Seeing the World Differently* professional development model, built from the idea that asking people lay to science to bring their native intelligence to bear in situations that simulate aspects of science culture can be an effective way to bring them to science work. The model presents a workshop as an initial and a final meeting and three core phases that were designed to engage teachers in culturally sensitive representational tasks prototypical of scientific modeling. The study successfully implemented the initial and final meetings and two of the core engagement phases for a small group of elementary-school teachers.

This section will review what the study found about the four research questions: (a) whether the engagements elicit specific modeling behaviors, (b) whether the engagements had subjective task value for the participants, (c) whether the intervention affected their self-efficacy beliefs, and (d) whether they valued the workshop as science professional development. It will then discuss what was learned about the model itself, including some suggested modifications. Finally, it will discuss the limitations and significance of the study.

Findings of the Study

Analysis indicates that participants engaged the modeling tasks with little off-task behavior and exhibited all of the targeted modeling behaviors as conceptualized in this study, uniformly felt all components were inherently interesting and useful professionally, and rated the workshop highly as professional development in science teaching. Data on self-efficacy beliefs were largely inconclusive but may suggest that the workshop caused teachers to doubt their current ability to teach science to their students.

RQ1. Prototypical Scientific Modeling Behaviors

Identifying modeling behaviors was difficult and remains an area to be explored further. Agreement between the primary and secondary coder wasn’t consistent enough to validate the modeling constructs well, but in an exploratory study like this, one of the purposes is to probe such questions.

Arranging for conditions of seeing. Teachers manipulated the materials at hand to allow them to formulate and pursue questions about the how and why of the target phenomenon. This was a common and consistent behavior and easy to agree upon. Teachers were observed carefully and repeatedly enacting target phenomena to better see what was happening, varying the circumstances to test different ideas, and isolating parts of interest.

Inventing measures. Inventing and using measures was the least common modeling behavior. Engagements may need more time to press people to need quantitative measures of their experience. Agreement was poorer here indicating that these behaviors were subtle and easy to miss in these engagements. When they did happen, groups were typically trying to describe properties in ways that would let them categorize or count things. On several occasions an individual quickly used her scheme to make judgments about relations between events she had been struggling with.

Developing representational competence. Representing thinking about the physical phenomenon was the most common and the easiest to agree upon. Some groups fell into these tasks easily, while others resisted the work of capturing thinking and perceptions on paper and at times complained mildly that that work was uncomfortably difficult. Putting words and drawings on paper were common and easy to agree upon, but more subtle competence such as evaluating a representation and qualifying its warrant proved difficult to distinguish from assessing the fit of the representation to reality. Though these constructs need reevaluation, conversations around representations, whether evaluating its usefulness and clarity or its fit to reality were the most change-producing exchanges in the engagements.

Developing epistemological competence. Developing epistemological competence was not common and was hard to agree upon. This behavior was typically in conversations in which group members worked to verbally but carefully articulate their descriptions and explanations. Speech about the meaning of words and symbols indicated groups were trying to make their descriptions and explanations better match the phenomenon. Those actions are difficult to distinguish from speech trying to make representations more clearly communicate thinking, which would indicate a different behavior. As in other cases, it was clear that something around carefully describing and explaining was going on, but it was difficult to agree upon what. Less common were direct statements about holding representations as tentative or about formulating tests of them, but these were observed. These discussions lead quickly to actively manipulating the materials to pursue new questions.

Did workshop participants move toward science practices? However subtle the process of identifying exactly which behaviors were happening, it was clear that the teachers in this study grappled seriously with the main task of describing and explaining simple phenomenon in ways that moved well past what would be considered necessary and worthwhile in daily life. It needs to be emphasized that the intervention designed in this workshop unmistakably provoked teachers to engage the physical world in ways very different from daily life and closer to the work of science. These adults clearly demonstrated sustained curiosity about ketchup, a stuffed toy swinging in the air, and a marble rolling in a box. They formulated and pursued questions. They grappled genuinely with how to talk about which way a marble rolled, how to move ketchup inside a bottle, and how to describe the path a toy makes when it is flung—features notably lacking in science classrooms around prescribed engagements with the physical world.

Teachers almost exclusively used their vernacular language and found that they needed to develop more technical words and symbols to frame and articulate what they were thinking, a clear opportunity to bridge to formal science. In conversation with the facilitator, they responded to questions about their thinking earnestly, and when he brought in questions about daily life, the teachers connected them with the phenomenon being enacted.

Without question, effects at stage one of the formal theory of change were observed, and because the model was implemented faithfully, it can be said that for these teachers, the combination of representational tasks, intersubjective contexts, and constructivist facilitation strategies did prompt adults lay to science to engage in behaviors prototypical of scientific modeling. This behavior took up all but a small amount of the time during the core engagement phases.

RQ2. Subjective Task Value

All indicators of the valuation of the work the teachers performed in the workshop were consistently positive.

Intrinsic task value. On average, the participants found all components both enjoyable and interesting. In particular, the core components which represent teachers' engagements with the modeling tasks all, on average, had high intrinsic task value for these teachers. This gives support to the model's hypothesis that cognitive work approaching science can be intrinsically valuable to adults who are lay to science culture.

Utility task value. On average, the participants found all components useful for both their own understanding of science and for understanding how to teach science, though to a lesser extent than they found it intrinsically valuable. This suggests that, though these teachers found the work interesting and enjoyable personally, they were not as sure how it could be used to help them understand and teach science. In particular, the components with whole-group were rated as more useful for understanding and teaching science than the small-group work.

Did participants find this work engaging? Given the culturally odd nature of tasks that require sustained and difficult engagements with obvious things with outcomes that do not lead to increased functioning or competence in daily life, it is remarkable that these adults found such consistent internal value in the work. This constitutes one effect hypothesized at level two of the formal theory of change. These teachers did enjoy and find interesting work prototypical of scientific modeling. It is less clear from the data that they found this work useful professionally. However, in discussions during the final meeting, several teachers indicated they believed the work was potentially very useful. Several asked if this workshop could be brought to their district for all teachers several noted that "their kids would love this", and one asked for follow-up work with her students in her classroom.

RQ3. Expectancy for Success

Data on the teachers' feelings that they were effective science teachers and that their students could understand science was incomplete and inconclusive due to administrative problems. At face value, the measures of some teachers' beliefs in their own ability to teach science dropped over the workshop, which was unexpected but suggestive. It could be that those teachers have been brought to think differently about science and science teaching and are now unsure of their current practice. Changes in outcome expectancy were too small and inconsistent to be suggestive.

However, it is unreasonable to put much weight in attitude changes over brief periods and single interventions. It would be more satisfying to probe these changes regularly over time to chart the effect the methods behind this workshop might have on the long-term, stable attitudes of teachers toward their own teaching of science.

RQ4. Social Validity of the Workshop as Professional Development

The data suggests that these teachers considered this workshop as valid professional development for science teaching in all dimensions except coherence with state and local standards for curriculum and teacher evaluation. They rated it highly for science content and pedagogy, for opportunities to discuss and explore new practices with other teachers, and for opportunities such work might provide for working in this way with other teachers at their grade level at their schools. They also rated it as something they would like to pursue further as professional development. This is an endorsement of the theory behind this model, that bridging everyday cultural tools with targeted features of science culture is an effective way of leading adults to do, understand, and find value in the work of science, and has potential for bringing elementary-school teachers toward the demands brought to them by the Next Generation Science Standards.

Summary

Overall, the study concludes that the components of the workshop model implemented have promise for bridging the lay culture of adults with the culture of actual science work. The theory behind the workshop model seems to have merit. Constructivist engagements with prototypical scientific modeling tasks are good candidates for engaging elementary-school teachers in approaching the physical world in ways that make science work attractive. Specifically, cognitive work approaching scientific modeling can have both intrinsic and utility value to elementary-school teachers. Overall, the study endorses the idea of bringing individual’s native intelligence and cultural tools to bear in situations prototypical of science work.

Recommendations

The four off-target attributions refer to the cultural norms of canonical science, mostly during the improvised revisiting and orientation period.

Implementation and Fidelity

Scaling the study to a larger population would provide more evidence of the effects of the model on a more general population, though there are some methodological aspects to consider in future research, which are noted in this section.

The workshop model needs more time than it was given in this study. There was not enough time to implement the entire model, the teachers were fatigued at the end of their workday, and there was no break time and no social time. Future work with this model needs to adhere to the complete half-day schedule.

Though the facilitator adhered closely to the protocol, he acted differently with different groups, which suggests that there are interactions of the facilitator that are worth studying further. For example, attributions for progress to proximal tasks was spread unevenly between the groups. Timing of interactions was markedly different with one group.

Measures

Pursuing the coding technique for the modeling behaviors and whether the constructs can be validated is a next step for this research. The difficulties with coding the modeling behavior could relate to the differences in expertise with science between the two coders, the need to better train the research assistant to code more effectively, or the possibility that the constructs could conceptualized differently. There seems to be overlap in the behaviors in some of these constructs, especially around epistemology and representation. It would be worthwhile examining this coding process in a small-scale bench-top study.

The STEBI instrument used to measure teachers' beliefs is a commonly used instrument but may be the wrong one for this model. More recently developed questionnaires (van Aalderen-Smeets, Walma van der Molen, van Hest, & Poortman, 2017; van Aalderen-Smeets, Walma van der Molen, & Asma, 2012) target constructs more closely aligned with attitudes toward teaching and attribution of difficulty in teaching. These should be looked at carefully to measure effects on teacher attitudes.

Limitations of the Study

This study did not sample randomly from any population. Participants volunteered based on their interest in pursuing science professional development and started with high science teaching self-efficacy beliefs. The group was all female, racially and ethnically homogeneous, and all from the same geographic location. The results cannot be considered representative of any real population and population inferences were to an ideal population of similar individuals, and at best can be used as rough indications of importance of the sample means as intervention effects.

The phenomenon examined represented a narrow range of the sciences, physics, which allows for simple materials and enactments. Other subject areas may prove more challenging to implement and more difficult for participants to manipulate and observe. Biological systems in particular would pose problems, because processes take longer to unfold. Areas like earth sciences or astronomy would require materials and situations that stood in for the physical phenomenon and would require another level of abstraction.

Significance of the Study

By implementing a workshop faithful to the *Seeing the World Differently* model, the study provides a recommendation that the general ideas behind the model are sound and worth pursing as professional development. In particular, the *Seeing the World Differently* workshop model is consistent with the picture of schooling in the *How People Learn II* report (National Academies of Sciences, Engineering, and Medicine, 2018). The report emphasizes that culture explains differences in what people believe is important to learn, what excellence in learning looks like, how children working with adults should behave, and core features of how people learn. It advises those who teach to actively bridge classroom experiences with the experiences and culture of those students.

Seeing the World Differently as implemented followed all of the heuristics around culture presented in the report. It expressly views students' outside culture as assets, not deficits. Participants freely used the language, representational style, peer relations they wished, and the facilitator did not introduce targeted distal content into their work. By focusing on proximal development using familiar materials and phenomenon, the workshop employed cultural modeling to allow the teachers to explore their competence in prototypical work. Teachers were free to draw upon their funds of knowledge without judgement, and the facilitator did not try to flip their work into canonical science or replace their ways of representing with academic conventions. The facilitator engaged the teachers in genuine and high-level conversations that specifically both referenced their thinking and ways of representing their thinking and discussed some of the imperatives of science culture, opening the “third space” for dialog bridging lay and science culture.

This study attended to and demonstrated that the work in the model has intrinsic task value for the participants, another key recommendation of *How People Learn II*. By doing so, it offers a way of thinking about science work in professional development that may help overcome the historical aversion of elementary-school teachers in particular have for engaging in science related tasks. It is hoped that these tools will facilitate studies of the subjective value of engagement in prototypical science work for learners and teachers, and the dynamics of the transmission of the cultural tools of science. This in turn should aid in the design of professional development workshops and of school science activities that better move teachers and students to understand, value, and do science work.

REFERENCES

Achieve, Inc. (2018). Achieve.org. Retrieved 25 Nov, 2018 from https://www.achieve.org/

Adept (noun). (2016). In *Merriam-Webster.com*. Retrieved 3 Jan 2016, from https://www.merriam-webster.com/dictionary/adept.

Aikenhead, G. (2002, May). *Renegotiating the culture of school science: Scientific literacy for an informed public*. Proceedings from Lisbon's School of Science conference.

Aikenhead, G. S. (2008). Science education: Border crossing into the subculture of science. *Studies in Science Education*, *27*(1), 1-52. doi:10.1080/03057269608560077

American Association for the Advancement of Science. (1990). Science for all Americans online. Retrieved Dec 1, 2018 from http://www.project2061.org/publications/sfaa/online/sfaatoc.htm

American Association for the Advancement of Science. (n.d.). Project 2061. Retrieved 25 Nov, 2018 from https://www.aaas.org/programs/project-2061

American Educational Research Association. (2006). Standards for reporting on empirical social science research in AERA publications. *Educational Researcher*, *35*(6), 33-40.

Angela, C. B. (2002). Urban science education studies: A commitment to equity, social justice and a sense of place. *Studies in Science Education*, *38*, 1. doi:10.1080/03057260208560186

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological review*, *84*(2), 191. doi:10.1037/0033-295X.84.2.191

Bartholomew, H., Osborne, J., & Ratcliffe, M. (2004). Teaching students "ideas-about-science": Five dimensions of effective practice. *Science Education*, *88*(5), 655-682. doi:10.1002/sce.10136

Beilin, H. (1992). Piaget's enduring contribution to developmental psychology. *Developmental psychology*, *28*(2), 191.

Bencze, L., Di Giuseppe, M., Hodson, D., Pedretti, E., Serebrin, L., & Decoito, I. (2003). Paradigmatic road blocks in elementary school science "reform": Reconsidering nature-of-science teaching within a rational-realist milieu. *Systemic Practice And Action Research*, *16*(5), 285-308. doi:10.1023/A:1027350722296

Blank, R. K., & de las Alas, N. (2009). *Effects of teacher professional development on gains in student achievement: How meta-analysis provides evidence useful to education leaders*. Washington, DC: The Council of Chief State School Officers.

Bleicher, R. E. (2004). Revisiting the STEBI-B: Measuring self-efficacy in preservice elementary teachers. *School Science and Mathematics*, *104*(8), 383-391. doi:10.1111/j.1949-8594.2004.tb18004.x

Bodrova, E., & Leong, D. J. (2006). Vygotskian perspectives on teaching and learning early literacy. In D. K. Dickinson & S. B. Neuman (Eds.), *Handbook of Early Literacy Research* (Vol. 2, pp. 243-256). New York, NY: Guilford Press.

Bonawitz, E., Shafto, P., Gweon, H., Chang, I., Katz, S., & Schulz, L. (2009, July). *The double-edged sword of pedagogy: Modeling the effect of pedagogical contexts on preschoolers exploratory play*. Proceedings from 31st Annual Meeting of the Cognitive Science Society, Amsterdam, Netherlands.

Bonawitz, E. B., Ferranti, D., Saxe, R., Gopnik, A., Meltzoff, A. N., Woodward, J., & Schulz, L. E. (2010). Just do it? Investigating the gap between prediction and action in toddlers' causal inferences. *Cognition*, *115*(1), 104 - 117. doi:10.1016/j.cognition.2009.12.001

Bonawitz, E. B., & Lombrozo, T. (2012). Occam's rattle: Children's use of simplicity and probability to constrain inference. *Dev Psychol*, *48*(4), 1156-1164. doi:10.1037/a0026471

Brewer, W. F. (2008). In what sense can the child be considered to be a "little scientist"? In R. A. Duschl & R. E. Grandy (Eds.), *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 38-49). Rotterdam: Sense Publishers.

Brigido, M., Borrachero, A. B., Bermejo, M. L., & Mellado, V. (2013). Prospective primary teachers' self-efficacy and emotions in science teaching. *European Journal of Teacher Education*, *36*(2), 200-217. doi:10.1080/02619768.2012.686993

Broderick, J. T. (2004). Initiating experiences with clay and drawing as dynamic conversations. *Canadian Children*, *29*(2), 7-13.

Broderick, J. T., & Hong, S. B. (2011). Introducing the cycle of inquiry system: A reflective inquiry practice for early childhood teacher development. *Early Childhood Research and Practice*, *13*(2), 1-10.

Bronfenbrenner, U. (1977). Toward an experimental ecology of human development. *American psychologist*, *32*(7), 513. doi:10.1037/0003-066X.32.7.513

Bronfenbrenner, U., & Ceci, S. J. (1994). Nature-nurture reconceptualized in developmental perspective: A biological model. *Psychological Review*, *101*(4), 568-586. doi:10.1037/0033-295X.101.4.568

Bruner, J. (1984). Vygotsky's zone of proximal development: The hidden agenda. In B. Rogoff & J. Wertsch (Eds.), *Children's learning in the "zone of proximal development"* (pp. 93-97). San Francisco, CA: Jossey-Bass. doi:10.1002/cd.23219842309

Bruner, J. (1997). Celebrating divergence: Piaget and Vygotsky. *Human Development*, *40*(2), 63-73. doi:10.1159/000278705

Burt, E. A. (1980). *The metaphysical foundations of modern physical science*. Atlantic Highlands, NJ: Humanities Press.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins and effectiveness*. Colorado Springs, CO: BSCS.

Castle, K. (1997). Constructing knowledge of constructivism. *Journal of Early Childhood Teacher Education*, *18*(1), 55-67. doi:10.1080/10901029708549137

Chaillé, C., & Britain, L. (2002). *The young child as scientist: A constructivist approach to early childhood science education*. Boston, MA: Allyn and Bacon.

Chalufour, I., & Worth, K. (2006). *Building structures with young children: Trainer's guide*. St. Paul, MN: Redleaf Press.

Costa, V. B. (1995). When science is "another world": Relationships between worlds of family, friends, school, and science. *Science Education*, *79*(3), 313-333. doi:10.1002/sce.3730790306

Csibra, G., & Gergely, G. (2011). Natural pedagogy as evolutionary adaptation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1567), 1149-1157. doi:10.1098/rstb.2010.0319

Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences*, *13*(4), 148-153. doi:10.1016/j.tics.2009.01.005

DeVries, R., Zan, B., Hildebrandt, C., Edmiaston, R., & Sales, C. (2002). *Developing constructivist early childhood curriculum: Practical principles and activities*. New York: Teachers College Press.

Driver, R. (1983). *Pupil as scientist*. Bristol, England: Open University Press.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Bristol, England: Open University Press.

Duckworth, E. (1964). Piaget rediscovered. *Journal of Research in Science Teaching*, *2*(3), 172-175. doi:10.1002/tea.3660020305

Duckworth, E. (1991). Twenty-four, forty-two, and I love you: Keeping it complex. *Harvard Educational Review*, *61*(1), 1-24. doi:10.17763/haer.61.1.c66250342483j56l

Duckworth, E. R. (2006). *"The having of wonderful ideas" and other essays on teaching and learning`*. New York: Teachers College Press.

Eccles, J. (1983a). Expectancies values and academic behaviors. In J. T. Spence (Ed.), *Achievement and Achievement Motives* (pp. 75-146). San Francisco, CA: W. H. Freeman.

Eccles, J. (1983b). Female achievement patterns: Attributions, expectancies, values, and choice. *Journal of Social Issues*, *1*, 1-22.

Eccles, J., Barber, B. L., Updegraff, K., & O'Brien, K. M. (1998, Jan). *An expectancy-value model of achievement choices: The role of ability self-concepts, perceived task utility and interest in predicting activity choice and course enrollment*. Proceedings from The Seeon Conference on Interest and Gender.

Eccles, J. S. (2007). Where are all the women? Gender differences in participation in physical science and engineering. In W. M. Williams (Ed.), *Why aren't more women in science: Top researchers debate the evidence* (pp. 199-210). Washington, DC: American Psychological Association. doi:10.1037/11546-016

Engel, S. (2011). Children's need to know: Curiosity in schools. *Harvard Educational Review*, *81*(4), 625-645. doi:10.17763/haer.81.4.h054131316473115

Enochs, L. G., & Riggs, I. M. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice elementary scale. *School Science and Mathematics*, *90*(8). doi:10.1111/j.1949-8594.1990.tb12048.x

Feynman, R. P. (2000). *The pleasure of finding things out: The best short works of Richard P. Feynman*. Cambridge, MA: Perseus Publishing.

Forman, G. E. (2010). When 2-year-olds and 3-year-olds think like scientists. *Early Childhood Research & Practice*, *12*(2), 1-5.

Forman, G. E., & Hall, E. (2005). Wondering with children: The importance of observation in early education. *Early Childhood Research and Practice*, *7*(2), 1-11.

Fosnot, C. T. (1996). Constructivism: A psychological theory of learning. In C. T. Fosnot (Ed.), *Constructivism: Theory, perspectives, and practice* (pp. 8-33). New York: Teachers College Press.

Foucault, M. (1972). *The archeology of knowledge and the discourse on knowledge* (S. Smith, Trans.). New York: Pantheon Books.

Galilei, G. (1957). Letter to Madame Christina of Lorraine, Grand Duchess of Tuscany, concerning the use of biblical quotations in matters of science (S. Drake, Trans.). In *Discoveries and Opinions of Galileo* (pp. 173-216). Garden City, NY: Doubleday Anchor.

Gardner, D. P. (1983). *A nation at risk: The imperative for educational reform*. Washington, DC: US Government Printing Office.

Giere, R. N. (1990). *Explaining science: A cognitive approach*. Chicago: University of Chicago Press.

Good, C. J. (2010). A nation at risk: Committee members speak their mind. *American Educational History Journal*, *37*(1/2), 367.

Gopnik, A. (2012). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. *Science*, *337*(6102), 1623-1627. doi:10.1126/science.1223416

Gopnik, A., & Schulz, L. E. (2004). Mechanisms of theory formation in young children. *Trends in Cognitive Sciences*, *8*(8), 371-377. doi:10.1016/j.tics.2004.06.005

Gopnik, A., & Wellman, H. M. (2012). Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. *Psychological Bulletin*, *138*(6), 1085-1108. doi:10.1037/a0028044

Heath, S. B. (1982). What no bedtime story means: Narrative skills at home and school. *Language in Society*, *11*(1), 49-76. doi:10.1017/S0047404500009039

Hestenes, D. (1992). Modeling games in the Newtonian world. *American Journal of Physics*, *60*(8), 732-748. doi:10.1119/1.17080

Hoover, T. (2016). Teaching discrepant events with the 5E instructional model. *Science Scope*, *40*(1), 14.

Ingold, T. (2004). A circumpolar night's dream. In J. R. Clammer, S. Poirier, & E. Schwimmer (Eds.), *Figured worlds: Ontological obstacles in intercultural relations* (pp. 25-57). Toronto: University of Toronto Press.

Jones, E., & Nimmo, J. (1999). Collaboration, conflict, and change: Thoughts on education as provocation. *Young Children*, *54*(1), 5-10.

Kazempour, M. (2014). I can't teach science! A case study of an elementary pre-service teacher's intersection of science experiences, beliefs, attitude, and self-efficacy. *International Journal of Environmental and Science Education*, *9*(1), 77-96.

Kind, P., & Osborne, J. (2017). Styles of scientific reasoning: A cultural rationale for science education. *Science Education*, *101*(1), 8-31. doi:10.1002/sce.21251

Kroll, L. R. (2013). Early childhood teacher preparation: Essential aspects for the achievement of social justice. *Journal of Early Childhood Teacher Education*, *34*(1), 63-72. doi:10.1080/10901027.2013.758538

Kuhn, T. (1962). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

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

Lay (adjective) [Def. 3]. (2016). In *Merriam-Webster.com*. Retrieved 3 Jan 2016, from https://www.merriam-webster.com/dictionary/lay.

Lee, O. (2002). Promoting scientific inquiry with elementary students from diverse cultures and languages. *Review of Research in Education*, *26*(1), 23-69. doi:10.3102/0091732X026001023

Lehrer, R., & Schauble, L. (2010). What kind of explanation is a model? In M. K. Stein & L. Kucan (Eds.), *Instructional explanations in the disciplines* (pp. 9-22). Peabody College, Vanderbilt University: Springer US. doi:10.1007/978-1-4419-0594-9

Lehrer, R., Schauble, L., & Lucas, D. (2008). Supporting development of the epistemology of inquiry. *Cognitive Development*, *23*(4), 512-529. doi:10.1016/j.cogdev.2008.09.001

Longfield, J. (2009). Discrepant teaching events: Using an inquiry stance to address students' misconceptions. *International Journal of Teaching and Learning in Higher Education*, *21*(2), 266.

Lucas, D., Broderick, N., Lehrer, R., & Bohanan, R. (2005). Making the grounds of scientific inquiry visible in the classroom. *Science Scope*, *29*(3), 39-42.

Lumpe, A., Czerniak, C., Haney, J., & Beltyukova, S. (2012). Beliefs about teaching science: The relationship between elementary teachers' participation in professional development and student achievement. *International Journal of Science Education*, *34*(2), 153-166. doi:10.1080/09500693.2010.551222

Lustick, D. (2009). The failure of inquiry: Preparing science teachers with an authentic investigation. *Journal of Science Teacher Education*, *20*, 583-604. doi:10.1007/s10972-009-9149-4

MacWhinney, B. (2000). *The CHILDES project: Tools for analyzing talk* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Maier, A. (1982). The achievements of late scholastic natural philosophy. In S. D. Sargent (Ed.), *On the threshold of exact science. Selected writings of Anneliese Maier on late Medieval natural philosophy* (pp. 143-170). Philadelphia: University of Pennsylvania Press.

Matthews, M. R. (1993). Constructivism and science education: Some epistemological problems. *Journal of Science Education and Technology*, *2*(1), 359-370. doi:10.1007/BF00694598

Matthews, M. R. (2000). Appraising constructivism in science and mathematics education. In D. C. Phillips (Ed.), *Constructivism in education: Opinions and second opinions on controversial issues* (pp. 161-192). Chicago, IL: National Society for the Study of Education.

Medawar, P. B. (1984). Induction and intuition in scientific thought. In *Pluto's Republic: Incorporating the art of the soluble and induction and intuition in scientific thought* (pp. 73-114). Oxford: Oxford University Press.

Merriam Webster. (n.d.). Merriam-Webster.com. Retrieved 3 Jan 2016, from https://www.merriam-webster.com

Munck, M. (2007). Science pedagogy, teacher attitudes, and student success. *Journal of Elementary Science Education*, *19*(2), 13-24. doi:10.1007/BF03173660

National Academies of Sciences, Engineering, and Medicine. (2018). *How people learn II. Learners, contexts, and cultures*. Washington, DC: National Academies Press.

National Association for the Education of Young Children (NAEYC). (2009). *Developmentally appropriate practice in early childhood programs serving children from birth through age 8 [Position statement]*. New York, NY: National Association for the Education of Young Children.

National Governors Association Center for Best Practices, & Council of Chief State School Officers. (2010a). *Common Core State Standards for English language arts & literacy in history, social studies, science, and technical subjects*. Washington, DC: Authors.

National Governors Association Center for Best Practices, & Council of Chief State School Officers. (2010b). *Common Core State Standards for mathematics*. Washington, DC: Authors.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2004). *How people learn: Brain, mind, experience, and school* (Expanded ed.). Washington, DC: National Academies Press.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades k-8*. Washington, DC: National Academy Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

National Science Teachers Association. (2014). *NSTA position statement: Early childhood science education*. Washington, DC: NSTA.

Nersessian, N. J. (2002). Abstraction via generic modeling in concept formation in science. *Mind & Society*, *3*(1), 129-154. doi:10.1007/BF02511871

Nersessian, N. J. (2005). Interpreting scientific and engineering practices: Integrating the cognitive, social, and cultural dimensions [In press]. In M. Gorman, R. Tweney, D. Gooding, & A. Kincannon (Eds.), *New directions in scientific and technical thinking* (pp. 17-56). Mahwah, NJ: Lawrence Erlbaum Associates.

Nersessian, N. J. (2008). *Creating scientific concepts*. Cambridge, MA: MIT Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: The National Academic Press.

O'Brien, T. (2010). *Brain-powered science: Teaching and learning with discrepant events* (1st ed.). Arlington, VA: National Science Teachers Association.

Olson, D. R. (1994). *The world on paper: The conceptual and cognitive implications of writing and reading*. New York: Cambridge University Press.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003a). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, *40*(7), 692-720. doi:10.1002/tea.10105

Osborne, J., Simon, S., & Collins, S. (2003b). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049-1079. doi:10.1080/0950069032000032199

Penrose, R. (2005). *The road to reality: A complete guide to the physical universe* (First American ed.). New York: Alfred A. Knopf.

Phelan, P., Davidson, A. L., & Cao, H. T. (1991). Students' multiple worlds: Negotiating the boundaries of family, peer, and school cultures. *Anthropology and Education Quarterly*, *22*, 224-250. doi:10.1525/aeq.1991.22.3.05x1051k

Piaget, J. (1963). *The origins of intelligence in children* (M. Cook, Trans. 2nd ed.). New York, NY: W. W. Norton & Company.

Pianta, R. C., & Hamre, B. K. (2009). Classroom processes and positive youth development: Conceptualizing, measuring, and improving the capacity of interactions between teachers and students. *New Directions for Youth Development*, *121*, 33-46. doi:10.1002/yd.295

R Core Team. (2013). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Reify. (2018). In *Merriam-Webster.com*. Retrieved 2 Dec 2018, from https://www.merriam-webster.com/dictionary/reify.

Riggs, I. M., & Enochs, L. G. (1989, March). *Toward the development of an elementary teacher's science teaching efficacy belief instrument*. Proceedings from National Association for Research in Science Teaching, San Francisco, CA.

Rimm-Kaufman, S. E., & Pianta, R. C. (2000). An ecological perspective on the transition to kindergarten. *Journal of Applied Developmental Psychology*, *21*(5), 491-511. doi:10.1016/s0193-3973(00)00051-4

Rogoff, B. (2003). *The cultural nature of human development*. Oxford: Oxford University Press.

Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *Journal of the Learning Sciences*, *12*(1). doi:10.1207/S15327809JLS1201

Schneps, M. H., Sadler, P. M., Woll, S., & Crouse, L. (1989). *A private universe*. Burlington, VT: Annenberg Media.

Schulz, L. E., & Bonawitz, E. B. (2007). Serious fun: Preschoolers engage in more exploratory play when evidence is confounded. *Developmental Psychology*, *43*(4), 1045-1050. doi:10.1037/0012-1649.43.4.1045

Schulz, L. E., Goodman, N. D., Tenenbaum, J. B., & Jenkins, A. C. (2008). Going beyond the evidence: Abstract laws and preschoolers' responses to anomalous data. *Cognition*, *109*(2), 211-223. doi:10.1016/j.cognition.2008.07.017

Shonkoff, J. P., & Phillips, D. A. (2000). *From neurons to neighborhoods: The science of early childhood development*. Washington, DC: National Academies Press.

Solomon, J. (1992a). *Getting to know about energy—in school and society*. Washington, DC: Falmer Press.

Solomon, J. (1992b). Learning as an extension of general knowledge. In J. Solomon (Ed.), *Getting to know about energy—in school and society*. Washington, DC: Falmer Press.

Solomon, J. (2000). The changing perspectives of constructivism. Science wars and children's creativity. In D. C. Phillips (Ed.), *Constructivism in education: Opinions and second opinions on controversial issues* (pp. 283-307). Chicago, IL: National Society for the Study of Education.

Suppe, F. (1977). Exemplars, theories, and disciplinary matrixes. In F. Suppe (Ed.), *The structure of scientific theories* (pp. 483-499). Urbana: University of Illinois Press.

Taber, K. S. (2006). Beyond constructivism: The progressive research programme into learning science. *Studies in Science Education*, *42*, 125-184. doi:10.1080/03057260608560222

Taber, K. S. (2008). Conceptual resources for learning science: Issues of transience and grain-size in cognition and cognitive structure. *International Journal of Science Education*, *30*(8), 1027-1053. doi:10.1080/09500690701485082

Thomson, M. M., & Kaufmann, E. (2013). Elementary teachers views of their science professional development attendance: An expectancy-value approach. *Eurasia Journal of Mathematics, Science & Technology Education*, *9*(1), 45-58. doi:10.12973/eurasia.2013.915a

Tinker, B. (1997). *Thinking about science*. Concord, MA: The Concord Consortium Educational Technology Lab.

Toulmin, S. E. (2003). *The uses of argument* (Updated ed., repr. ed.). Cambridge: Cambridge University Press.

van Aalderen-Smeets, S., & Walma van der Molen, J. H. (2015). Improving primary teachers' attitudes toward science by attitude-focused professional development. *Journal Of Research In Science Teaching*, *52*(5), 710-734. doi:10.1002/tea.21218

van Aalderen-Smeets, S., Walma van der Molen, J. H., & Asma, L. J. F. (2012). Primary teachers' attitudes toward science. A new theoretical framework. *Science Education*, *96*(1), 158-182. doi:10.1002/sce.20467

van Aalderen-Smeets, S., Walma van der Molen, J. H., van Hest, E. G. W. C. M., & Poortman, C. (2017). Primary teachers conducting inquiry projects: Effects on attitudes towards teaching science and conducting inquiry. *International Journal of Science Education*, *39*(2), 238 - 256. doi:10.1080/09500693.2016.1277280

van Eijck, M., & Roth, W.-M. (2010). Theorizing scientific literacy in the wild. *Educational Research Review*, *5*(2), 184-194. doi:10.1016/j.edurev.2010.03.002

Vygotsky, L., & Luria, A. (1994). Tool and symbol in child development. In R. van der Veer & J. Valsineer (Eds.), *The Vygotsky reader* (pp. 99-174). Oxford: Blackwell.

Vygotsky, L. S. (1962). *Thought and language* (E. Hanfmann & G. Vakar, Trans.). Cambridge: MIT Press.

Vygotsky, L. S. (1979). The genesis of higher mental functions (J. V. Wertsch, Trans.). In J. V. Wertsch (Ed.), *The concept of activity in Soviet psychology* (pp. 144-188). Armonk, NY: M E Sharpe, Inc.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *17*(2), 89-100. doi:10.1111/j.1469-7610.1976.tb00381.x

Young, B. J., & Kellogg, T. (1993). Science attitudes and preparation of preservice elementary teachers. *Science Education*, *77*(3), 279-291.

Zan, B., & Geiken, R. (2010). Ramps and pathways: Developmentally appropriate, intellectually rigorous, and fun physical science. *Young Children*, *65*(1), 12-17.

APPENDICES

Appendix A: Coded Transcript of the Initial Meeting

Table 22

Coded Transcript of Initial Meeting

Time	Abridged transcript	Themes	
		Content	Process
0:00	This is part of my dissertation study… Got kind of a script… Anyone not completed the survey… Informed consent… IDs		
1:00	Let's get started… first thing… look at the handout. Called "Seeing the world differently"… something I made up… used in high school, kindergarten… adult teachers. Folks liked it, so I want to know [about it]. Have to collect data… video recording… the way you think about science before… survey… Happy to follow up… relationships with teachers…		
2:50	[Refers to handout.] Purpose… help elementary teachers bring science thinking into the classroom… Works toward a number of goals… next generation science standards… English language arts… math. Involve modeling… [standards] want teachers to get children to model, to change their view of the world because they model, then to argue about their ideas… I think this approach helps get all those done… and get science thinking into the class	CAligns, CSciencey	
3:40	My focus is on modeling…. I use physics. you can do physics with anything… no fancy stuff	CAligns	
4:00	This kind of work looks at everyday phenomenon, stuff that you've seen but probably haven't thought about… Part of the idea is physics is not a natural way to think… very strange… Getting people to do it is a bit of a trial	CNewLook, CSciencey	
4:30	[Holding bath towel.] Anybody ever fold a towel like this? How many have asked … why does that work… everyday phenomenon, by why does it work… what am I doing. Those are science questions… not fancy, but hard	CNewLook, CSciencey CDescExpl	
4:58	[That's] the kind of thing we could explore… anything that happens in day-to-day life is fit for this method.	CAligns	
5:10	[Picks up clipboard.] Get back to my script… Looking at physical phenomenon from daily life… What I want to generate is thinking not sciencey answers… Look at your page [refers to handout] it says it right there, thinking not sciencey answers…circle that…	CSciencey	
5:34	Next one [looks at handout] … making thinking visible… that means represent your thinking. What I ask folks to do is to represent what you see. … [towel] example… how would you describe what just happened so someone else could see what you think. Very hard… part of the exercise… very hard work to describe what just happened… and then to explain how it worked. I want people to represent their own minds when they look at simple things… this is how science works	CDialRep, CSciencey, Copen CDescExpl	PRepr, PEnact

6:24	Last little blurb there [holds handout] … this lets you build what? “Sciencey” ways of looking at the world… This is what I want to bring into the classes… what those standards look for.	CSciencey, CAligns	
6:45	You do this by using conversations about representations… circle that part there… conversations about representations… No one is going to tell you what momentum is in this workshop. We’re going to talk about what you see and what you think.	CDialRep, COpen	PDialRep
7:00	[Folds handout to show schedule.] That’s where we’re going to go, and here’s how we’re going to get there. I want you to scribble on this a bit… We’re rushed… 4 ½ workshop broken into two 1 ½ hr days. We are here… what’s it say… develop themes… Give a little presentation… going to develop themes… the reading I asked you to do is part of that		
8:00	Once we’ve finished that, these three little blobs… everybody partner up… little groups visit a very simple phenomenon… getting ketchup to the top of a bottle. So…why does it do that… why does it work… anybody know? [T: no response] … we’ll find out. [T: laugh]	CAligns	PPeers, , PProvoc, PEnact
8:25	That’s an example of what scientists do that other people don’t… think about really stupid things.	CNewLook, CSciencey	
8:30	Another is… we’re going to turn a little [toy] around in a circle and let it go… Try to figure out what did it do and why did it do that. Third one is to simulate a redneck with a pickup truck and a bowling ball up near the cab… What happens to bowling ball when [accelerates]? You’re going to try to figure that out… Describe what it did and try to explain why did it do that. Very hard… it’s about thinking not about knowing.	Copen CDescExpl	PProvoc, PEnact, PRepr
9:00	That’s what these three circles [in handout] are… Going to use centers, stations… Get a group, go to a station, do what it says to do, times up, move to another station. Need good transitions.		PProvoc, PPeer
9:30	[Points to handout.] Find the grey bar, draw a big line through it… That’s the end of today… our first half. Second half… have a big conversation about what you did… what’s working and what isn’t. The last blurb [in handout]… You get to try one last time to give your best description… How do you want the rest of the world to know how you thought about this…. Then wrap it up with a meeting at the end. … a lot of thinking and scribbling.	CDialRep, COpen	PPeer, PRevisit, PDialRepr
10:15	any questions about that part?		
10:20	[refers to script] … check if I’m on target… OK.		
10:25	So, let’s develop some themes. What about [pre-workshop reading]? What was it called? T1: The. Having of. Wonderful Ideas. The Virtue of not Knowing Yeah… it’s a weird title… say it again. A book written by Elanor Duckworth… excellent… but hold off a bit… we’ll get to that in here.		
11:00	[screen image: flipbook cover on screen]	COpen, CAligns, CDialRep	PRepr

	So this is what you're going to build… Build a little booklet with your sketches and words in it… big as you want. Little kids can do this too… In each of those sessions… you will build a book about your thinking.	
11:30	[slide image: mg and young children looking intently at a bowling ball] So, here's me… doing something… what do you see T1: looks like you're trying to blow the ball across the floor Blow the ball across the floor. yeah. how dumb is that? T2: kids are really into it. Isn't that something… this gal thinks I'm nuts, she's like "whoa", he's just enjoying it, he can't hold himself together… kindergartener… youngest. … summer camp at Little Bucs on campus at ETSU. I called it "arguing with a bowling ball"	CAligns, CNewLook
12:45	So, how do you get physics into the head of little kids… you don't. You give them experiences that they can wonder about and try to understand. Learn through our bodies… learn physics through our bodies. I wanted to get them to say "how do I get this bowling ball to move?"… so I was yelling at it "move." I'm losing this argument… it's winning, I'm losing. Introducing the idea of force and inertia… in a comical way.	CSciencey, CAligns
13:25	[slide image: same setup, girl trying to lift bowling ball] This gal had a theory. The broom makes it move because it is heavier than the bowling ball… her picture of the world. What do I do when she says that? T: let her lift it up So I said, let's try it… she said oh my god, it's really heavy. This is the way people build physics experience and science experience. Through actually engaging the physical world. We had a great time.	CAligns, CScience
14:05	[Slide image: what about the "virtue of not knowing"] Let's talk about that two page [reading]. Anybody have a thought on what she meant? T1: my first thought… we talk about children having personal connection … when they are first exposed… maybe good thing if they don't have that connection… can form their own ideas… if that makes sense It does. Does that makes sense to you guys… what does she mean… T2: like with the bowling ball… no idea what it is until they do it Yes… no idea, no idea. If you've ever heard of Piaget, he says children equate heft with size… she just realized that's not always true	
15:45	You want them to have physical experiences. One reason I'm at this age, not at high school where I started… when they get there, their physical experience has been misunderstood for ten years. I have to unwind that, or to forget it and teach them to use equations and give me definitions… fairly useless knowledge. I want to go back to where people are starting to build their physical experience with the world and see how we can organize that.	CAligns
16:15	[slide image: quote from reading] Here's what Eleanor said: "in most classrooms it's a quick right answer that's appreciated". … Do you agree with her… think about all the school you've gone through… as soon as somebody knows something they get kudos… [reads] "Knowledge of the answer ahead of time is more valued than figuring it out"	
16:35	What happened in science 300 years ago, people came up with a method for figuring things out. that's what the standards want you to teach.	CSciencey, CAligns
16:45	[reads] "Knowing caries no risks, no decisions. You either know it or you don't"	

	… no thinking… remember that thing I had you circle?	
17:05	[reads] “What’s involved when you don’t know something.” Any impressions [from the reading]? T: They have to think differently… to apply all the different… ways to think Which kids are actually pretty good at.	COpen
17:45	[slide image: text] Elanor Duckworth got poetic… What do feel like when someone asks you a question you don’t know? T: Awkward Can you give the definition of the “sine” of an angle [from trig] T: Give the definition of the sine of an angle? Yeah… you probably saw it… think I should know it… don’t ask me, ask her. One thing that asks after years of school. Timid… withdrawn. Little kids aren’t there yet.	
18:35	[slide image: text] [Reads] “They feel surprise, struggle, puzzlement, excitement” Look at these wonderful words. “dawning certainty”. These are wonderful human feelings. One thing that drives scientists to do the stupid stuff they do. [Reads] “these virtues stand by themselves even if you don’t get the right answer”.	CNewLook, COpen
19:00	In the reading… story about a kid who thought that a pendulum went fastest at the ends… the bright one… all the rest of the kids didn’t want to say anything. Remember? how did the teacher in this classroom handle this kid being wrong? T: it’s the end of the day… She got a little TV and had a movie of a pendulum… leak in bag… piled up sand… pile got bigger on the ends. Smart boy kept saying… then other kids slowly began saying… no… then it wouldn’t be doing this… What did the teacher do? Let them argue it out until everyone finally agrees… When that happens, the kids in the class get to feel these things.	CAligns, COpen
20:14	This is what the new standards are asking us to put in front of kids. This kind of thinking [workshop] is one way…	CAligns
20:25	[slide image: mg and two students making measurements on a floor] A quick run-through of what physics looks like. … [Problem was] what actually happens when you roll two bowling balls into each other? Well, you know what happens, they bounce and roll away… not good enough if you’re a physics guy. We had to come up with a way of keeping track of where every ball…	CNewLook
20:50	[slide image: apparatus made of yard sticks taped together] Another example. Problem: can we measure the weight of something by throwing it? … This fellow created a gizmo… came up with a way of finding the mass of something by seeing how high it got.	
21:35	This is the kind of thinking we can do with little kids… if we find the right way to do it.	CAligns, CSciencey
21:40	[slide image: toy with tape on it] How does this work. That was my question. … “roly-poly toy” … kid says he thinks he knows… let me take it apart and I’ll show you. wouldn’t let him… hamstrung… what did he do instead… if I make something like I say and it acts [like the roly-poly] is that good evidence? I say.. that’s brilliant. He took this ball… that ball… a weight… he hit it and it rolled right back up.	

22:15	That's what physicists do… and I think we can get kids up and down [the grades]…	CSciencey, CAligns	
22:25	[slide image: machine with tape on it] This thing comes from a noble prize winner's lab… coldest refrigerator in the world… duct-taped a piece of wood and pipe to the back of it to make it work. They don't care about pretty… they care about thinking and getting it right.		
22:40	[slide image: text] So this is your task when we get going… describe what you see and explain why it works… The ketchup: what do you see and why does it work?	CDescExpl	PRepr
22:50	[slide image: repeat of arguing with bowling ball slide] Must skip this activity: Fun to try to make a bowling ball go in a circle, and you will see what a big argument you get into [with the bowling ball]… You do that and try to figure out how it works… it's good fun		
23:20	[slide images: hallway with kids sitting on floor with tape measure, etc] Little Bucs again… trying to figure out if something rolls differently if you throw it or push it with a broom. Had this group of kids make this machine… tape measure… mark floor… timer… Olivia with broom… one kid bragging about his timer… emotions run high.	CAligns	
24:00	[slide image: drawings of hallway juxtaposed with photo of hallway] These are representations of a hallway… Tyler sat here… drew a picture of what was happening… tried to show perspective. T: How it's narrowing down… Yeah… He was so proud… "If you want to know how to make a hallway, I can tell you…" Olivia did the same thing. Misspellings… who cares. This is a literacy exercise… Draw a picture and label the important parts… huge mental work… they came up with names…	CAligns, COpen, CDialRep	
25:00	These are what I'm asking you guys to do. Draw what you see… tell me what's the important parts.	CDialRep	PRepr
25:10	[slide image: a third drawing overlaid] Haley… she didn't draw it that way… which is the better drawing? T: They're just different perspectives They capture different things. They are really quite brilliant… this one you can see the sequence better… didn't follow her rule… more abstract thinking… not drawing what you see, but what you know… there's a difference.	CAligns, CDialRep	
25:45	We can do this with little kids… kindergarten, even pre-K… They can draw, tell you what things are, you can put down the word or put down blanks they fill in… a pre-literacy exercise.	CAligns, CDialRep	
26:00	[slide image: photo of kids at table playing with and drawing ketchup bottles. Title is "provocation"] Here I asked those kids to do the ketchup bottle thing… they loved drawing ketchup bottles… 20 minutes… didn't figure out what was going on… interested in making a pretty ketchup bottle… not what physicist wants… wants the duct-tape on the machine.	CAligns, CDialRep, CNewLook	

26:23	[slide image: return to first slide. Photo of a flipbook cover] About to the end of the themes… About to launch into actually doing something… What you're going to do is create a flipbook at a station to see if you can describe what you see. The trick is… seeing is different from knowing… when I did the thing with the bowling ball… grown people drew a picture and they got it completely wrong. They put me moving the bowling ball like this… but you actually have to have the broom on the outside. If you think you know the answer and you draw that, chances are you're not really understanding the real world. Ever try drawing an eyeball… almost always look the same from person to person… because no one actually looks at the eyeball… it doesn't look like what you think. You can think you know something… you have to knock that out of your head and start looking and draw what you see. That's where we are going next.	CDialRep	PRepr, PProcov
27:50	[slide image: text] Your job is to see what's in front of you. See it, not know it, then capture what you see and think as best you can. There is no right… I want to know what's in your head… If it's in your head, it's right. … interested in thinking.	CDialRep, COpen	PRepr
28:10	We're going to move through these centers. Every center has a provocation and a setup. [Holds sheet an ketchup bottle.] There's a little sheet that tells you what to do… and here's the real world [Holds up ketchup bottle]. Just do it and try to draw it.	CDialRep	PProvoc, PEnact, PRepr
28:32	[holding flipbook pages.] Before we launch into building these books… here are the pieces.		PRepr
28:40	[Assistant puts instructions and enacting materials on teachers tables]		
28:45	[Hands out participant journals] What I am interested is what you think about what you are doing. Everybody gets a journal… ID number… Pop it open… should see form.. every one of the components of the workshop has a form… what do you see… next page… must take a minute and react. … scribble down what you think… I want to know how you value different parts of the workshop… be honest and give it a little thought when you put your reactions down… at the end, a large survey on the whole experience.		
30:35	[picks blank flipbook pages.] These are what makes up a flipbook		PRepr
31:00	Break up into groups, 2, 2 and 3. Choose your partner… come up with a name for your group… put it on your thing… put a roster in ID numbers [teachers move among tables, choosing their groups.]		PPeer
31:40	When you go from station to station, bring your group thing with you… you'll need a cover…		PProvoc
32:15	Here's where the thinking starts. There are two kinds of pages… one for drawing and a caption. Don't fuss over who's the best artist… not about drawing a pretty ketchup bottle… capturing what you see. If you don't like the way you drew it… think it's not right, fine. Don't throw it away. That's thinking. We want to see thinking evolve. Get a new sheet and put it on top. If… a little writing you want to do, there's a sheet just for text. …text sheets, sketch sheets, layered together… then we'll talk about them… come get as many as you want.	CDialRep, COpen	PRepr, PRevisit, PDialRepr
33:10	About to yell go… everyone know what they're doing?		
33:20	Alright… go		

-end of initial meeting-

Appendix B: Provocations for Representational Tasks

The focus of day 1 will be teachers observing and representing their own descriptions and explanations of the how and why of movement in very simple situations.

There is no right way to think about these provocations.

KETCHUP

The question here is

> *How do you get all the ketchup to go from the bottom to the top of the bottle and why does this work?*

This is about OBSERVING and REPRESENTING.

What to do

Make or extend a flipbook for this situation. Start numbering with page 1.

A. Make a new flipbook **Cover page** for this phenomenon.

B. LOOK CAREFULLY at what you do to get the ketchup all to the top of the bottle. Look very carefully at what happens and why it works.

C. Take a flipbook **Sketch Page**. Title it “First viewing” or something like that. In the sketch box, represent what you saw. Explain it on the lines to the left. Do the best you can. If you need more lines, add a **Text Page**.

D. Now, REVISIT the situation. Look again at what happens when you get the ketchup from the bottom of the bottle to the top. Then, REVISIT your drawing. If you see something you’d like to change or add, TAKE A NEW sketch page and redraw it and explain. Retitle it.

E. Continue this until you are satisfied with your drawing. USE AS MANY pages as you want.

Number the pages in order and add them to the flipbook.

The focus of day 1 will be teachers observing and representing their own descriptions and explanations of the how and why of movement in very simple situations.

There is no right way to think about these provocations.

BALL

The question here is

> *Why does a bowling ball move the way it does when it is loose in the bed of a pickup truck while it's starting or stopping?*

This is about OBSERVING and REPRESENTING.

What to do.

Make or extend a flipbook for this situation. Start numbering with page 1.

A. Make a new flipbook **Cover page** for this phenomenon.

B. Take a box and a ball. PRETEND the box is the bed of a pickup truck and the ball is a bowling ball. Put the bowling ball inside the bed at the front. IMAGINE what will happen if the driver stomped down on the accelerator. Now, accelerate the truck forward quickly. LOOK CAREFULLY at what the ball does when the truck takes off. Look very carefully at what happens and why it works.

C. Take a flipbook **Sketch Page**. Title it "First viewing" or something like that. In the sketch box, represent what you saw. Explain it on the lines to the left. Do the best you can. If you need more lines, add a **Text Page**.

D. Now, REVISIT the situation. Look again at what happens when you accelerate the truck with the ball at the front of the truck bed. Then, REVISIT your drawing. If you see something you'd like to change or add, TAKE A NEW sketch page and redraw it and explain. Retitle it.

E. Continue this until you are satisfied with your drawing. USE AS MANY pages as you want.

Number the pages in order and add them to the flipbook.

The focus of day 1 will be teachers observing and representing their own descriptions and explanations of the how and why of movement in very simple situations.

There is no right way to think about these provocations.

BEAR

The question here is

> *If you swing a toy bear in a circle and let go, why does it do what it does?*

This is about OBSERVING and REPRESENTING.

What to do

Make or extend a flipbook for this situation. Start numbering with page 1.

A. Make a new flipbook **Cover page** for this phenomenon.

B. Swing the bear in a circle. IMAGINE what would happen if you let go of the string. Now, let go of the string. LOOK CAREFULLY at what the bear does when you let go of the string. Look very carefully at what happens and why it works.

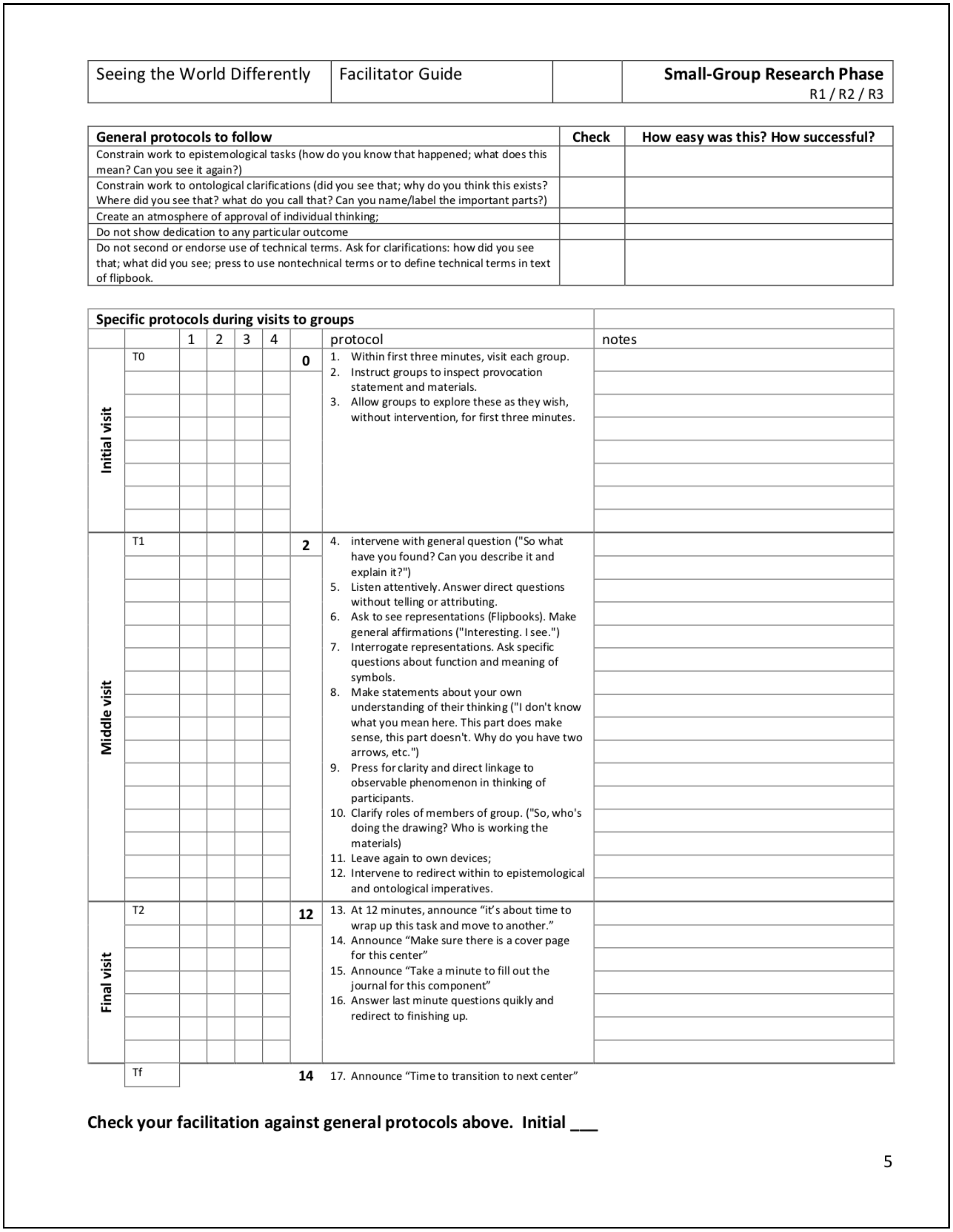
C. Take a flipbook **Sketch Page**. Title it “First viewing” or something like that. In the sketch box, represent what you saw. Explain it on the lines to the left. Do the best you can. If you need more lines, add a **Text Page**.

D. Now, REVISIT the situation. Look again at what happens when swing the bear in a circle and then let go of the string. Then, REVISIT your drawing. If you see something you’d like to change or add, TAKE A NEW sketch page and redraw it and explain. Retitle it.

E. Continue this until you are satisfied with your drawing. USE AS MANY pages as you want.

Number the pages in order and add them to the flipbook.

Appendix C: Research-Phase Facilitation Checklist



Seeing the World Differently	Facilitator Guide		**Small-Group Research Phase** R1 / R2 / R3

General protocols to follow	**Check**	**How easy was this? How successful?**
Constrain work to epistemological tasks (how do you know that happened; what does this mean? Can you see it again?)		
Constrain work to ontological clarifications (did you see that; why do you think this exists? Where did you see that? what do you call that? Can you name/label the important parts?)		
Create an atmosphere of approval of individual thinking;		
Do not show dedication to any particular outcome		
Do not second or endorse use of technical terms. Ask for clarifications: how did you see that; what did you see; press to use nontechnical terms or to define technical terms in text of flipbook.		

Specific protocols during visits to groups								
		1	2	3	4		protocol	notes
Initial visit	T0					**0**	1. Within first three minutes, visit each group. 2. Instruct groups to inspect provocation statement and materials. 3. Allow groups to explore these as they wish, without intervention, for first three minutes.	
Middle visit	T1					**2**	4. intervene with general question ("So what have you found? Can you describe it and explain it?") 5. Listen attentively. Answer direct questions without telling or attributing. 6. Ask to see representations (Flipbooks). Make general affirmations ("Interesting. I see.") 7. Interrogate representations. Ask specific questions about function and meaning of symbols. 8. Make statements about your own understanding of their thinking ("I don't know what you mean here. This part does make sense, this part doesn't. Why do you have two arrows, etc.") 9. Press for clarity and direct linkage to observable phenomenon in thinking of participants. 10. Clarify roles of members of group. ("So, who's doing the drawing? Who is working the materials) 11. Leave again to own devices; 12. Intervene to redirect within to epistemological and ontological imperatives.	
Final visit	T2					**12**	13. At 12 minutes, announce "it's about time to wrap up this task and move to another." 14. Announce "Make sure there is a cover page for this center" 15. Announce "Take a minute to fill out the journal for this component" 16. Answer last minute questions quikly and redirect to finishing up.	
	Tf					**14**	17. Announce "Time to transition to next center"	

Check your facilitation against general protocols above. Initial ___

5

Appendix D: Modified Science Teaching Efficacy Belief Inventory

STEBI-A (Inservice) Science Teaching Efficacy Belief Instrument - Modified*

Please indicate the degree to which you agree or disagree with each statement below by placing an “X” on the appropriate letter to the right of each statement. SA=STRONGLY AGREE, A=AGREE, UN=UNCERTAIN, D=DISAGREE, SD=STRONGLY DISAGREE

1.	When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	SA	A	UN	D	SD
2.	I am continually finding better ways to teach science.	SA	A	UN	D	SD
3.	Even when I try very hard, I do not teach science as well as I do most subjects.	SA	A	UN	D	SD
4.	When the science grades of students improve, it is often due to their teacher having found a more effective teaching approach.	SA	A	UN	D	SD
5.	I know the steps necessary to teach science concepts effectively.	SA	A	UN	D	SD
6.	I am not very effective in monitoring science experiments.	SA	A	UN	D	SD
7.	If students are underachieving in science, it is most likely due to ineffective science teaching.	SA	A	UN	D	SD
8.	I generally teach science ineffectively.	SA	A	UN	D	SD
9.	The inadequacy of a student’s science background can be overcome by good teaching.	SA	A	UN	D	SD
10.	The low science achievement of students cannot generally be blamed on their teachers.	SA	A	UN	D	SD
11.	When a low-achieving child progresses in science, it is usually due to extra attention given by the teacher.	SA	A	UN	D	SD
12.	I understand science concepts well enough to be effective in teaching elementary science.	SA	A	UN	D	SD
13.	Increased effort in science teaching produces little change in students’ science achievement.	SA	A	UN	D	SD
14.	The teacher is generally responsible for the achievement of students in science.	SA	A	UN	D	SD
15.	Students’ achievement in science is directly related to their teacher’s effectiveness in science teaching.	SA	A	UN	D	SD
16.	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child’s teacher.	SA	A	UN	D	SD
17.	I find it difficult to explain to students why science experiments work.	SA	A	UN	D	SD
18.	I am typically able to answer students’ science questions.	SA	A	UN	D	SD
19.	I wonder if I have the necessary skills to teach science.	SA	A	UN	D	SD
20.	Given a choice, I would not invite the principal to evaluate my science teaching.	SA	A	UN	D	SD
21.	When a student has difficulty understanding a science concept, I am usually at a loss as to how to help the student understand it better.	SA	A	UN	D	SD
22.	When teaching science, I usually welcome student questions.	SA	A	UN	D	SD
23.	I do not know what to do to turn students on to science.	SA	A	UN	D	SD

*Modified from Riggs (1989), Enochs and Riggs (1990), and Bleicher (2004).

VITA

MICHAEL GARRETT

Education:

B.S. Chemistry, University of Illinois, Urbana, Illinois, 1983

M.A.T Secondary Education, University of Memphis, Memphis, Tennessee, 1989

M.S. Digital Media, East Tennessee State University, Johnson City, Tennessee, 2001

Ph.D. Early Childhood Education, East Tennessee State University, Johnson City, Tennessee, 2019

Professional Experience:

High School Teacher, Physics, Computer Science, and Mathematics, Memphis City Schools, Memphis, Tennessee, 1997 – 1999

High School Teacher, AP Physics, Physics, Chemistry, Physical Science, and Literacy, Sullivan County Schools, Blountville, Tennessee, 2004 – 2008

High School Teacher, AP Physics, IB Physics, Physics, and Physical Science, Johnson City Schools, Johnson City, Tennessee, 2008 – 2010

Research and Teaching Assistant, Early Childhood Education, East Tennessee State University, Johnson City, Tennessee, 2010 - 2014

Adjunct Faculty, Early Childhood Education, Mathematics and Statistics, and Physics, East Tennessee State University, Johnson City, Tennessee, 2014 – 2018

Facilitator, McNair Program, East Tennessee State University, Johnson City, Tennessee, 2014 – 2018

Junior Researcher and Project manager, DEC Recommended Practices, East Tennessee State University, 2016 – 2018

Service, Honors, and Awards:

Research Fellow, Early Childhood Education, East Tennessee State University, 2011 – 2012

Peer Reviewer, *Journal of Autism and Developmental Disorders*, 2016 – 2018

Exceptional Non-Tenure-Track Faculty, Department of Mathematics and Statistics, East Tennessee State University, 2017