This is to certify that the
dissertation entitled

EMPOWERING STUDENTS' SCIENTIFIC REASONING ABOUT ENERGY THROUGH EXPERIMENTATION AND DATA ANALYSES

presented by

Hasan Abdelkareem

has been accepted towards fulfillment
of the requirements for the

Ph.D. degree in Curriculum, Teaching, & Educational Policy

Charles W Anderson
Major Professor's Signature

8/12/08

Date

EMPOWERING STUDENTS' SCIENTIFIC REASONING ABOUT ENERGY THROUGH EXPERIMENTATION AND DATA ANALYSES

By

Hasan Abdelkareem

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Curriculum, Teaching, and Educational Policy

2008

ABSTRACT

EMPOWERING STUDENTS' SCIENTIFIC REASONING ABOUT ENERGY THROUGH EXPERIMENTATION AND DATA ANALYSES

By

Hasan Abdelkareem

The goal of this study was to explore how middle school learners reason from the scientific data that they collect while conducting energy related activities. Specifically, the targeted data analysis skills were: realizing the variables of investigation, finding patterns in data, and developing model-based reasoning about energy. The study was conducted as part of a science curriculum design project called IQWST- Investigation and Questioning our World through Science and Technology.

Two experienced science teachers and their 30 middle school students from an independent school participated in this study by piloting a designed unit about energy. Data was collected through classroom observations and in-depth clinical interviews. Those interviews were hold towards the end of the energy unit enactment with a focus group of six students. Participants responded to two types of questions: direct data that were similar to the investigations they conducted in the classroom and indirect data that were represented by energy scenarios. Students' reasoning from data was then analyzed and synthesized using a special coding technique in order to answer the research questions.

Findings of this research have shown three types of results:

a) Middle school learners have shown a tendency to use force-dynamic causation about energy (e.g., energy is associated with living things, an enabler to do work

and activity, and a materialized thing that moves like fluid). Very few students were able to reason about energy using a model-based perspective.

b) Participants were able to reason about scientific data on the local level (i.e., connecting data with direct observations) but rarely were they able to transform these local skills into global reasoning that implies developing models about energy.

c) Although the two science teachers were able to enact the designed activities through dialogical approach, there was no evidence that they had tendency to reinforce model-based reasoning among their students.

To my wife, Raba.

Acknowledgements

Many people have participated in this accomplishment. At the top of my acknowledgments list is my adviser, Andy Anderson. Dr. Anderson provided me with unique opportunities for doing research in science education. His continuous support, encouragement, and wisdom have always been with me through this journey in order to achieve my goals. I deeply appreciate your time and support, Andy. I would like also to thank all my committee members: David Fortus, Lynn Fendler, and Randi Stanulis. Dr. Fortus did not hesitate when I told him that I am interested in conducting my research through his IQWST project. His comments, feedback, and support were very important for facilitating the data collection process. My deepest thanks to Dr. Fendler, who taught me the first graduate course at Michigan State University. Her critical perspectives about teaching and learning encouraged me to think differently about my own experience as a science teacher and as a teacher educator as well. I appreciate Dr. Stanulis comments and support not only while doing this study, but also in many other occasions. Many thanks, Randi.

I would like to thank the two science teachers and their students who welcomed me very nicely to their classrooms. Indeed, I tasted a different style of teaching and learning science there. My visits to your classes were very productive and enjoyable occasions; I never felt like a stranger in your school.

I would like to thank my family members. My wife, Raba, and my five children: Maysam, Mahmoud, Ihab, Issam, and Dana. I know how you were patiently accepting my commitments and assignments as a graduate student. I am proud that in spite of the many challenges and difficulties that we faced in those four years, we together got the mission done. Thank you so much guys and I dedicate this dissertation for you. From the bottom of my heart I thank my family in Palestine for their unlimited support and encouragement through my graduate school study. I feel so lucky to have such a supportive mother, sisters, and brothers.

My sincere acknowledgments go to my American friends who helped our family in many different ways. Very special thanks to Stefanie Kendal, Anne Schneller, Sally McClintock, Peter Briggs, Brooke Stokdyk, and Rosemary Max for their continuous support.

TABLE OF CONTENT

List of Tables IX

List of figures X

CHAPTER ONE: INTRODUCTION: 1
Theoretical framework 3
Data Analysis as part of inquiry-based Learning: 8
Definition of the Problem: 12
The significance of this study 13
Definitions of the main terms: 14
Chapter Summary 16
Dissertation overview 16

CHAPTER TWO: REVIEW OF LITERATURE 18
Introduction: 18
Inquiry-based learning and constructivism: 18
Considering Scientific Data as evidence: 21
Students' reasoning from scientific data: 23
Anomalous Data and conceptual change: 27
Science-Related professions and reasoning from data 28
Research on students' conception of energy: 30
Why should energy be in science curricula? 31
What can be done? 35
This study: 36
Chapter Summary 37

CHAPTER THREE :METHODOLOGY 38
The context of this study 38
- *The IQWST project:* 38
- *The Energy Unit:* 39
- *Study Site:* 40
- *Sample of the study:* 41

Instruments and data sources 42
A) Classroom Observation: 42
B) Field Notes: 42
C) Clinical interviews: 43
D) The interview protocol: 44
Data Management and Data Analysis 47
- *Analyzing data from interviews:* 47
- Analyzing data from classroom observations: 50

Chapter Summary 52

CHAPTER FOUR: FINDINGS & RESULTS 54
Findings about learners' data analysis skills 54
A) Reasoning about investigation variables: 55
B) Realizing patterns in data: 59
C) Drawing conclusions and making evidence-based arguments: 62
Students' reasoning about energy 63
1. Energy is associated with living things: 63
2. Energy as enabler to do things: 65
3. Energy transformation and conversion (ETD & ECD): 67
4. Integrating in-school formal knowledge with out-of-school experiences: 70
Overall results for cases 71
Pedagogical aspects of data analysis 75
- *Teachers' ways of exploring investigations variables:* 75
- *Finding patterns and drawing conclusions:* 78
- *Treating conflict with anomalous data:* 81

Chapter Summary 84

CHAPTER FIVE: DISCUSSION AND IMPLICATIONS 85
Findings Summary: 85
Discussing the results of the study 87
A) Local to global reasoning from data: 87
B) Force-dynamic causation to model-based reasoning: 88
C) From conceptual change to conceptual integration: 90
Study Limitations: 91
Implications: 92
Reflection 94
Chapter Summary 96

APPENDICES 97
Appendix A: Description of the Energy Unit 97
Appendix B: The interview protocol 99
Appendix C: Exemplar sheet about Coding students' response 104

***REFERENCES* 105**

LIST OF TABLES

Table 1: Contrasts between constructivist and traditional learning environments..........21

Table 2: Data analysis skills and their distribution among the interview questions 46

Table 3: Participants data analysis skills codes 49

Table 4: Participants' reasoning about energy codes 50

Table 5: Coding the teaching practices that are embedded in reasoning from data 52

Table 6: Students' performance in data analysis skills 72

Table 7: A summary of students' reasoning about energy in two scenarios 74

Table 8: The energy unit lessons and activities 98

Table 9: The interview data table..99

Table 10: An example of coding the students' data analyses skills........................ 104

LIST OF FIGURES

Figure 1: Knowledge and practices of model-based reasoning 5

Figure 2: Long-Term objectives of science education 19

Figure 3: A model for measurement, data, and evidence 23

Figure 4: Energy conversion models for a falling book and a compressed spring 68

Figure 5: Energy transfer models (ETD) for two different students 69

Figure 6: Wood in fire place 100

Figure 7: A graph of the relationship between burned wood and a room's temperature.101

Figure 8: A picture of the elastic energy activity... 101

Figure 9: A graph of the relationship between springs types and moving distance...... 102

Figure 10: A picture of a car at a gasoline station...102

Chapter One

Introduction

A couple of months ago, I watched the documentary movie *An Inconvenient Truth* as a part of my participation in the Environmental Literacy project at Michigan State University. The goal of the documentary, which was produced by former U.S. Vice President Al Gore and his colleagues, was to make the public aware of the crises of climate changes. The main scientific point was the negative impacts of the increased concentration of the carbon dioxide (CO_2) in the atmosphere. This is the main argument of the movie producers:

> Carbon dioxide and other gases warm the surface of the planet naturally by trapping solar heat in the atmosphere. This is a good thing because it keeps our planet habitable. However, by burning fossil fuels such as coal, gas and oil and clearing forests we have dramatically increased the amount of carbon dioxide in the Earth's atmosphere and temperatures are rising. The vast majority of scientists agree that global warming is real, it's already happening and that it is the result of our activities and not a natural occurrence. The evidence is overwhelming and undeniable. We're already seeing changes. Glaciers are melting, plants and animals are being forced from their habitat, and the number of severe storms and droughts is increasing. (Gore, 2008)

That is, Gore and his colleagues relied heavily on observation and scientific data to support their essential argument regarding the relationship between the cause (CO_2) and the effect (i.e., Earth's temperature). The movie's authors have used considerable amounts of data and various types of graphical representations to support their main claim about the two variables. Reflecting on one of the graphs that illustrates how both CO_2 and the Earth's temperature have been changing for the last 650,000 years, Gore concluded that "the relationship [between carbon dioxide and temperature] is actually very complicated, but there is one relationship that is far more powerful than the others and it's this: when there is more carbon dioxide, the temperature gets warmer because it traps more heat from the Sun inside" (Gore, 2008).

However, the *An Inconvenient Truth* movie caused an ongoing debate among scientists, particularly about the controversial relationship between CO_2 and the Earth's temperature. For instance, Tim Ball, a climatology professor, argued that temperature increased significantly till 1940 when human production of CO_2 was relatively low (Ball, 2008). Then, in the post war years, when the industries and the human production of CO_2 were increasing, the global temperature was going down. Using a similar reasoning, professor Lan Clark (2008), an Earth scientist from the University of Ottawa, argued that carbon dioxide cannot be causing temperature changes, but rather it is a product of temperature changes. If the average citizen had been watching the previous debate, he might have been confused about making decisions regarding which argument is scientifically acceptable.

In spite of the fact that I do have a sincere commitment towards environmental issues, the purposes of the previous example is not directly related to environmental crises or to the political debate over global warming. Furthermore, I am not trying to defend Gore's or his opponents' arguments in spite of the fact that they are very interesting. Rather, I am using that introduction as an example of how the same observations and the same scientific data could be analyzed and interpreted by scientists and other public communities differently. Making sense of scientific data and building evidence-based arguments are essential areas in science learning (Duschl & et al., 2007; Fortus & Shwartz, 2006). As a result, data analysis and reasoning from evidence is a cornerstone in inquiry-based science classrooms.

The purpose of this study is to explore the learning and teaching aspects that are associated with one of the inquiry practices: learners' skills in data analysis that are mobilized in classroom conversations about energy-related investigations. In this chapter, I will address the research theoretical framework, study problem, research questions, and the significance of the study and its goal. I will finally close with an overall summary of this dissertation to give the reader a sense about what will be coming next.

Theoretical framework

In their last insightfully comprehensive report, which they called *Taking Science to schools: Learning and Teaching Science in Grades K-8,* Duschl (2007) and his colleagues stated that:

> Science is both a body of knowledge that represents current understanding of natural systems and the process whereby that body of knowledge has been established and

being continually extended, refined, and revised. Both elements are essential: one cannot make progress in science without understanding of both (p. 26).

That is, science consists of two integrated parts: one refers to the final products, which represent tentative facts and the accurate scientific stories, whereas the other represents the practices that scientists usually use to reach their ultimate goals. Consequently, addressing both the body of knowledge and the processes that facilitate its formation are essential in the field of science education. Furthermore, I argue that for orchestrating effective science classrooms, the body of knowledge and the process of acquiring it goes hand in hand. This study addresses an essential scientific practice about learners' reasoning from scientific data while conducting various activities about energy. In fact, there is a general agreement among science educators that data analysis skills are essential embedded practices in the inquiry-based learning activities (Jeong, Songer, & Lee, 2007; NRC, 2000).

The following diagram includes both the body of scientific knowledge and the process that is used by scientists to develop it (Anderson, 2007). There are two important points that should be noted in this diagram. The first is related to the triangle, whereas the second explains the direction of the arrows at both sides of it.

At the bottom of the diagram are the unlimited ranges of experiences. These experiences include ecosystems, physical phenomena, living and non living things, and all other unorganized types of data and observations (i.e., knowledge and experience). We experience these almost on a daily basis even without giving them any attention. As a result, learners come to school with a wide range of experiences about their real world throughout their communication with it. Thus, one of the major goals of school science, I believe, should be finding a reasonable equilibrium between these experiences, the intuitive knowledge which usually is loaded with many misconceptions about science, and the formal school science. However, one should keep in mind that there are many differences between the way the scientists and learners approach science, but I will talk about such differences in another area.

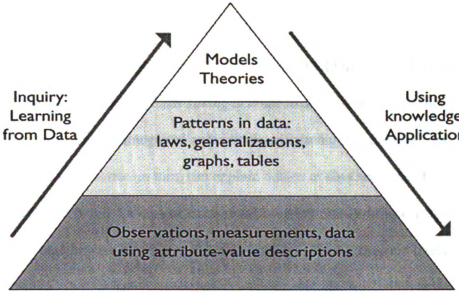

Figure 1: Knowledge and practices of model-based reasoning (Anderson, 2007, p. 18)

In fact, the accumulative bodies of scientific knowledge were formed by collecting and analyzing data through long periods of time. Scientists start by making observations and taking measurements, which ultimately form the foundation of making evidence-based claims. These experiences might be gained in the short term, as in a classroom setting, or through longer periods of time forming what Kuhn (1962) called paradigms—the accepted norms of knowledge discourse in any field. These observations could be organized, classified, and rearranged in different ways, such as tables, graphs, and specific kinds of classifications. For example, we say that plants are living things which use the sunlight to make their food independently through photosynthesis. Animals are also living things but they have a different life cycle and food production. However, both plants and animals are related to each other and they are both parts of a bigger system that represents food chains and energy flow in ecosystems. This sort of scientific reasoning is an example of how we realize patterns among our various experiences and observations.

In the last stage scientists draw conclusions and build models and theories relying on solid evidence. Borrowing from *Taking Science to School* report, "the body of knowledge includes specific facts integrated and articulated into highly developed and well-tested theories. These theories, in turn, can explain bodies of data and predict outcomes of experiments" (p. 26). Of course, one should keep in mind that these are tentative theories and laws and they are never completed or finalized. Hence, they are likely to be modified and changed as new data or empirical evidence develops. According to the previous diagram, theories and models are represented at the top of the diagram because they are abstract representations of knowledge that can explain huge amounts of observations and patterns. Developing models and theories in that way is inquiry that scientists do so often. Moving from the bottom of the triangle (the real world experiences and observations) towards the top is a complicated process. In other words, it is impossible to separate the "body of knowledge" from the "process" that facilitates producing it.

In fact, this process of inquiry is embedded within the scientists' techniques and work when they move between the material world and the abstract models. Once a theory or a model has been tested and developed, it becomes a powerful tool to explain other kinds of data that are governed by the same patterns. Thus, scientists use theory and models in order to make sense of new observations and experiences that they did not necessarily investigate before (i.e. application). In spite of the fact that both approaches (inquiry and application) are valid venues for constructing meaningful learning, science educators support the notion of inquiry-based learning. There is an assumption that helping students make sense of their world and reinforcing them to modify their worldview of science is more accessible through inquiry. However, the two communities, scientists and school learners, work in two different contexts.

Students don't necessarily explore their world the same way that scientists do. For instance, students rely heavily on their daily life experiences, thus their patterns and theories are influenced by such observations. When scientists develop their patterns and models, on the other hand, their personal experiences and observations have less control on their thinking. Furthermore, the purpose of doing inquiry in the two communities is not quite similar. Scientists usually work towards developing, testing, or discovering new theories. In the classroom setting, science teaching usually focuses on helping students integrate formal science with their personal experience (i.e. conceptual change) or confirming some facts that they already know. Yet, these are fruitful strategies for doing inquiry. Finally, there is an important distinction between scientists' and learners' ways of reasoning: force-dynamic causation versus the model-based reasoning.

Model-based reasoning means using scientific theories, principles and laws, and sophisticated models while explaining how things happen. Scientific models have three interrelated characteristics. The first one is the metaphorical nature of them. Both scientists and students use metaphorical narratives to describe their models. We say that water molecules contain the H (Hydrogen) arranged around O (Oxygen) like the ears on the human head. These are useful stories that help us by connecting abstract scientific narratives with concrete examples in real world. The second characteristic is that those models have constraints. These are rules and principles that govern a model. For example, we say when a physical change happens in the water state, the molecules are rearranged and their motion becomes slower. Lastly, scientific models have many representational forms such as diagrams, chemical equations, maps and cross sections. Unlike students, scientists have access to these three aspects of scientific models and thus they can explain how things happen using model-based reasoning.

There is evidence in research that students in different stages have a tendency to use force-dynamic causation rather than model-based reasoning (Jin & Anderson, 2007). Force-dynamic causation usually explains why things are happening in a specific way using natural tendency approaches (e.g. plants need water to grow; we eat food because it gives our bodies energy). According to this perspective, scientific phenomena occur because there are enablers that force them to happen. Finally, force-dynamic learners focus on macroscopic and visible parts of systems rather than realizing hidden parts and mechanisms.

Data Analysis as part of inquiry-based Learning

Generally speaking, people collect and analyze data in order to have a piece of evidence (Duggan & Gott, 2002) that helps them make appropriate decisions in different circumstances. In fact, our daily lives have many examples where understanding data in order to make decisions, or to understand some claims that are supported by this data, is crucial. Perhaps the *An Inconvenient Truth* documentary movie is a good example in this regard. An informed citizen has to decide, as a result of watching this movie, which argument or data sounds more convincing to him. Along the same line Kanari and Miller (2004) stated that:

> Claims are made, for instance, that certain foodstuffs increase (or decrease) the risk of certain diseases or conditions, or that the use of mobile phones increases the risk of brain tumors. Deciding what to make of such claims, and whether to act or not on them requires some understanding of how to interpret data and assess its trustworthiness" (p.768).

The previous examples reflect science educators' perspectives about the relationship between teaching science and citizenship (Lee, 1997).

Similarly, science related professions require also dealing with data analysis on a daily basis manner to make appropriate decisions. For example, the first step that a physician usually makes is collecting data from his or her clients. This data collection includes: measuring the body temperature, blood pressure, and any additional information that the patient reports. Advanced data analysis, such as testing a blood sample or taking an X-ray photo, might be necessary in order to make sure that the available data are "good enough" (Aikenhead, 2004) to make further decisions. A similar case is when a mechanic tries to solve a problem in order to fix a broken car. He ultimately has to make decisions and take actions to solve a problematic situation.

However, the situation in the science classroom is different. Although data collection and analysis in the previously mentioned examples have many common aspects, they differ in purposes, techniques, and consequences. A mechanic or a physician collects data in order to find a solution for specific problem such as a broken car or a sick person. Put differently, he is not necessarily trying to test or change his own theory. Rather, his main purpose is to integrate the data he collects with his own theory to make further decisions regarding the case in hand. In a science classroom, on the other hand, learners gather and analyze data in order to change their institutive or previous theories (e.g. conceptual change) or to test the correctness of their predictions (Fortus & Shwartz, 2006). Conducting scientific investigations for conceptual change is essential in inquiry-based learning environments (Driver & et al., 1994; Chinn & Malhotra, 2002). The main assumption in this case is that learners come to classrooms with a wide range of experience about the material world around them. This knowledge could be advanced (or even modified) as a result of meaningful engagement opportunities in well-designed activities (White & Frederiksen, 1998).

Learning and teaching science through engaging students in inquiry investigations has recently been one of the most important fields for research in science education as a response to the recent calls for national curriculum reforms (Kanari & Millar, 2004; Reiser & et al., 2003; Blumenfeld & Krajcik, 2006). According to the National Research Council, developing sufficient understanding about inquiry and its practices is one of the essential standards in science education (NRC, 1996). The American Association for the Advancement of Science (AAAS) has also pointed to the importance of developing "habits of mind" through engaging learners in inquiry-based activities (AAAS, 1989).

Although science educators have been using the term "inquiry" in different ways, there is a general agreement about the main characteristics of the concept. The National Research Council, for example, pointed to five aspects of inquiry:

a) Learner engages in scientifically oriented questions.

b) Learner gives priority to evidence in responding to questions.

c) Learner formulates explanations from evidence.

d) Learner connects explanations to scientific knowledge.

e) Learner communicates and justifies explanations (NRC, 2000, p. 25).

Along the same lines, many science educators called for introducing learners to opportunities where they can ask and refine questions, design and conduct experiments, and collect and analyze data in order to make evidence-based arguments (Chinn & Malhotra, 2002; Gott & Doggan, 1996). According to Edelson (2000), inquiry skills should include "formulating hypotheses, collecting and evaluating the evidence, and defending conclusions based on evidence" (p.362).

Looking closely at the previous educators' suggestions and the way they identify inquiry characteristics, one may draw two important assumptions. First, students are capable agents and they can effectively participate in developing meaningful knowledge. In other words, not only they can advance content understanding, but also they can feel kind of knowledge ownership. By doing so, authoritative resources, such as textbooks and teachers as experts, may not keep the traditional positions. The second assumption is related to designing science curriculum materials that reinforce inquiry-based learning. In fact, this is a big challenge as these materials should be educative for teachers (Callopy, 2003; Davis & Krajcik, 2004) and at the same time should open new rooms for students to work like scientists. Having said that, science teachers' roles could be seen as mediators and dialogue facilitators between formal curriculum materials and students' recent knowledge.

Definition of the Problem:

In spite of the fact that the inquiry-based learning has been widely studied and described in science education literature, studies that were conducted about specific aspects of this approach, such as students' skills in data analysis, still necessary. Thus, I believe that exploring students' reasoning from data and how they communicate with various types of it is essential in order to understand the functioning of the inquiry-based environments. Additionally, this study is an attempt to shine some light on both scientific practices (data analysis skills) as they are nested in students' reasoning about energy (content knowledge).

The central goal of this research is to answer the following major question: how are data analysis tasks exhibited by middle school students and implemented by science teachers while conducting scientific investigations about energy?

While this is the key question, these are other supportive sub-questions:

RQ1: What are the general data analysis skills that have been developed by learners after participating in the energy unit activities? The basic targeted skills include:

a) Reasoning about investigation variables.
b) Finding patterns in scientific data.
c) Developing model-based reasoning about energy.

RQ2: What are the pedagogical aspects that are associated with those data analysis skills?

The significance of this study:

In the last three years, I participated in designing science curriculum materials for middle school learners through a project called IQWST[1] (Investing and Questioning our World through Science and Technology). This project aimed at developing curriculum materials in many interrelated fields including earth science, chemistry, and physics. I participated in developing light and energy lessons as a member of the physics team. The focus of this research was the Energy Unit. This unit, which will be described in detail in the methodology chapter, was designed for middle school learners.

As a team of science educators, our main goal was designing inquiry-based lessons about different types of energy and how energy is transformed from one type to another. Engaging learners in hands-on activities that promote reasoning from data skills while learning about energy concepts was essential goal in that curriculum. Additionally, our focus was designing educative materials for science teachers (Schneider & Krajck, 2001). The significance of this research lies not only in its focus on a corner stone in inquiry-based learning (i.e. middle school students reasoning about scientific data and energy), but also it takes into consideration the teaching practices that are associated with it. Linking students' learning in a specific area, such as energy, and teaching practices is an interesting approach in terms of building an integrated picture about science classrooms discourse. Furthermore, it will also provide valuable opportunities for deliberation considerations for our work as curriculum developers. Thus, the feedback and results of this research might be useful for additional revisions in IQWST curriculum.

---

[1] More details about IQWST project will be presented in the third chapter when I discuss the study methodology and procedures.

Definitions of the main terms

This is a short description about the main terms and concepts that I am using in this study:

Curriculum materials:

These are the lesson plans that were developed by the IQWST team of researchers. In this research, the curriculum materials include the written texts, the supportive apparatus and equipments. It also includes the Internet and videos demonstrations that were used for conducting activities to reinforce learning energy concepts.

Data:

In the context of this study, the term data refers to the outcomes that are produced as a result of learners' engagement in a scientific investigation. For instance, it may mean a student-generated table of results that shows how much a cube of Play-Doh was smashed as a result of dropping different masses from specific elevation. Data could also mean observations, like watching a video that shows a specific phenomenon about energy. Although the term data is often used to describe outcomes of scientific activities and experiments in school settings, learners "observe" various kinds of informal data in their daily lives (e.g. intuitive knowledge). Examples of these observations include different types of motion, human activities, plants, animals, and various scientific phenomena. In other words, data includes in-class formal activities and outside experiences as well.

Data analysis:

A cognitive process that refers to a set of skills and abilities that help a learner make sense of specific kind data. This includes realizing the variables of an investigation, finding the pattern, drawing appropriate conclusions, and building evidence-based arguments. In this study, data analysis is contextualized within the energy concepts and processes. Furthermore, I use the terms data analysis and reasoning from data interchangeably. It's important to differentiate between "data analysis" that refer to my work as a researcher and "data analysis skills" that refers to students' reasoning from the data that they collect in the classroom while exploring energy concepts.

Data representations:

For the purposes of this research, data representations are visual scientific expressions that summarize data in organized forms such as tables and graphs. It also means other types of diagrams such as Energy Conversion Diagrams (ECD) and Energy Transformation Diagrams (ETD).

Model-based reasoning:

The concept model refers to a set of ideas, or even to a physical picture, that a learner holds about a phenomenon or a theory. Models are helpful tools for explanations, predictions, and putting coherent representation about scientific concepts and processes together. By the same token, model-based reasoning means the ability to reason about scientific phenomenon attempting to explain how it happens. This includes using metaphors, realizing the system roles and its macroscopic and microscopic parts, and using abstract scientific representations.

Force-dynamic causation:

Force-dynamic causation is a term that refers to a reasoning way that justifies why things happen rather than explaining how an event or a scientific phenomenon occurs. This type of reasoning, as an opposite of the model-based reasoning, focuses more on cause and effect approach (e.g., cars need gas to move from one place to another). Learners who rely on this type of reasoning usually focus on the visible parts of the system, give more attention to natural tendency, and so often trust their intuitive experiences.

Chapter Summary

Although the processes of data gathering, organization, and analysis are important areas in science education, this study pay specific attention to the data analysis skills. Those skills are very important for learners in order to reason from evidence and for scientific argumentations. The goal of this research is to give many examples of how middle school learners reason from different sets of data that are related to energy activities. Furthermore, informed citizens need basic skills in this regard so that they can participate in science driven issues in their community. This reflects the importance of science as a tool for citizenship especially in today's world where various sets of data and information are delivered through technology and media.

Dissertation overview

Chapter 2:

In chapter 2, I review the relevant literature that has been done about students' reasoning from data (i.e. inquiry practices). I also will be giving specific attention to literature that focused on students' concepts of energy (content) in order to situate this study with literature. I finally refer to some research that has been conducted about data analysis outside school contexts, such as science professional fields.

Chapter 3:

Here, I explain the general context of the study including: participants, school, teachers, and the IQWST curriculum. Additionally, I explain my data collection methodology through observations and clinical interviews. I finally, discuss the data analysis techniques that I have used to synthesize the findings and results of this study.

Chapter 4:

This is the chapter that tells the story about my dissertation. It will be used to help the reader make connections about the various parts of the research. The results that I concluded from participants' interviews and the classroom observation are summarized in this chapter. Three areas of results are reported, two of them about learning aspects of data analysis and energy and one about science teaching.

Chapter 5:

The last chapter of this dissertation has two main parts: the discussion of the main findings, where I integrate this research with the field, and the reflection part. In this later one, I reflect on my actions and decisions as a researcher. Additionally, I discuss the research implementations for teaching and learning, curriculum, and for future research.

Chapter Two

Review of Literature

Introduction:

Making sense of scientific data is an essential tool for scientists, professionals, and informed citizens. Looking closely at the literature that has been reported on data analysis and scientific reasoning, which is also called reasoning from data or evidence-based argumentations; I organize this chapter around three main themes. The first focuses on situating reasoning from data within a wider domain about scientific knowledge acquisition. It also addresses the theoretical aspects of data analysis and my literature review regarding learners' reasoning from data. A particular attention will be given to energy because it represents the scientific topic under investigation. The second area highlights literature about science-related professionals' reasoning from data. This area illustrates the relationship between schooling and learners' future careers. Finally, I will report on some literature that considers reasoning from scientific data as a part of scientific literacy and citizenship. These areas are represented in the following diagram.

Inquiry-based learning and constructivism:

I see the inquiry-based learning approach as a tool for promoting both meaning construction and sense making of the real world experiences. As I have explained in the first chapter, inquiry approach opens additional rooms that help learners investigate scientific phenomena about their real world experiences. By doing so, they have more responsibilities and additional tools while learning science. I also believe that science educators' calls for adopting inquiry approach in science teaching and learning are rooted in constructivism, where learning is constructed and integrated in a meaningful manner.

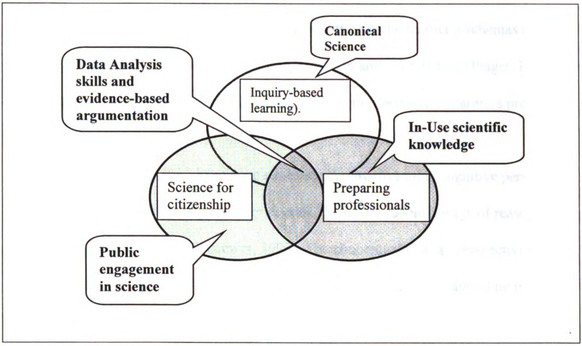

Figure 2: Long-Term objectives of science education.

Constructivism is a learning theory that explains how learners depend on their faculties, which include their own senses and former experiences, in addition to external supportive tools to construct meaningful knowledge (Brooks & Brooks, 1993). Students come to science classroom with a wide range of concepts and worldviews about the material world around them. In spite of the fact that these intuitive experiences are legitimate, many of these worldviews and ideas are not accepted from scientific point of view, i.e. misconceptions. When they are introduced to scientific situations that investigate particular phenomena, students relay heavily on these personal experiences to make sense of a new situation. Rooted in cognitive psychology, constructivists assume that learners are capable agents who are responsible for their own learning. This occurs while interacting actively with the new experience and through social communication with other learners (Vygotsky, 1978; Trumper, 1990). From Piagetian developmental perspective, the disequilibrium between new experiences and preexisting knowledge facilitates the learning process. Consequently, a change in the learner's schemas and frameworks happens by what he calls accommodation and assimilation (Piaget, 1968). These two terms refer to the internal cognitive interaction between a learner's previous and current knowledge.

Considerable literature in science education departs from this cognitive perspective reporting on conceptual change (Posner & et al., 1982) or students' ways of reasoning from anomalous data (Chin & Brewer, 1993). The conceptual change perspective assumes that clarifying the contrast between the new concept, which should be fruitful and scientifically powerful, and the learner's recent knowledge would be helpful in advancing the current knowledge (Resnick, 1987; Driver & et al., 1994). Anomalous data is the data that was collected by learners but sounded contrasting their predictions or expectations. In fact, many science educators referred to this kind of data as a sufficient tool for the conceptual change.

Adopting constructivism and inquiry-based learning for science learning and teaching requires considerable changes in the teaching methods. It also assumes reconsiderations of curricula designers' work and education policy (Shwartz & et al., 2005). The following table summarizes the main differences between the constructivist and traditional science learning and teaching environment (Brooks & Brooks, 1993). A vivid difference that is illustrated by this table is educators' beliefs regarding knowledge, learners, and the teachers' roles. However, what is missed from such a comparison is the big picture about the relationship between schooling and society. Additionally, one should keep in mind that although educators tend to support constructivism and inquiry approaches, this does not mean that they have magical solutions for the classrooms complexities and limitations. I believe that every single classroom is a unique context that has its own circumstances.

Table 1: Contrasts between constructivist and traditional learning environments

Traditional Classrooms	**Constructivist environment**
Knowledge is transferred from authoritative resources (e.g. teachers and textbooks) to learners.	Knowledge is constructed through social interaction and meaningful activities.
Students work individually with more emphasis on returning back what they memorize.	Students work in groups and share knowledge construction through a learning community.
Curricular activities rely heavily on textbooks and workbooks	Activities are conducted using various sources of data and manipulative materials.
Teachers seek correct answers as a valid way for evaluating students' learning	Assessments include multiple dimensional tools including portfolios, student exhibitions and informal observation.
Scientific activities concentrate mainly on confirmation labs that require following step-by-step procedural learning.	Activities emphasize big ideas investigations around main concepts and problems taking learners prior knowledge into consideration.

Considering Scientific Data as evidence:

The term data is used by many communities, particularly scientists and mathematicians, to refer to various meanings. Mathematicians, for instance, use the term data as quantitative representations and therefore data analysis form this perspective means the ability to reason statistically (Leinhardt, Zaslavsky & Stein, 1990; Ridgway, Nicholson, & McCusker, 2007). Many math educators have also used statistical literacy to explain the importance of data analysis in mathematics curricula (Ben-Zvi, Arcavi, 2001; Nicholson, Ridgway& McCusker, 2007). In science education, the term data is used in a broader way that includes qualitative observations in addition to quantitative representations. Furthermore, in science classrooms data is contextualized within investigations that support learners' understanding of scientific process or phenomenon. Regardless of the context in which the term data is used, an important question will be: when can data be trusted and treated as solid evidence?

Evidence-based reasoning is one of the most essential aspects while conducting scientific investigations and developing scientific argumentations (Lubben & Miller; 1996). Perhaps the work of Gott and his colleagues is a good example that shows how data should be treated in order be seen as evidence. From their perspective, "evidence is data that have been scrutinized by various methods of validity and reliability" (p.257). In other words, evidence has a higher degree than data and it's more creditable. Data reliability refers to consistency in readings over time or by mutable measures. Validity deals with the question: does a reading measure what claimed to be measured?

The following diagram, which should be read from center to out, illustrates that a datum is consisted of several measurements (or readings). The accumulated datum elements can produce data. In school settings, for example, a datum could be one measure (e.g. the measure of a gas volume). Once this process is repeated many times and considering another variable, such as the temperature, then we produce a data table.

Further, a datum could be quantitative (like measuring the mass of an object) or qualitative such as observing a boiling water. The outer ring of the model, "wider societal issues," means that the final meaning of evidence might be influenced by the social context. For example, the evidence about some environmental issues, such as global warming, is so often related to political and social perspectives.

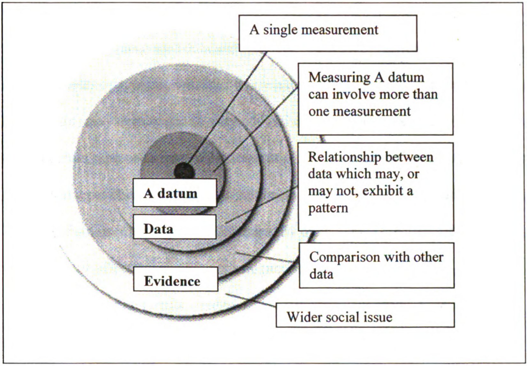

Figure 3: A model for measurement, data, and evidence (Gott, Duggan & Roberts, 2003, p. 268).

Students' reasoning from scientific data

Many studies addressed to the importance of students' reasoning from data while conducting scientific investigations (Chinn & Malhotra, 2002; Kanari & Miller, 2004; Varelas, 1997; Lubben & Miller, 1996; Vellom & Anderson, 1999). In other studies, research in this regard focused on students' conceptual changes and treating anomalous data (Varelas, 1997; Chinn & Malhotra, 2002). These two trends of research are located within the canonical science as illustrated in figure 2 at the beginning of this chapter. Next, I introduce examples of these studies.

Frequently, science education researchers explored how learners reason about the variables that are involved in scientific phenomena. The assumption was that grasping the relationship between those variables is essential for finding patterns and drawing conclusions. Kanari & Miller (2004), for example, studied how 60 participants, ages 10, 12, 14 years-old, interpreted data and reasoned about investigation variables. In that study, students carried out activities where a dependent variable (the oscillation period of a pendulum) may or may not co-vary with other independent variables (e.g. the length of the pendulum rope or its mass). Participants were supposed to find a pattern that supports the scientific conclusion about the relationship between the variables under investigation. The pendulum oscillation period depends only on its length (co-variation variable), the mass does not affect the oscillation time (non-covariation variable).

Two interesting results were reached by the previous study. First, there were no significant differences in participants' reasoning in terms of the tasks contexts or the participants' ages. I am concerned about the conclusion about the context. I noticed that participants have conducted two investigations within the same topic: force and motion. Thus, it was not clear to me if these were really different contexts. Many studies found that the context of investigation play essential role in learners' reasoning abilities (Kuhn, Amsel, and O'loughlin, 1988; Koslowski, 1996). Furthermore, the participants' ages in Kanari & Miller's study were close, thus they will likely have similar reasoning abilities. The second result was that very few participants were able to show sufficient reasoning about non-covariant situations. I found many other studies that support such conclusion

(Chin & Brewer 1998; Masnik & Morris, 2002). The non-covariant situations are very complicated even for high school learners. Many researchers critiqued the formal curricula focus on co-variation examples and leaving opportunities for other types of investigations are rare (Chinn & Malhotra, 2002; Kanari & Miller, 2004).

In a similar study, Koslowski (1996) found that learners' abilities in realizing patterns in data depend on their hypotheses about the relationship between variables. If students can imagine a plausible reason why two variables might covary, then a small amount of data showing no covariation is unlikely to make them reject the hypothesis that the variables covary. By the same token, if they cannot imagine a relationship linking two variables, a small amount of data showing covariation is unlikely make them conclude that they are related. Put differently, people treat their ideas about the relationships between variables as working hypotheses, and modify them when confronted with anomalies in a way that takes into account their theory and data together.

Along the same lines, Kuhn, Amsel, and O'loughlin (1988) have examined how students at different ages evaluate given theories using given evidence, and the influence of the students' own theories on this process. They introduced students to a problem, elicited their theories about it, and then asked them to say whether given pieces of data supported or conflicted with that theory and explain their reasoning. Findings suggested that the process of theory and evidence coordination undergoes developmental change (conceptual change). This means that many students don not consider the possibility that their theory might be false or that alternative theories are even exist. Other studies found that when data don't clearly point to a clear conclusion, students often impose patterns on their data, based on their prior expectations (Leinhardt, Zaslavsky & Stein, 1990; Ridgway, Nicholson, & McCusker, 2007).

In one of the most recent studies, Jeong and her colleagues (2007) researched how a group of sixth graders reason about "evidentiary competence" within the atmospheric science. They tested six aspects that are related to evidence-based arguments: priority, relevancy, objectivity, repeatability of evidence, interpretation of tables, and examples. Results showed that students' understanding of scientific evidence and the data collection process was quite weak. However, students' reasoning about data was assessed depending on their responses to various sets of data that they did not collect. I argue that using written tests, which usually call for responding to given data, may not be a sufficient tool for drawing accurate conclusions about students' reasoning. There is evidence in research that students make more sense if data was collected by them as part of an investigation that sounds interesting to them (Lubben & Millar, 1996; Schauble, 1996).

Other examples of research in this regard focused on students reasoning from various data sets that are varied in size and on how students identify errors in data. Masnik & Morris (2002) researched how American students (from 3rd grade till college levels) reasoned from data sets that varied in sample size, consistency, and the variability about the mean. They found that students from all ages had greater confidence in conclusion drawn from larger data sets. Furthermore, learners tended to ignore the data that were inconsistent or did not fit with the average.

Lubben et al., (2001) explored how South African freshman students, who were studying physics, reasoned about different sets of data. They found that participants could be described as "point" or "set" learners. The latter participants showed better understanding of error, using a set of values to represent a measured quantity rather than seeking evidence that one single measurement was correct or the best in the set. In other place of literature such differentiation was called as "local" against "global" reasoning from data (Ben-Zvi & Arcavi, 2001). Global learners not only were more confidants in their conclusions, but also they were more successful in transforming scientific knowledge from one context to another.

Anomalous Data and conceptual change:

Anomalous data are observations or pieces of collected data that scientifically valid and yet are contrasting with the learner's theory about a phenomenon[2] (Austin, Bell & Danials, 1991; Chin & Brewer, 1998). Many examples regarding reasoning from data refer to the conceptual change to report on the interaction between learners pre-existing knowledge and anomalous data. Chinn & Malotra (2002) attempted to understand why students don't change their previous scientific views about a phenomenon even after collecting anomalous data. In order to help learners change their misconceptions, the researchers pointed to the importance of making accurate observations, correct interpretation, generalization, and retention. For instance, incomplete observations or interpretations might block the new data and therefore a learner may stay with his own theory. There is evidence in research that although students may be able to carry out simple investigations, they often collect insufficient or inadequate data (Schauble, 1996).

---

[2] For example, many people believe that if a heavy and a light objects are dropped from the same elevation, then the massive object will reach the ground first. If an accurate experiment was conducted from reasonable height, it will prove that the two reach the ground together. Such data is anomalous for those who hold that misconception.

As a result, they either draw conclusions that are inconsistent with their data or prefer to stay with their intuitive conceptualizations (i.e. their own theories).

However, I am not sure about the efficiency of the conceptual change in such cases, especially when it comes to the learners' authoritative intuitive knowledge that has been developed through considerable period of time. I alternatively support the notion of conceptual development and integration. Learners' own framework and worldviews about science are very resistive and thus replacing them is a complicated process. Perhaps we need to put more emphasize on what Duit (1983) called the "ground level" of negations in order to integrate the out-of-school experiences with the formal science knowledge. There are many recent calls for valuing what students know in order to develop more realistic and accessible science curriculum rather than imposing experts' agendas. Examples of these approaches are the learning progression new trends in science education research (Jin & Anderson, 2008; Covitt & Gunkel, 2008).

Science-Related professions and reasoning from data:

An essential goal that is assumed by science curriculum designers and education policy makers is to prepare students for science related careers in industry, government, engineering and health professions. Curriculum developers expect students to integrate scientific content into their own thinking so that this content is accessible later when students are employed in a science-rich workplace (Aikenhead, 2004). This relationship between future occupation and formal science was addressed by some literature. This kind of literature concentrated on how professionals in some fields collect and analyze data while dealing with science related circumstances (Aikenhead, 2004; Gott, Duggan & Johnson, 1999).

An insightful study that was conducted by Glen Aikenhead about nurses' reasoning from the data they collect in a hospital surgical unit. The main idea in his study was investigating to what degree is the in-school canonical science (sometimes he called it pure science) could be practical in terms of decision-making for those who work in science-related professions such as nurses. It was noticed that from the nurses point of view data become evidence if it follow a specific trend and is also supported by another source (e.g. fever and blood pressure). Interestingly, only one of the six nurses in the study used canonical science content in their clinical reasoning. The authors' differentiation between the school formal knowledge, "knowing that," and the procedural knowledge, "knowing how" (p.243) sounds interesting. Although professional employees use data in a way that differs from the classroom context, school science and inquiry practices could form important bridges between learners' future careers and schooling.

Duggan & Gott (2002) found that most of the scientific conceptual understanding used by employees was learned in the job, not in high school or university courses. They called this kind as "knowledge-in-use" (p.674). Such a conclusion was also supported by other studies. Chinn et al., (2004) found that "School learning is focused predominantly on declarative knowledge [knowing that], while workplace is focused predominantly on procedural knowledge [knowing how]. The science found in workplace differed significantly from the science learned in schools" (p.129). Although this contrast sounds reasonable, I don't agree with some educators' calls for putting a greater emphasis on the explicit teaching of the procedural understanding related to data and evidence, and a reduced emphasis on teaching canonical science content. Most of the procedural knowledge concepts would be learned in the job site, thus emphasizing procedural knowledge on favor of canonical science may not guarantee developing learners' skills in terms of reasoning about evidence.

In addition to students in school settings and employees in different occupations, reasoning from data is also important for average citizens. Tyler and her colleagues reminded us that "Judgments about evidence are often central in the interactions between science and the public." (p. 817). For example, parents deciding whether or not to have their infant child immunized, taking a position regarding debates over some public issues related to science, an deciding which policy argument to support require sort of reasoning about evidence and scientific data. Duggan and Gott (2002) have insightfully argued that sense making of science issues in general, and understanding concepts of evidence specifically, lie at the heart of scientific literacy as part of citizenship.

Research on students' conception of energy:

Energy is a shady and perhaps one of the most complicated concepts in science. There are many reasons that make it such confusing and difficult to understand. In the one hand, students experience many out-of-school experiences about energy. These experiences reinforce them to construct intuitive knowledge about the concept energy. In stores, for example, they see different kinds of food and drinks labeled by "energy drinks" names, or explaining how much energy a specific food contains. Furthermore, mass media send messages to public that there are some wars and conflicts in this world because of the energy resources. To make things even worse, we use the term in our daily discourse by saying: today, I am really tired and I don't have energy to do any work!

Together, these circumstances likely shape the learner's powerful and resistive conceptualizations about energy.

On the other hand, the school formal science curriculum introduces students to a totally different language about energy. In school, students learn about energy using what Aikenhead called "decorative knowledge" about energy: kinetic energy is the energy of motion; gravitational energy depends on an object's mass and elevation; electrical energy depends on the electrons movement; heat is a form of energy; energy is conserved, but it could be transformed from one system to another, and the list continues. They also supposed to learn how to calculate the amount of energy by implying the roles of energy conservation and transformation. It is not a surprise, then, that students develop a long list of energy synonyms and meanings such as force, power, momentum, and work.

Why should energy be in science curricula?

In spite of my previous introduction, energy is still considered as an important topic that is virtually introduced in all science courses (Watts, 1983; Nordine, Fortus & Krajcik, 2005). According to Duit (1984), there are four basic aspects of the concept energy. These aspects or "energy quadriga" (p.185), represent the four basic scientific principles about energy: energy transformation, conservation, transport, and energy degradation. Science educators as well as scientists in various fields draw on these principles in order make sense and simplify complicated systems that include energy.

Duit & Haeussler (1994) have nicely summarized the historical roots of the term:

> In the early nineteenth century, the science research program was much influenced by the romanticist idea of intimate interrelation between the forces of nature. Researchers investigated the change of electricity into magnetisms, magnetism into

electricity, heat into electricity, electricity to heat and many other phenomena. The concept of energy may be viewed as the scientific way of expressing the idea of a unifying, overarching romanticist force of nature. It is important to know that this idea is still at the center of the contemporary science energy concept. When we speak of energy today, we have to be aware that the changes are occurring at the phenomenological level. The very idea of energy is that the amount of energy does not change despite all changes at the phenomenological level. At the conceptual level, there is only a change of energy's manifestations that are usually called energy forms (p.186).

I brought the previous quotation for two reasons. First it gives the reader a sense about two of the main principles about energy: conservation and conversion. The second reason is showing the abstractness nature of the concept. In other words, we observe and experience the "phenomenological" aspects of energy and this adds more complicity to the term (Lijnse, 1990; Trumper, 1993). The other two aspects of energy, transport and degradation, are associated within the two others. Frequently, energy is manifest in various places and thus it is viewed as 'transport" or "flow" through systems. Degradation is used as an indicator of energy behavior in closed systems to indicate that if any process is taking place, such a chemical reaction or a moving car, the amount of energy is conserved but the usefulness of energy declines.

There is a general agreement among science educators regarding the difficulty and abstractness of the term *energy* (Duit, 1984; Watts, 1983; Lijnse, 1990; Duit & Haeussler, 1994). Frequently, studies on learners' understanding of energy and other related topics (e.g. heat, photosynthesis and carbon cycle) gave cumulative evidence about misunderstanding and confusion about energy. Furthermore, research shows those students conceptions of energy is also influenced by the context or the place in which they live.

One of the earlier long-term studies was done by Duit in Germany. He followed 300 of sixth graders, before they were introduced to physics course or any instruction about energy, for four years. After they were taught about energy, he found that "students in grade 10 were able to give a lot more examples for energy forms than in grade 6. But did not mean that the students learned the idea of energy transformation" (p.191). He reached two interesting conclusions: students usually don't learn the basic aspects of the energy concepts and they do not necessarily transform energy language as taught in school into real life situations. However, using written tests, as in his case, may not give students real chances to express their ideas. Thus, more specific findings about students reasoning were found when learners were interviewed.

An example of these studies was conducted by Solomon (1983a, 1983b). In the first study, the author tried to see how students use the concept using their own language. Three main frequent findings were summarized by her: energy is associated with living things, energy is associated with motion and activity, and finally energy is used to run machines. Some of participants in the study have also expressed some concerns about energy conservation. In the second study, Solomon argued that students' informal knowledge (e.g. daily life experiences) has too much influence on the way that they reason about energy. Similarly, Arzi (1988) interviewed middle school learners and asked them to explain what they think about energy when they see a box of chocolate or yogurt. She found that participants have severe difficulties in using the school science about energy to explain that situation.

Perhaps the study of Lijnse (1990), a Netherlands science educator, was one of the most comprehensive ones in this regard. Following are her findings about students' views of energy:

- *Human centered energy.* This is an example of the frequent occurrence of anthropomorphic thinking, which with respect to energy especially finds expression in the idea of being energetic, having a lot of energy to be active, or having lost all energy and therefore feeling exhausted.
- *A depository model of energy.* This idea suggests a notion of energy as a source of power, as a cause of activity, and as such stored in objects that possess energy.
- *Energy as an ingredient or as a product.* In these cases energy is not so much considered to be a cause, but rather a result of, or a reaction to, something. Energy is found in food but only becomes active after you have eaten it. Or, energy is stored in coal but manifested only after combustion.
- *Energy as an obvious activity.* In this notion, energy is identified with the presence of the activity, particularly motion. Energy is motion.
- *Energy is functional.* In many situations energy is conceived to be a general kind of fuel, as something that is especially useful and has something to do with technology.
- *Energy is some kind of fluid.* Energy is then materialized as a kind of fluid that flows and may enter and/or leave something. (p. 574).

One of the most recent studies was done by Liu and McKeough (2005). They studied the development of the energy concepts among elementary (as young as grade three) through high school American students. They analyzed the 27 items of energy related questions in the Third International Mathematics and Science Study (TIMSS). They found that some younger learners' views of energy were concentrated around the idea of energy as an activity cause (the ability to do work). However, complicated aspects of energy such as transformation, conservation, and degradation were not accessible before high school level.

What can be done?

The previous examples about students' reasoning about energy have consistently reported learners' difficulties about energy. The question becomes, then, what are the areas that sound difficult for learners and how could reasoning from data be advanced in order to make this abstract concept more accessible for them? In fact, answering such a question is not simple. In spite of that fact, there are many promising attempts in that direction. These attempts depart from the assumption that both well-designed curriculum materials and good instruction may make a difference.

Duit and Haeussler (1994) proposed integrating the everyday conceptions of energy with the science formal concepts. From their point of view:

> The main focus should be the understanding of energy issues in everyday life and society as well as energy concerned behavior. If this is the focus, it has far reaching consequences for the conceptual change we have to arrange. We have to reject the idea of replacing students' conceptions by scientific ones. If we were to try (it would most probably not work anyway), students would learn a conception that is at least partly contradictory to the life-world energy conceptions. Hence, it would not be very useful in life-world contexts" (p.197).

The authors were proposing a new approach of teaching energy. This approach aims at combining issues of STS (Science Technology and Society) and constructivism. The believe that starting with students' ideas and ways of talking about energy, which they called ground level, and moving towards more theoretical aspects of energy could be effective. However, their approach did not introduce sufficient suggestions in terms of curriculum materials or teaching strategies.

A recent study that was conducted by Nordine and his colleagues (2006) concluded that curriculum materials play essential role in developing learners' concepts about energy. The authors stated, "We believe that the right curricular design can help students develop an understanding of the rather abstract energy concept. By providing them with adequate supports, we feel that middle school students can exhibit the kind of energy conceptions that many insist out of their reach (p.15). After interviewing participants multiple times, most participants have shown considerable progression towards energy conversion after the unit enactment. Yet, this study did not tell us anything about the pedagogical aspects that were developed through the unit enactment.

This study:

Looking back at the previously stated literature, one may realize the interesting work that has been done about students' reasoning from data or about their concepts of energy. However, I noticed that many of these studies, especially those about students' reasoning from data were de-contextualized. In many cases, participants were introduced to ready-made data rather than primary data (data that is collected by them). Furthermore, the previous research focused basically on learners' data analyses skills with less emphasis on the scientific knowledge. In other cases, research about energy focused on the students' concepts and ideas about energy without giving enough attention to the pedagogical aspects. This research is an attempt to combine both the inquiry skills, such as data analysis and finding patterns in data, with the context of teaching and learning energy.

Chapter Summary

Although science stakeholders practice data analysis differently (i.e., depending on their purpose and context), yet it is a powerful tool that might develop our scientific knowledge and abilities to make evidence-based decisions. Considerable research has shown that a limited portion of the canonical school science is transformable from formal settings into science-rich places. In today's world, average citizens find themselves involved in scientific arguments about scientific issues such as global warming, food quality, and medication efficiency. Consequently, they need sort of ability, which should be guaranteed through scientific literacy, to reason about various types of data and to be able to engage in evidence-based argumentations as part of their citizenship.

Previous research has frequently reported that energy is an abstract concept and students have many difficulties in grasping its scientific principles. There are some new trends in teaching about energy that take into consideration curriculum materials, teaching methods. The recent study aims at focusing on students' reasoning about data while trying to develop models about energy.

Chapter Three

Methodology

In this chapter, I describe the following three related areas about the study procedures and methodology: the context of the study, data collection and the research instruments, and the data management and analyses procedures. Under the study context title, I will be discussing the IQWST project, participants, and the study site. Then, I will explain the tools of the study and the data sources with particular attention to the observations and clinical interviews. In the last part, I explain the data analysis techniques and how the research questions were answered. Finally, I summarize this chapter with some details about the methodological considerations and decisions that I deliberately made while collecting and analyzing my data. I will start by describing the context of the study.

The context of this study

- *The IQWST project:*

This study is a part of a long-term project called IQWST (Investigating and Questioning our World through Science and Technology). The main goal of the IQWST project is to design research-based science curriculum materials for upper elementary and middle school learners. In this project, many groups of researchers have been working towards developing curriculum materials in biology, chemistry, earth science, and physics. The IQWST approach emphasizes on common "big pictures" among those disciplines. In this context, big pictures mean central scientific concepts that have powerful overlap among many areas.

The physics team has been working on developing three units: the light unit light for sixth grade, the energy unit for seventh grade, and lastly the force and motion unit for the eighth grade. Energy is one of the "big ideas" that is supposed to be addressed across grade levels within the same content, which means that energy will be addressed within the three physics units, and also across subject matters such as biology and chemistry. In that sense, IQWST approach emphasizes on developing curriculum materials that reinforce interdisciplinary nature of science.

- *The Energy Unit*[3]*:*

The Energy Unit is consisted of fourteen lessons that are organized around four central questions. Organizing the unit around driving questions aims at keeping learners' attention focused around an interesting scientific phenomenon about the main topic: energy (Fortus, 1997). For example, the first question, "*why do some things stop while others keep going?*" introduces students to many scientific concepts and principles that are related to kinetic, gravitational, and elastic energies. Other lessons focus on other types of energy such as chemical, electrical, and thermal energy and how it might be transformed from one type to another. Each of the fourteen lessons is built around two or three activities that require hands-on experience. Additionally, the activities are designed in a way that requires the science teachers to adopt guided inquiry teaching.

There are many assumptions that could be noticed in the IQWST curriculum. These assumptions reflect the curriculum developers' beliefs about scientific knowledge, teaching, and learning. One of these assumptions is the importance of the hands-on and inquiry-based investigations. Departing from this point, most of the energy unit lessons

[3] Detailed descriptions about the Energy Unit are available in Appendix A

include some of these activities. While conducting these activities, students make predictions, collect, organize and analyze data in order to make evidence-based arguments and draw conclusions about energy. Another vivid assumption is the importance of integrating the formal curriculum and the learners' intuitive knowledge. There are many examples in the lessons to reinforce such an approach: readings, demonstrations, and homework assignments. Furthermore, the IQWST curriculum materials take into consideration the teacher's content knowledge. The "teacher background knowledge" readings, to name some examples, were explicitly addressed to promote the idea of considering the teacher as a learner. The general assumption in IQWST, I believe, is that engaging students in those well-organized activities, in addition to support teachers with educative materials, will help learners grasp new concepts and processes about energy. In spite of all these assumptions, one should keep in mind the context of the classroom and the complicity of the enactment process. Learning outcomes and classroom environments, even with best materials and expert teachers, are unpredictable.

- *Study Site:*

This study took place at one of the American suburban independent schools in mid Michigan. Although I agree with Stake's (2005) perspective that in qualitative research we don't usually have a long list of choices, this site was convincing for many reasons. At the top of these reasons was the logistic support that the IQWST project has received from the school staff and the science teachers. The head of the school stated its vision as "a community that values learning as a life-long process and teaching as an art." In addition to this philosophy, there are many interesting characteristics about the school that should be reported here. First, the schedule of the classes was dynamic, which meant to have extended lessons in specific days. Additionally, the average class size was around 15 students. These classes were well-equipped in terms of technology and scientific apparatus. Another reason for selecting this school was the teachers' willingness to enact the Energy Unit. The two teachers were enthusiastic and highly-committed to integrate their teaching with research. In fact, having researchers in their classes is not an unusual experience for them. Both teachers are experienced and they have been teaching science for more than 25 years.

- *Sample of the study:*

Students from two eighth grade sections participated in this research. The total number of students in the two classes was 30 students: 12 in the first section and 18 in second one. The majority of those eighth graders were females; only 7 boys were enrolled in both classes. However, for the interview purposes, which will be described later, I selected only 6 students (three from each class). Taking students' academic level into consideration, I cooperated with the teachers to select 2 students from high, medium, and low levels (one participant of each level from each section). Having students from various levels was meant to provide the study with a reasonable range of data in terms of students' skills and abilities. All participants were informed in advance about the interviews and that their participation was optional, they all agreed to be part of this research.

Instruments and data sources

A) Classroom Observation:

For the purposes of this study, I depended on two main data collection tools: classroom observations and clinical interviews. Keeping the research questions in mind, I decided to observe the lessons and activities that were explicitly designed to address data analysis aspects and skills. In fact, I ended up observing more than 80% of the Energy Unit enactment. I found myself following what Johnson (2002) has called the productive diversions of observing. These rich opportunities were fruitful as two expert science teachers have enacted the same lessons in the same building. Observation was very important for this study, it served as a tool that enabled me to make sense of the enactment of the IQWST curriculum. Such experience could not be reached otherwise.

Technically speaking, the classroom observation was such a helpful tool for achieving two goals. First, reporting on students' engagement in the data analysis activities. Without observation as part of the research methodology, it would be difficult to know how students have interacted with scientific data and how they made sense of it. Furthermore, the classroom observations were productive venues in developing the interview protocol. The second goal of these observations was to report on how were the data analysis tasks orchestrated by the two science teachers in order to answer the second research question.

B) Field Notes:

In addition to my silent camera, I continuously took field notes from every class. These notes were short descriptions about the class flow. As a member of the IQWST developer team, who was familiar with what's going on, I was indirectly involved. Thus I was a partial participant even without direct involvement in the class. While taking notes, I paid more attention to the students' tasks, questions, and the way they communicated with each other and with their teachers about data. For instance, the way in which students analyze data for a specific activity, their acceptance or rejection for a pattern, and their conclusions, were reported. This was a helpful tool to remind me about some interesting moments in the class flow in order to observe them again for further analysis. However, one should keep in mind that "our own perspective color what we see when we look" (Hatch, 2002, p. 79). Consequently, "each [observation] is shaped by the observer and what she or he brings to the task, the situation and its conditions for observing, and what is being observed" (Weiland, 2005). Although those educators were reflecting on observation in other qualitative areas such as ethnographic research, I believe that their comments are valid here as well.

C) Clinical interviews:

Collecting data through clinical in-depth interviews was necessary for this study purposes. This tool was the main source of data to answer the first research question. Furthermore, it helped me synthesize a comprehensive picture about learners' reasoning about data in different contexts (e.g. classroom and interview settings). These interviews were held towards the end of the Energy Unit enactment.

After arranging the time of the interviews with the science teachers, each of the six participants was interviewed at the school site. At the beginning of the interview, I explained its purpose and how the data that I was collecting would be used for research. In order to remind the interviewees about the original activities that they have earlier conducted in the class, I used the classroom projector to help them visualize the situation. The interview protocol included many pictures and tables that were related to the questions. All interviews were audiotaped for further analysis. The time of each interview was varied between 20-30 minutes. The length of the interview depended on the discussion flow and how participants interacted with data. Next, I explain the interview questions and scenarios.

D) The interview protocol:

The interview protocol has been modified many times so that it meets the research goals. For instance, the initial version of interview questions focused on data that were collected by learners while conducting energy-related activities. However, additional questions and scenarios were added to that version in order to include intuitive experience about energy. The final version of the questions and scenarios consisted of four parts. Some of these questions addressed direct experiences from the classroom activities. The goal of this kind of questions was investigating participants' reasoning from data skills. By doing so, I was able to have another deeper take on students' classroom discussions about data analysis. The other type of questions was more general. I designed some energy scenarios that represent interesting aspects of energy transfer and processes. These questions were meant to see how students reason about energy from a broader perspective. Following is a detailed description of the interview scenarios and questions.

The first question aimed at exploring students' reasoning from quantitative data set that was represented in a table. Furthermore, this numerical data was directly related to two of the activities that students have conducted while investigating the factors that influence gravitational and kinetic energies. The goal of this set of questions was addressing the following data analysis skills: 1) identifying the independent variables, such as mass and elevation, and correlating them to energy (gravitation and kinetic), 2) finding a pattern in the data, 3) drawing appropriate scientific conclusion, 4) comparing two data sets and identifying problems in data, and 5) presenting energy conversion diagrams (ECD). However, these skills were not restricted to this question. Many of them were included in other questions as well.

Unlike the first set of questions, scenario B represented indirect data about energy. However, it was relevant to chemical and thermal energy concepts, which have already been addressed in the curriculum. The scenario was presented by a picture of a fire place in an apartment. A set of follow up questions then were asked in order to see whether participants were able to transform the formal in-school science to out-school contexts (i.e. integrating formal with intuitive knowledge). Additionally, this scenario aimed at exploring students' skills in analyzing scientific data that was represented in graphs.

The third set of the interview questions, scenario C, was directly relevant to the elastic energy conceptions. It was designed as a result of the classroom confusion in order to have a deeper look at the participants' reasoning. My observation of that activity has shown that this scenario was problematic from learning and teaching point of view. Thus, it has been re-introduced again in the interview. Like in scenario A, this set of questions addressed the following data analysis skills: 1) reasoning about the investigation variables, 2) treating graphical data and representing ECD, 3) making evidence-based scientific arguments, and 4) exploring learners' reasoning about anomalous data.

Finally, the last set of questions aimed at exploring learners' general reasoning about energy. Like the second scenario, scenario D starts with a picture of a car at a gasoline station. The questions in this scenario focused on: energy conversion by explaining how the gasoline was consumed in the car, representing the Energy Transformation Diagram (ETD), and tracing energy through the system. Using a fire place at home or filling a car with gasoline is "intuitive experiences" about energy. Learners are familiar with them, but they are not necessarily correlating them with scientifically acceptable reasoning (See appendix B for more details about the interview questions).

The following table summarizes the four scenarios with a brief description of the targeted data analysis skills. Although the scientific knowledge varies from one scenario to another, one should expect that many data analysis skills are common among them.

Table2: Data analysis skills and their distribution among the interview questions.

Scenario	Description of the question	Reasoning from data skills addressed in the scenario
A. Gravitational and Kinetic energy	- Data in this question is represented in a quantitative form (table). The table mainly focused on gravitational and kinetic energies. - The variables in this question are mass and height. - Learners are supposed to conclude how elevation and mass affect gravitation and kinetic energy.	1- Reasoning about variables of investigation. 2- Realizing patterns from a data table. 3- Comparing (evaluating) two sets of data. 4-Representing ECD; energy conversion diagram 5- Making predictions from current data.
B. Wood in fire place	- This scenario is represented by a picture of wood in the fire place in an apartment. - The goal of this question is exploring how students reason about energy and its conversion. - The question calls for transforming in-class experience into general models.	1- Realizing the pattern of a graph. 2- Reading a graph locally and globally. 3- Transforming local understanding to a general model-based reasoning. 4- Drawing conclusions from data.

Table2 (Continued).

C. Springs' motion (elastic energy).	- This question is about the elastic energy in springs. It is designed to extend the students reasoning about anomalous data. - This is direct experience about a similar activity that was conducted in the class.	1- Reasoning about variables. 2- Realizing patterns in graphical representations. 3- Representing ETD. 4- Drawing evidence-based arguments
D. "A car's gasoline tank being filled with gas" scenario.	- Qualitative data that is represented by a picture of a car filling gasoline. - Intuitive experience and indirect association with the classroom activities.	1- Reasoning about energy conversion in the system (Model-based reasoning from qualitative data). 2- Representing ETD, energy transformation diagrams

Data Management and Data Analysis

This study is a qualitative research that focused on specific data analysis skills as they were addressed by the interview protocol. The collected data was analyzed using a special technique in order to answer the research questions. The ultimate goal was to synthesize an exemplar table and examples among students' reasoning patterns that were identified by the clinical interviews and the classroom observations. In the following sections, which I called data management, I explain the process of the data analysis. It includes organizing, filtering, and analyzing/synthesizing aspects.

- *Analyzing data from interviews:*

The main purpose of the clinical interviews was to report on how middle school learners reason about specific sets of scientific data about energy. The previous table, table 2, connects the interview scenarios with the data analysis skills among them. Thus, I used that table as a guidance to classify students' responses. Following is the detailed procedures that I did:

1. *Transcribing the interviews data*: the first step was transcribing the six interviews, I did that process and this was helpful in terms of making more sense of what the students have said. The interviewer questions, the researcher, and the students' response were colored differently in order to manage them for further analysis.
2. *Summarizing responses:* The next step was summarizing each of the six interviewee's responses according to the data analysis skills as they were proposed by each of the four scenarios (I called the scenarios A, B, C, D). The first scenario, for example, was divided into the following sub-questions: A1 (Reasoning about variables- mass & elevation), A2 (Finding a pattern in data), A3 (Connecting data with energy), A4 (drawing Energy Conversion Diagram (ECD) model), A5 (comparing group A's and B's data), and A6 (Making predictions from recent data). These sub-skills were the columns of one of the four excel sheets (one sheet for each scenario). The rows of that sheet represented the six cases. The result of each scenario was a matrix that contains all response in each sub questions. For instance, the first matrix contained 36 cells, each one of them has the actual response of the interviewee in that sub-question.
3. *Cross comparisons and coding:* The next step was the making the cross comparisons between cases. The goal of such comparisons was to find a general pattern among participants' reasoning skills. There were two kinds of comparisons: the first one focused on students' data analysis skills. These skills were distributed between the four scenarios. Thus, all items that were focusing on

the same skill (e.g.. reasoning about variables or finding patterns in data) were classified together. To make sense of theses data, I used a special coding schema to classify the responses according to their scientific appropriateness and according to their ranking if compared with each other's. These codes are explained in the following table. An exemplar of that process is shown in appendix C.

Table 3: Participants data analysis skills codes

Code	Kind of response
3	Participants response is accurate and complete
2	Response is almost accurate, one part is missed
1	The response is partially accurate, more than one part are not included.
0	The response is irrelevant to the question.

Taking the classified skills together, I generated a table that contains all cases and each response codes. That table was then used to report on students' data analysis skills and also to make comparisons among the cases.

4. *Comparisons of participants' reasoning about energy:* The second type of comparisons was focused making on qualitative comparisons between the students' response that mainly came from the second and the third scenarios. All responses were summarized in an exemplar table. To find a general pattern among responses, participants' similar responses were categorized together. I then followed the work of Duit & Haeussler (1994), Heejun (1994) and Anderson (2008) in order to give the participants response special codes. The following table summarizes these codes.

Table 4: Participants' reasoning about energy codes.

Code	Participant's reasoning about energy
EL	Energy is needed for life or activity (vitalism)
EA	Energy is an enabler to do things (agency)
EM	Energy is a synonym of momentum or force (motion)
EI	Energy is an ingredient or a product (stored in or a cause for)
EF	Energy is some kind of fluid (materialized)
MBR	Model-Based Reasoning tendency.
FDC	Force-dynamic Causation

The results of this coding process were used to report on the general patterns among participants in terms of their ideas about energy.

- *Analyzing data from classroom observations:*

The data that were collected from the classroom observations was a supportive tool that has two goals. First, it was used to report on teachers' strategies mediating the dialogue between students and data. Secondly, they were also used to track students' reasoning in both the classroom discussions and the participants' responses in the interviews. For practical and simplification purposes, I decided to focus on the enactment of three main activities of the Energy Unit. These three activities were selected because they are directly related to the interview scenarios. Then I selected the teaching episodes that are relevant to the data analysis or reasoning about energy. These periods were varied from 5 to 10 minutes in the videos of the intended classes.

A similar technique was used here again. I first transcribed the focus episodes and then they were colored differently to separate the teachers' talks from the students' responses. The dialogue between teachers and students in this case was more open than the discussion in the interviews. In this case we have the entire class rather than one participant. Thus, students' responses here don't necessarily refer to the same students who were interviewed, but they still from the same section. Furthermore, the discussion in these episodes was not continues (i.e. it was distributed mainly before, within, and after conducting the activities). All these new circumstances were taken into consideration while analyzing the data from the classroom episodes.

Again, the students' reactions were classified together and were divided into two related areas: reasoning about data, and ideas about energy. I implemented the previous coding techniques (tables 3 & 4) whenever this was possible[4]. Furthermore, I linked the interviewees' reasoning in the class with their reasoning in the interviews.

The teachers' talks were coded differently. After separating students' and teachers' talks, I classified the teachers ideologue according to period time of the activity: a) before conducting the activity (treating variables and dealing with learners' predictions), b) conducting the activity (measurements and data consistency), and c) after the activity (drawing conclusions and treating anomalous data). The following table shows the codes that were used to find the pattern of the teachers' practices. I used these codes in order to decide whether this aspect were available in the teacher's dialogue or not. The results from these periods were used to introduce descriptive examples about the teaching aspects in this regard.

---

[4] Students' reasoning in the teaching episodes was not necessarily similar to their responses in the interviews. Yet, their discussions, predictions, and conclusions about data and energy were used for coding.

Table 5: Coding the teaching practices that are embedded in reasoning from data.

Code	Description	Central pedagogical question
VR	Variables of investigation	• How do teachers address the variables of investigation? • How do they respond to learners' predictions, misconceptions?
PF	Patterns Finding	• What are the teachers' decisions when patterns are apparent? • How conclusion and evidence-based arguments were discussed?
AD	Anomalous data	• When data is anomalous, what are the teacher's decisions?
MB	Model-based reasoning	• Are there indicators of teaching strategies that ask for model-based reasoning?

Chapter Summary

This study aimed at exploring middle school learners' reasoning from scientific data while conducting activities about energy. This unit was designed by a group of science education researchers in a project called IQWST (Investigating and Questioning our World through Science and Technology). Two classes, around 30 students, participated in this research. Data were collected using two main methods: interview and classroom observation. A focus group of six participants was interviewed for in-depth follow up investigation using a specific protocol.

In this study, many decisions were deliberately made for economical and pragmatic reasons. For instance, having six students in the clinical interviews was an important decision from the time management perspective. This convincing sample was "good enough" to give an example about their reasoning from selective stets of data. Interviewing students through their school day should take into account their commitments to other classes besides science and the school schedule. Furthermore, traveling a long distance in order to hold these interviews on time was an issue for me as a researcher. Thus, the idea was to minimize the number of interviewees and the interview times without influencing the richness of the collected data.

Similarly, the classroom activities that I have selected were relevant to the interview questions in terms of data analysis skills and the scientific content. Although the purpose of these three focus classroom activities was not to evaluate the teachers' performance or the IQWST curriculum, they were analyzed as supportive data in order to link the learning and the teaching aspects of data analysis.

Chapter Four

Findings & Results

The main goal of this study was to report on middle school learners' general abilities in data analysis skills while learning about energy. In this chapter, I will synthesize the study results from the clinical interviews and the field observations. The study findings will be organized around four major highlights. The first area is about learners' skills in data analysis from a general perspective (i.e. how they reason from data sets). In this case, I will be giving more emphasis on the analysis skills and less focus on the concepts that have something to do with energy. The second kind of results is about participants' reasoning from data with specific attention to energy and the learners' conceptualization about it. In the third part, I will summarize the pattern of the six participants' responses in terms of data analysis skills. The goal of this area will be an attempt to see if participants' are able to reason about energy using model-based scientific reasoning (as a contrast with the force-dynamic causation). Finally, I will report on some pedagogical aspects that emerged from my observation of the energy unit enactment in order to correlate that with the other areas about data analysis skills.

Findings about learners' data analysis skills

This area included the participants' reasoning from data skills that were addressed in tables 2 in the analytical chapter in order to answer the first research question (RQ1). Students reflected different levels of performance in this regard. In this part, I report on participants' abilities in realizing the variables under investigation, finding a pattern in data and reading data locally and globally, drawing conclusions and evidence-based argumentations about scientific phenomena, and treating various types of data representations.

A) Reasoning about investigation variables:

Realizing the variables under investigation is essential because other data analysis skills, such as realizing the pattern and making accurate conclusions, depend on it. This skill was explored throughout three sub-questions of the clinical interview scenarios (see for examples questions A1, C1, and C2). Findings in this regard showed that most participants were able to reason about the investigations variable at the local level (i.e. the direct observations that learners made). Being able to reason about those variables locally means that they can identify the relationship between variables as cause and effect (e.g., more mass implies more smoosh on the Play-Doh). However, when it comes to reasoning scientifically about correlating those variables to scientific concepts, such as gravitational or kinetic energy, a few of them were able to give adequate justifications. In other words, students tended to correlate variables to observations on the local levels, such as the "smoosh" factor, rather than general models. The cross comparisons in this regard showed that only one interviewee was able to give a complete scientific explanation about the variables of investigation and to also correlate them to gravitational and kinetic energies[5]. Following are some examples of the participants' response when they were asked to explain some variables.

[5] Gravitational energy (GE) depends on two factors: mass (m) and height (h) and it could be mathematically represented by the equation $GE = mgh$, where g is the gravity acceleration constant. Similarly, kinetic energy (KE) depends on mass (m), and velocity (v). The mathematical representation of kinetic energy is $KE = \frac{1}{2} mv^2$. In IQWST, these mathematical equations were deliberately avoided as the developer team believed that introducing them will be difficult for learners at this age.

In the first scenario, which includes dropping different masses from different elevations, I asked participants to reason about the mass and height as variables. Chandler is one of the students who explained that sufficiently.

> *Me: Why do you think that we have dropped five different masses from two different elevations in this activity?*
>
> *Chandler: I think that we used 5 different masses to see how mass affect the Play-Doh block height (the "smoosh"), mass was the only variable. We also dropped them from two different elevations to see how elevation affects how much energy we have.*

In our follow up discussion, Chandler explained that the "smoosh" factor is important because it is an indicator of kinetic energy. Interestingly, most students were able to point to the "smoosh" of the Play-Doh, but rarely did they connect it with either gravitational or kinetic energies. For instance, Maddy, one of the high level students according to her school scores, reasoned about the variables "logically." When I asked her the same question, she said: "I think that the logical answer and the logical claim is when you drop it [the book] with more mass and with more height then it will have more smoosh." Again, talking about the "smoosh" factor, which refers to the difference between the Play-Doh cube's height before and after the collision, was a typical response for most participants. This is an indicator of the participants' local reasoning about data. Connecting direct observations with the gravitational and kinetic energies means that a learner has developed an advanced ability of reasoning that connects direct observations with scientific conclusions.

Similarly, in another scenario questions (i.e., C1 &C2), students were also required to reason about the investigations variables. In this activity, the dependent variable was the height that a spring jumps as an indicator of how much elastic energy it has. That distance depends on two factors: the spring hardness, which usually is called K by physicists, and the distance of compression (X)[6]. Looking at students' explanations, one might see that they were confused about the independent variables. A reasonable source of this confusion might be their pre-assumption that "softest springs can go higher because they are easier to compress." Blake is one of the students who insightfully reasoned about the variables and yet has such an assumption. This is a part of our discussion:

Me: Why did we use three springs?

*Blake: to find if the um, the **hardness** of the spring affected the **elastic energy** of it.*

Me: Why do you think that the teacher asked you first to compress the springs for 1cm and then for 2 cm?

*Blake: to see if also **the distance of the compression** in the spring affects the elastic energy, the higher [it jumps], the more elastic energy [it has].*

Me: what did we measure in this activity?

Blake: we measured the distance.

Me: which distance?

Blake: Um, the spring jumps.

Me: Why did you measure distance?

Blake: as evidence for our claim that soft springs jump higher than hard springs and that the more you compress, the higher it goes.

Although Blake's last comment about the relationship between hardness and distance is inaccurate, he showed a sufficient understanding of the variables involved in this

[6] Theoretically, the stored elastic energy in a spring that has been compressed for X distance, and has a K factor is $\frac{1}{2} KX^2$.

activity. For example, he specifically mentioned the hardness of the springs (i.e., the K factor) and the distance of compression and their relationship with elastic energy. Most other students were confused about the hardness of the spring (K) and the distance of compression and thus they were not able to differentiate between the two variables. Like in the "smoosh" factor in the previous question, most students in this scenario mentioned the importance of the distance that a spring jumps, but without connecting this indicator with the elastic energy.

Looking closely at the results, one may conclude that participants from various academic levels have reasoned about the investigation variables differently. Whereas high and middle level students were able to reason sufficiently about the variables or they missed one important part, lower level students introduce naïve explanations. For example, when I asked Amma to explain why we dropped different masses from different elevations she said, "Probably to get different results, because if like you use the same ones, you will have the same stuff the whole time." Such a response was also found in the discussion with Austen while explaining the elastic energy variables. Justifying why we used different springs, he said "Um, each of them are going to give different results. Because some of them [the springs] are lighter than the other and some are heavier, some is harder to compress."

The previous examples suggest that some participants' were confused about separating dependant variables from the independent ones. Such confusion about the variables under investigation and their association with the central variable of the activity might negatively influence learners' reasoning in other relevant areas such as realizing patterns in data. Without grasping the relationship between investigation variables, which one is the cause and which one reflects the effect, realizing a pattern in a data set might be impossible. In the following part, I will report on results that have to do with this particular area.

B) Realizing patterns in data:

Seeing the pattern in scientific data is an essential skill. Not only because it enables learners to understand the relationship between variables, but it also helps them draw sufficient conclusions about their inquiry. Final results of this research showed that students' skills in terms of finding a pattern in data have two main characteristics: relying heavily on the mathematical consistency and the authority of their intuitive knowledge. While the first refers to the quantitative nature of the used data sets, the latter has something to do with participants' responses to anomalous data that contrasted their pre-assumptions. In this study, participants were required to find a pattern in various data sets. For instance, in the first scenario data was presented in a table (see the data table in the first scenario in appendix B) that shows the relationship between independent variables (i.e. mass and height) and the smoosh factor as an indicator for gravitational energy.

Four of the six participants expressed their concerns about the mathematical consistency in the data table. Mathematical consistency here means a constant rate of change (e.g. a constant change in the "smoosh" factor as a result of increasing the mass for one bound in each trial). I noticed that if students did not see that rate of change between variables, then they likely will not consider a pattern in data[7]. For instance, when

[7] In the first scenario, the general pattern was about the relationship between the independent variables (mass and height) and the dependant one (smoosh factor) as the indicator of gravitational and kinetic energy.

I asked participants if they see a pattern in the data table in the first scenario, most of them focused on specific trials that they considered "inconsistent" with the rest of the outcomes in the table. Maddy, one of the outstanding students, said that "I don't see a pattern except for in two [trials] of them; in the first elevation and then in three for the 20 inches [height]." A similar inference was found in Amma's response: "Well, not really because the first column has the same thing, I don't really think that there is consistency." However, Chandler was the only student who realized the pattern and explained that by saying, "Yes, I see that. I think that if you increase the mass, the smoosh factor increases, and I think that the 20 inches elevation generally has more smoosh factor than the 10 inches." In other words, Chandler was reasoning about a general pattern in the data rather than concentrating on local specific points.

Finding the pattern in data depends also on the type of the representations. Results of this study show that realizing the pattern in graphical representations, for example, was much easier than finding the pattern in a table. Most of participants realized the pattern that was graphically introduced to them about the relationship between the number of burned logs of wood and the room temperature. One of the students concluded that "There is a pattern in the graph; I think that the Elm slope stays steady: it always has the same consistency going up. For the Oak wood, it stays the same till five [logs of wood], after that it has bigger slope and it burns much harder." Mathematically speaking, realizing a pattern in graphs was more accessible to learners than tables since graphs usually show the general trends, whereas tables show details about particular points.

In addition to their tendency to use mathematical reasoning while finding patterns, participants in this study have also relied heavily on their intuitive experiences. In other words, when learners have some experience about data, they trust their own theories rather than the pattern that they see. For example, when students were asked if they see a pattern in a graph that represents different kinds of springs and the distance they travel, all students were able to see the pattern. However, when it comes to correlating that pattern to scientific conclusion about the spring hardness, most of participants gave a wrong explanation. A typical response was similar to Maddy's, "Well, for each spring the distance goes down, I think that the hardest one is number 5 because the hardest one should spring the least amount of distance, and number 1 is the softest because it jumps most." Only one student has drawn the appropriate conclusion which is the opposite of what Maddy said. In fact, reasoning about this particular question was also influenced by what happened in the class when students conducted the activity. A safe conclusion that one might draw here is the difference between scientists' and learners' ways of seeing patterns in data. Scientists usually trust their data and consequently they don't consider their personal experiences. In the classroom settings, on the other hand, finding patterns by students is usually governed by their personal experiences.

While reasoning about patterns in data, some students focused on comparing the two groups' results (group A dropped masses from a10-inch elevation whereas group B dropped them from a 20-inch elevation). From Kit's perspective, "In the first one [group A's data] yeh, because it changes a little bit each time, but for group B it [the smoosh] stays the same for the 3 and for the 4 bounds, and it does not seem to make sense." Along the same lines, when participants were asked to compare the results of the two groups, all of them were able to identify at least one "illogical result" from the three that were included in the data table. Surprisingly, none of the students accepted the results as they were, in spite of the fact that it's experimentally possible to have such results due to human or instrumental errors. In order to fix these problems, the interviewees suggested making more trials in order to have accurate results that fit with the pattern. Although identifying experimental error was not an essential goal of this study, comparing data sets could be seen as part of the data analysis skills.

C) Drawing conclusions and making evidence-based arguments:

Central to inquiry-based learning and data analysis is the learners' ability to draw appropriate conclusions and to make evidence-based arguments. Noticeably, high and middle academic level students were able to draw sufficient evidence-based arguments from data. For example, we asked participants what they might conclude from the graph that shows Oak and Elm burning, Kit concluded that "Oak will probably be more efficient than Elm because temperature increases more each time for the same amount of logs. It's probably more efficient to burn like two logs of Oak than three logs of Elm." In a similar question but in a different scenario, she gave another example when she connected a claim with evidence. Reflecting about evidence that she used for elastic energy she added "um, we measured the height that the spring went like when it went over the ruler. We did that to see how much energy it has when it's going up and coming back, the higher bounce then probably the more energy."

Students' abilities to draw conclusions varied from one context to another. For example, when the conclusion was about activities with "transparent data," they did not have troubles connecting claims with evidence. Example of that kind of data is the gravitational and kinetic energies. In such cases, most participants were able to draw appropriate conclusions and predictions. It seems that in this kind of activities, whether a learner relied on force-dynamic causation or model-based reasoning, he can come with a sufficient conclusion. In other data sets, such as the spring or the car at the gasoline station scenario, there is a need for more advanced reasoning (i.e., model-based reasoning). These stances calls for realizing more complicated scientific laws and principles about energy conversion.

Students' reasoning about energy

Results of this part mainly come from the second and fourth scenarios because they were represented in the form of qualitative data. Furthermore, unlike data in the rest of the interview questions, these two scenarios were deliberately designed to see how participants reason about intuitive data. That is, data that are indirectly related to energy as part of the formal curriculum but still valid general examples about energy. The most frequent findings that can be reported from students' responses in this regard were: energy is associated with living things; energy is an agent that helps us do something, energy is something that is similar to matter (fluid) that moves through conversion. Next, I will discuss these areas with examples of students' responses.

1. *Energy is associated with living things:*

In the second scenario, participants were asked to reflect on a picture that shows wood in the fireplace. Frequently, students thought that energy is associated with living things (e.g. wood had energy when it was alive). For instance, when I asked participants if they think that wood has any type of energy, most of them said that it has a small amount of chemical energy stored in it. From their perspective, it should have more energy when it is part of a living tree. Results suggested that associating energy with living things was common among students regardless of their academic levels. However, high achiever students seemed to have more access to more developed reasoning in respect of tracing energy and explaining its conversion through systems. Following is a short portion of the conversation with Amma, while discussing that scenario:

> *Me: [after introducing the picture of the fireplace]: do you think that wood has any type of energy?*
>
> *Amma: Um the wood, maybe there is a little bit of chemical energy.*
>
> *Me: Why a little bit?*
>
> *Amma: because the, [silence]*
>
> *Me: if there is any energy, could you please tell me where from did it come?*
>
> *Amma: Um, the heat it comes from the fact that the wood used to be alive, like*
>
> *Me: so, once it was alive it has energy?*
>
> *Amm: yeh, once it was alive it has to have energy to grow, but when you cut it there probably still some energy left, but not a lot.*
>
> *Me: could you please explain to me any energy transformation when you burn something like wood?*
>
> *Amma: probably, those to be the wood and then the fire is both chemical and thermal energy, and as it is just burning it gain, like it gain the thermal, as it burns it gain thermal but it might loose the chemical.*

A similar response was found in Austen's reasoning, in his words "wood does not have energy at all because it is just passed away; not doing anything else it is just staying there."

However, a few students seem to have more access to sophisticated reasoning, especially in terms of tracing energy and scientific explanation. The term sophisticated here means the ability to tell an accurate scientific explanation in away that reflect sort of model-based reasoning. For example, one of the students showed an acceptable scientific narrative explaining that:

> Wood has chemical energy, which is like potential energy. It originally comes from the Sun, the Sun gives this energy to the leaves which perform the photosynthesis and all that stuff to make the tree better grows, and then later when the tree is cut down, these blocks of wood still have energy stored there.

Another student thought that energy has been transformed to the tree by some carriers; she explained that by saying "I think it [the wood] has chemical energy that comes from its surroundings. It has to grow and it needs energy, so when you cut it, it still has some energy that comes from the Sun, soil, the surroundings." The previous quotations show also that students see energy as something that could be gained, lost, or travel through systems. This might reflect their confusion between energy and matter.

2. Energy as enabler to do things:

In addition to their ideas about energy as something that is associated with living things, students tend to picture energy as a tool that enables us to do things. This could be vividly concluded from participants' explanations when they were tracing energy in a car. Reflecting on a picture of a car at a gasoline station, four of the six interviewees used terms that refer to force-dynamic causation[8]. In fact, in this scenario it was even hard to draw a line that differentiates between students' reasoning in terms of their academic levels. For example, one of the outstanding students in the class said:

---

[8] I am using the term force-dynamic causation as opposite to model-based reasoning. In the first one, learners usually depend on their accounts and experiences to explain ***why*** a scientific phenomenon happens. Examples of these include: plants need light to grow; gasoline is used by the car to help it move from one place to another. So often, they depend on their intuitive and daily life experiences to explain things. The model-based reasoners, on the other hand, rely on more sophisticated scientific models to explain ***how*** a phenomenon happens. They also can smoothly go back and forth between the formal science constraints and principles and the intuitive science suing representations and scientific laws.

> Well, the gas was used to power the car and the engine of the car. Then, I mean it probably came out of the car through the exhaust. When the car is done with it, it probably has some device that like leads it to the exhaust pipe and then come out in smoke; I guess it gets transferred into other parts of the car like the engine.

A similar response was also expressed by a student who steadily tended to use force-dynamic causation. According to him, "It [the gasoline] is burned off, it's not really burned off, but it is just like run away to the exhaust. I am not totally sure about where does it go but the car used it up and threw it away." However, in spite of the fact that students from various academic levels have similar explanations, especially when it comes to intuitive experiences, yet a few of them have access to richer terminology.

Blake, an average student according to the formal assessment perspective, was a good example of model-based learner. In his words:

> The gas is sort of chemical energy and that chemical energy was burned in the internal combustion of the engine. This made the pistons move up and down, which made the car move to the Upper Peninsula. This process produces carbon dioxide and monoxide as a waste gas and also produces lots of heat. The heat is in the engine and above it.

When I asked him to say more about energy conversion that happens inside the car, he pursued "if you stick a camera inside the pistons you can see light, and sound energy. It's coming from the motion inside the pistons when the engine is working and also all the gear shifting and all that stuff."

3. Energy transformation and conversion (ETD & ECD):

A central goal of the energy unit was helping learners understand the main principle that energy is conserved, but it might be transformed from one type to another. To develop such an understanding, IQWST curriculum gave a special attention to scientific models and representations. Examples of these models included the Energy Conversion Diagrams (ECD) and the Energy Transformation Diagram (ETD). The first one, the ECD, emphasizes a sort of quantitative reasoning and it pushes learners to predict how much energy of each type might be involved in a specific process. The second one, ETD, concentrates on qualitative predictions, particularly when the system is complicated and making quantitative estimations is impossible[9]. Next, I introduce some examples about participants reasoning in this regard.

Three areas of the interview scenarios required participants to draw ECD or ETD. Furthermore, they were asked to explain what they mean by their models in terms of energy types and its ratios. Students were able to insightfully represent and reason about cases that they have similar experience with. Except for one of them, all interviewees have drawn an acceptable ECD for a free-falling and a compressed spring. They were able to identify what are the energy types and how they were converted from one type to another. The following diagram shows how Kit translated the motion of a falling book and a launched spring into qualitative representations.

---

[9] For example, in some activities students dropped masses from known heights. Depending on some indicators of gravitational energy, such as elevation and mass, students can draw a pie chart that shows that it has 50% of gravitational energy and 50% of kinetic energy at the middle of the trip. Similarly, in a process that making estimations is impossible, such as in a chemical reaction, students rather can realize the kinds of energy might be involved in that process.

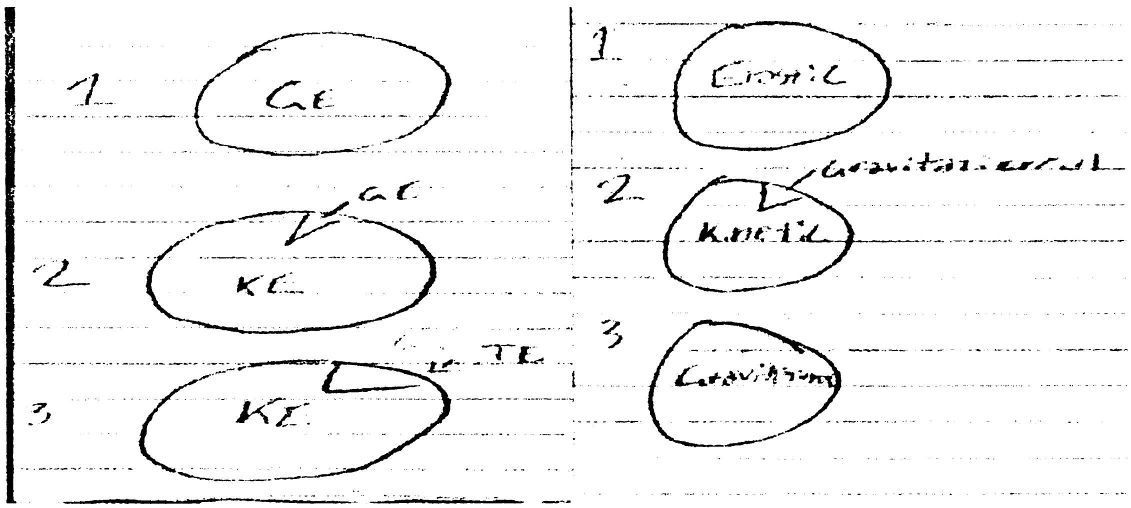

Figure 4: (Students work) Kit's ECD for a falling book (left) and for a spring (right).

Reflecting on her first drawing, which represents how a falling book gravitational energy is converted into kinetic energy, Kit explained that by saying:

> In [position] #1, it's probably all gravitational energy because it's the highest point. The second position # 2, there is kinetic energy since it falls and it says half of the way and it's loosing some gravitational energy. The third one is probably a lot of kinetic energy but still (hah?), I am trying to figure out what [type of energy is that], I can't remember but when it touches the play-doh, um, I think thermal energy maybe?

Looking at her drawings, Kit explanation is accurate in terms of the types of energy that are involved here. In fact, she was the only one who considered having thermal energy (TE) as a result of the collision between the book and the play-doh. However, her problem was in representing the ratios of kinetic and gravitational energy in the second position for both the falling book and jumping spring.

Students reasoning in the cases of the energy transformation diagrams (ETD) was different from the other type. In general, high academic level students were able to identify more types of energy with more sophisticated models of energy conversion. In the following diagram, there are two main differences between the upper and the lower models: first, the number of the energy types that are involved and the second in the arrows directions. The first model shows that there are only three types of energy conversion involved in the car scenario: chemical, kinetic (the student used the term speed) and sound energies. Further, it pictures energy as fluid that changes from one type to another in a linear direction. The second model has three additional types of energy and looks more complicated as indicated by the directions of the arrows. Most students' models were similar to the linear kind with additional types of energy.

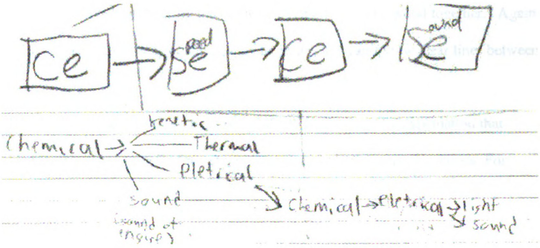

Figure 5: (Students work) Energy transformation models (ETD) for two different students.

4. Integrating in-school formal knowledge with out-of-school experiences:

An interesting result of this study was learners' confusion while integrating their formal activities in the energy unit with similar phenomena from their daily lives. An example of that is the question that asks students if they see similarities between burning wood in the fireplace and the chemical reaction in the class activity. Although they all see some similarities between the two cases, many of them were confused about the energy-matter conceptualization. For some students like Amma, the thermal and chemical energies are "mixed together" in order to start burning wood. Additionally, some types of energy stay there and others disappear, "when you burn wood you start with chemical and thermal energy together, and when it is just burning it's only thermal and it looses the chemical [energy]. The chemical reaction and burning are similar because they both are gaining thermal energy." Along the same lines, another student thinks that the heat of fire is produced as a result of "mixing the flame of the match and the wood together." Again, such ideas support the conclusion that students in this age can't draw clear lines between matter and energy.

In very rare cases, some students were able to use a scientific explanation that reflects their ability to transfer formal scientific knowledge to general contexts. For example, from Blake's point of view:

> When you burn wood, chemical energy is converted into heat, light, sound and kinetic energies. Chemical reaction and wood burning are alike because they both start with chemical energy and produces thermal energy. They also may produce other new products such as ash and carbon dioxide.

Overall results for cases

In the two previous sections I focused on particular examples from the six participants' reasoning regarding data analysis and ideas about energy. However, those selective examples may not give the reader an overall picture about the participants' reasoning. Thus, it is also interesting to see if there is any sort of overlap between students reasoning in one area, such as the data analysis skills, and another (i.e. students' ideas about energy). I will summarize the results in two tables: the first focuses on the data analysis skills (questions 1 & 3 in the interview) whereas the second table summarizes the students' ideas about energy (see scenarios 2 & 4).

Table # 6 results suggest that students' data analysis skills not only depended on their academic levels[10], but also they varied from one skill to another. The trend of the table shows that while learners were able to see patterns in data that is represented by graphs, realizing the pattern in a data table was less accessible for most students. Another noticeable result in this part is the contrast between some students' reasoning as reported by the interview and their performance through traditional assessment. According to the table the results, the overall best result was for a B-level student. This result is reasonable since the research interview questions were focused on specific areas of data analysis skills, whereby science teachers have other areas of interest (i.e. content knowledge). The rest of the results were generally consistent with the students' levels.

---

[10] Students' levels (A, B, & C) represent their academic grades depending on the school tests and their teachers' recommendation. For more details about the codes, see the data analysis section in the previous chapter.

Table 6: Students' performance in data analysis skills

Skills / Student (Level)	Reasoning about variable			Finding patterns in data			Evidence-based argument		Overall results
	A1*	C1	C2	A2 (table)	B5 (L.graph)	C5 (charts)	B4	C3	
Maddy (A)	2	2	3	2	2	3	3	3	20
Chandler(A)	3	2	2	3	3	3	3	3	22
Blake (B)	3	3	3	2	3	3	3	3	23
Kit (B)	2	1	1	2	3	3	3	3	18
Amma (C)	1	2	1	1	3	3	2	1	14
Austen (C)	2	0	1	2	2	3	2	2	14
Total	**13**	**10**	**11**	**12**	**16**	**18**	**16**	**15**	

* This represents the first sub-question in scenario #1.

Another interesting question would be: what students' reasoning about energy looks like within the entire group? The following table aims at reporting general comparisons among participants in order to answer that question. In addition to what was stated in the second section of the results about learners' ideas about energy, a deeper look at this table illustrates two additional findings. First, naïve ideas about energy, such as its association with living things and seeing it as an agent, could be found even among the best students. Maddy, one of the A-level students, thought that "other things give wood energy" and this energy originally comes from the match. She further believes that "the gas was used to power the car" and the gasoline eventually "comes out" once the car is done with it. However, she drew an energy conversion diagram that has seven types of energy and shows the process as a continuous cycle.

Secondly, the cross comparison results suggest that there is some sort of horizontal consistency among students' reasoning about energy. Put differently, there is evidence that those who reasoned superficially about one aspect of energy have done the same in other aspects. For example, students who believe that energy is associated with living things, which in fact was explicitly expressed by four of them, have also pictured energy as an enabler that helps the car move. Furthermore, their models of energy conversion were linear (e.g. one direction arrows). Similarly, students who tended to use more developed models about energy, were also able to explain energy conversion and to talk about many invisible parts of the system. Blake's and Chandler's responses in the table reasoning are examples about that.

Taken together, there is an interesting contrast between the two tables. In the one hand, the pattern in the first table shows that many participants reflect considerable reasoning about scientific data. It's true that some skills like comprehending the relationship between variables were not accessible for lower level students; most participants were able to realize patterns, make scientific predictions, and draw appropriate conclusions from data sets. On the other hand, the second exemplar table indicates that most students still have naïve conceptions about energy. It seems that although learners may collect and analyze reliable data and involve in the inquiry practices, this does not guarantee adequate reasoning about energy. Learners may develop many skills on the local level (i.e., reasoning bout variables and patterns), yet moving towards global models about energy stay limited and difficult.

Table 7: A representative summary of students' reasoning about energy in two scenarios.

Scenario	Wood in fireplace		A car at the gas station
Case (level)	**Energy in wood**	**Burning wood and chemical reaction**	**Where did the gas have gone?**
Maddy (A)	Wood has to burn somehow, but I think other things give the wood energy. When trees are alive, they have energy from water, soil, and the Sun.	Burning wood is similar to the chemical reaction because you have new substances like the ash. Energy comes from the match converting chemical energy into heat and light energy.	The gas was used to power the car. When the car is done with it, probably it has a device that leads to the exhaust pipe and then it come out as smoke.
Chandle (A)	It has to grow and it needs energy. Energy comes from the Sun, soil, and its surroundings. When you cut it, it has some chemical energy.	Burning wood is a chemical reaction; producing substances and heat. Chemical energy converted to thermal energy.	The car uses the gas in its engine as chemical energy and then is turned to thermal energy; the gas is burning and producing heat. Then it goes into some stuff in mechanic so that the car turns it into kinetic energy so that the car moves.
Blake (B)	Energy is stored in wood like chemical potential energy. It comes from the Sun through photosynthesis.	When you burn wood, CE is converted into heat, light, sound and kinetic energy. Chemical reaction and wood burning are alike because they both start with chemical energy and produces thermal energy and other new products such as ash and carbon dioxide.	The gas is chemical energy and it was burned in the internal combustion of the engine, which made pistons move up and down which made the car move to the Upper Peninsula. This produces carbon dioxide and sometimes monoxide as a waste gas and also produces lots of heat above the engine.
Kit (B)	Wood has too much energy when it's alive. Wood molecules have kinetic energy even when you cut it down.	When you burn wood, energy comes from the match when its light is mixed with nutrition of wood. Burning wood is similar to chemical reaction because wood is turned to fire and ashes.	When you use gas in the car it burns. The gas has energy, and when you burn it, it uses the thermal energy to power the car. The more the car drives, the more gas you use. The gas is burned away and gets out of the car from the gas exhaust.
Amma (C)	When it was alive it has to have energy to grow. This energy comes from the fact that it used to be a live.	When you burn wood you start with chemical and thermal energy together, and when it is just burning it's only thermal and it looses the chemical.	The gas has to be used to turn the car so that it could go to wherever you wanted to go, and when it ran out, there was not any more power for the car. I think that the gas might have a little bit of chemical energy that has to be used in the vehicle.
Austen (C)	Wood has no energy at all because it is just passed away, not doing anything else it is just staying there	Fire heat is a result of mixing the flame of the match and the wood.	It is burned off, it's not really burned off, but it is just like run away to the exhaust. I am not totally sure about where does it go, but the car used it up and threw it away. The gas does not have any energy at all.

Pedagogical aspects of data analysis

In the previous sections, I attempted to help the reader make sense of the learning aspects of data analysis within the context of energy. In this part, I pay more attention to the process of enacting the designed activities with particular emphasis on three areas: discussing investigation variables, looking at pattern in data and drawing conclusions from it, and treating anomalous data. The purpose of focusing on those three activities is primarily to compare how the participants reasoned about data in the classroom as well as in interviews and to report how the teachers responded to their interaction with the caitiff data. In other words, it is not to evaluate the teachers' enactment or to evaluate the IQWST designed activities.

However, these teaching aspects are helpful because they form some interesting aspects of the comprehensive story. One should keep in mind that this unit was enacted by two experienced, committed, and enthusiastic science teachers. They patiently went the last mile in order to help their students make sense of a shady scientific concept, like energy, through guided inquiry and continuous dialogical process. Among many other significant characteristics, those teachers willingness' to learn new scientific topics was remarkable.

- *Teachers' ways of exploring investigations variables:*

Findings from classroom observations suggest that the two science teachers who enacted this unit have followed a dynamic, but a well-organized, technique while translating the designed activities into classroom experiences. In spite of the fact that the energy lessons were orchestrated differently, the teachers tended to use the following strategy in a systematic manner: housekeeping, introducing the activity through discussing students' intuitive knowledge, data collection in groups, and drawing conclusions. The longest period in terms of the class flow was usually the introductory discussion about students' ideas. So often, teachers tended to use them as a scaffolding transition to introduce learners to new scientific concepts about energy. Within that introductory discussion, I focused my analyses on the variables of investigation because they sounded central in most energy activities.

Anne, one of the two science teachers who enacted the unit, used to discuss the investigation variables in order to make data collection more accessible to all groups. However, when an investigation has multiple variables involved, such as height, mass, and speed, she relies heavily on pushing students to reason in a way that is consistent with the designed curricula. Following is an example of her discussion when she was trying to help students isolate the variables that might affect the kinetic energy of a falling book:

Teacher: let's go back a second, what is kinetic energy?
Students: motion.
T: motion, do you think about kinetic energy for those textbooks while standing there?
A student: no, unless we drop them.
T: that's a great idea! We are going to do that in a minute. But let me remind you about the list [of factors] that you came up with yesterday. Who can read it for the class?
S: mass, speed, weight, height, movement, motion, power, density, and gravitation.
T: when we talked about the volleyball, I heard two words in most of the groups: mass and speed. Those are the two that we are going to look at, let's start with speed. We are going to drop books on the play-doh and look at something called "smoosh"

factor, could you please go to activity 2.2 and read the purpose silently? (Teacher and students read).

Ann then explained the purpose of the activity was to learn about the factors that affect how much kinetic energy an object might have. Furthermore, students wrote their predictions about the activity's central question: *How can we use play-doh to determine whether there is a relationship between the* <u>*speed*</u> *of a moving book and the amount of kinetic energy it has?* As one might expect, students came with many ideas that were not necessarily overlapping with the teacher's agenda. This was obvious to me when the teacher responded to one of the student's suggestions while answering the central question.

T: who can give me one sentence as a response to that question, what can we do to figure this out?
S: drop the textbooks on the play-doh from different heights.
T: Ok, what can we get from that, then?
S2: the higher the book, the faster it will be.
T: Will you be able to see the speed?
SS: no.
T: does everybody's idea include different heights?
Some students replied by yes, but others said no.
T: let us say this, we are going to look at height, but we are not going to do that today. What we want to do is somehow change the speed, but not height. You're making an assumption or maybe from your experience in terms of what height do to speed.

Scientifically speaking, dropping books from different elevations is a valid suggestion to change speed. Height will however be the central variable in the second lesson when students will be investigating gravitational energy. Consequently, the teacher was more committed to the designed curriculum in spite of the dialogical approach that she has shown while discussing students' initial thoughts. Interestingly, discussing the investigation variables was not enacted similarly by the two teachers in spite of the fact they refer to same activities. The second science teacher preferred to be more straightforward in terms of stating the variables and discussing them. So often, she listed the dependent, independent, and control variables on the board without developing controversial arguments about them.

- *Finding patterns and drawing conclusions:*

There is solid evidence that the two science teachers who implemented the energy unit were deliberately reinforcing students' reasoning from scientific data in order to develop evidence-based arguments. According to findings from the classroom observations in most of the focusing teaching episodes, the teachers have explicitly discussed the terms evidence, pattern in data, and scientific conclusion. Regarding helping students realize patterns in the data, teachers have reflected two different roles while mediating the discussion between students and data. Frequently, students were able to make appropriate predictions about what they think the results might be. In other words, finding the pattern in data was not used as a method to inquire an unknown result, rather it was collected to reassure the prediction that students have made (i.e. confirmation lab). In such a case, teachers did not face problematic situation and thus students accepted the pattern in data and were able to draw appropriate scientific conclusions. In other investigations, although they were limited in numbers, teachers were confused when they faced a situation when students collect anomalous data. Anomalous here means having accurate scientific data that contrasts with learners' predictions. In this latter case, the powerful students' intuitive experiences and the teacher content knowledge were the main sources of trouble. Consequently, patterns in data were not realized insightfully and sometimes the data was rejected. Next, I will give an example that illustrates each case.

While introducing the gravitational energy, Chris, the second science teacher, reminded her students about the last activity, the kinetic energy, and about its central variables: mass and speed. With a smooth transition, she returned back to the arguable variable they brought in the previous class, "because you mentioned elevation last time, I told you that we'll come to that later." Like their peers in Ann's class, students in this class have also argued that elevation could be a factor that can change the kinetic energy of a falling object. In the following discussion, Chris was trying to force students to make scientific predictions about the relationship between a falling object's elevation and how much gravitational energy it might has.

> *T: Now, in this activity you are going to make a prediction. You are going to try and determine: if I throw objects at different heights, how it influences the smoosh factor of the play –doh? I don't want you to say that it will affect the smoosh factor, I don't want you to make a lucky guess, but I want you to explain why do you think so? Remember, it is OK if it's a wrong guess.*
>
> *T (after 4 minutes of writing predictions): Can some one give their opinion?*
>
> *Chandler: um, the higher the drop is, the more smoosh will be because when the book is higher it has more energy.*
>
> *T: OK, the higher the book is the more energy it has. Anybody else?*
>
> *Sarah: the higher you have the book, the faster it drop down and having more kinetic energy and better impact.*
>
> *T: anybody have anything different? They are pretty the same thing?*
>
> *T (as nobody responded): Why do you think it will have more smoosh?*
>
> *Kit: because it has more momentum as it falls.*
>
> *Alex: because of gravity.*

T: what about gravity?

Alex: because it pulls it back down.

T: OK.

Chandler: like if you drop a penny on your head from 2-feet elevation nothing will happen to you, but if you drop it from 100 –feet height, it might kill you.

T: OK, those are great ideas! So, what do you thing about the relationship between height and energy, then?

Kit: the higher you drop the book the more speed it will gain.

T (repeats the answer): OK.

Again, students have valid predictions and legitimate ideas about motion and energy even before carrying the activities out. However, they may not necessarily collect the data the way that teachers expected. For instance, many students were throwing the books rather than dropping them[11]. Other students were measuring the thickness of the play-doh inaccurately. In spite of that, students were able to find a general trend that there is a positive relationship between gravitational energy and its two factors: mass and height. Thus, the conclusion that "the higher and the heavier an object is, the more gravitational energy it will have," was reached by all groups.

Looking closely at some inconsistent results, where the lighter book or the one that was dropped from less height seemed to have more "smoosh" factors, the teacher's justification that "maybe the weather temperature has affected the play-doh" did not sound convincing. All groups used the same play-doh and even if its condition has changed, this has nothing to do with odd results. In fact, one of the students' reasoning sounds more reasonable when he said, "perhaps the ten centimeters elevation was not big

---

[11] By doing so, the falling object will have initial velocity (i.e. $V_o \neq 0$) instead of the free falling supposed case, and thus there is another variable other than the height.

enough to show real differences in the outcomes." The teacher did not pay considerable attention to his insightful suggestion.

- *Treating conflict with anomalous data:*

Patterns in data are usually easier for students to realize and for teachers to negotiate as long as they are consistent with students' predictions. These pre-existing thoughts are usually developed in a long period of time throughout learners experiences with the world around them. This was vivid in most of the focus activities that had something to do with motion and falling objects (i.e. gravitational and kinetic energy). However, if data show a trend that contrasts with students' conceptualization, then science teachers may find themselves in a controversial situation. This particularly becomes more complicated if the teachers themselves don't have sufficient content knowledge in that area. The teachers faced such a situation while explaining the free falling objects and elastic energy examples[12]. The following example explains how the teacher and students interacted with data when it showed a pattern that is opposite to their predictions.

While conducting the elastic energy activity, students thought that soft springs will jump higher than hard springs. This is not an unusual prediction because students were referring to daily life experiences that imply pushing soft springs is easier than the heavier ones. However, in the spring activity there were additional variables besides the spring hardness such as the distance of compression and the spring's mass. This perhaps

[12] Free falling phenomenon happens when an object falls under the influence of the gravity force. Students' misconception in this regard includes their thinking that heavy objects fall faster than light objects (for example, a 10 Kg block versus a penny). Some students, however, think the opposite: because the penny is lighter it falls faster than the heavy object. Theoretically, the two objects fall at the same speed under gravity acceleration, unless the shape of them was influenced by air resistance.

was the main source of the confusion. The following discussion took place when students reported the data they collected after conducting an investigating about three springs.

T: When you did this experiment, which one was the easiest to compress?

S1: spring number one.

T: number one, did it go the highest, the lowest, or something in the middle?

S1: it was the highest.

T: so, for you, your easy spring was the highest. OK, how bout this table (asking another group)?

S2: number one was the easiest, but it went like (trying to read the result).

T: OK, which one went the highest?

S2: number three.

T: number three, and that was the hardest to compress. All right, Steven what about your spring?

Steven: the heaviest went the highest.

T: your heaviest went the highest. OK, Alah, what did your group decide?

Alah: number three went the highest.

T: OK, number three. What about this group?

Kit: number one was the highest, but that was the average! We have like spring number three was sometimes higher.

T: you want the average, though. So, for your average the easiest one was the highest.

In fact, most groups found that the harder the spring was, the higher distance it reached. Only one group found the opposite. In spite of this fact, the teacher decided that, "we don't have any conclusive evidence and the groups' results were split." Furthermore, she did not pay enough attention to the student who was trying to explain the problem in her average. Kit was right when she explained that "number one was the highest, but this was the average." If there was an extreme wrong measurement in the three trials, this likely might lead to misleading average. The result in such a case was mathematically reasonable, but scientifically inaccurate. An interesting opportunity for measurement errors and its implications from science and mathematics perspectives was missed.

The discussion that followed reporting the results was important because it could be linked to the students' reasoning in the clinical interviews. According to Chandler's response in the class, "the hardest requires more energy to push it down and thus it has more elastic energy stored in it." In fact, Chandler was the only interviewee who drew an appropriate conclusion about the same scenario. Students who resisted the new data, like Austen, still think that "the soft spring is easier to compress and so it makes sense to me that it went higher." Again, this kind of reasoning was found in most of the interviews. Thus, finding a similar line of reasoning in the classroom discussion was not a surprise for me.

Looking closely at the previous results from the classrooms dialogue, I noticed that the two teachers did not show explicit teaching strategies that motivate students to use model-based reasoning. It is not clear, however, if their lack of content knowledge, such as the physics of the moving spring for instance, or the nature of the activities themselves was the reason for that. Again, patterns in some activities in the energy unit, such as the kinetic and gravitation energy activities, could be realized whether learners used force-dynamic or model-based reasoning. Other activities or scenarios, such as patterns in the spring's motion, were sophisticated in terms of their physics and thus using force-dynamic causation was not helpful to find the pattern[13]. My study design, however, did

---

[13] A force dynamic learner will say because you pushed the spring more, it has stored more elastic energy, thus softer springs go higher. A model-based learner would say that the hardness of the spring is important in this case. There is a difference between pushing two different springs by the same force and pushing them for the same distance. He also realizes many factors that matter here: the hardness of the springs, the mass, and the distance of compression. Understanding the relationship between these factors is not like the case of dropping books.

not include data collection methods that give the two science teachers reflection opportunities to justify their actions and decisions.

Chapter Summary

Findings of this study show a line of consistency among students' reasoning about investigation variables and patterns findings in the interviews and the classroom observations. Many examples of confusion and difficulties were reported in both cases. Furthermore, students' ideas about energy, particularly as reported in the general scenarios, are still governed by force-dynamic reasoning. They see energy as something that is associated with living things, a helper that enable us do our work, or a fluid that moves from a place to another. In other words, transforming local knowledge into more complicated scenarios is not clear.

Chapter Five

Discussion and Implications

In this commentary chapter I address two main topics. First, I discuss the findings of this study, particularly learners' reasoning from data and their worldviews about energy. Additionally, I correlate those results to literature. It is an attempt to make some interesting contrasts that were revealed from this study. The second part, which I called reflection, is another way about thinking "outside the box." This part is about my experiences as a researcher. Next, I will summarize the main findings before to help the reader make sense of the discussion that follows.

Findings Summary:

Major findings of this study could be summarized in the following three areas:

- *Reasoning from data results:*

a) The final findings found that most participants were confused about treating the variables under investigations. They concentrated on local observations (e.g., the smoosh factor) rather than moving towards general model reasoning about kinetic and gravitational energy.

b) The second result in this regard was finding patterns in data. Participants' skills here were influenced by many factors: mathematical consistency in data, and the type of data representation (tables versus graphs), and students intuitive knowledge.

c) Most participants were able to develop evidence-based argumentation as long as the data was representing a simple scenario, once data refers to complicated scenarios only high level students could draw valid evidence-based arguments.

d) Students were able to draw both Energy Conversion Diagrams (ECD) and to till accurate scientific narrative about energy conversion. However, when it comes to the Energy Transformation Diagrams (ETD) that were new to them, the models were mostly simplified and one directional for most students, some sophisticated models drawn by two of them.

- *Participants' ideas about energy:* Findings in this regard were to some extent similar to other findings in the literature about students' conceptualization of energy.

  a) Energy is associated with life.

  b) Energy is an enabler (or agent) that helps us do things, or machines run.

  c) Energy is materialized, it could be mixed or be a product of something.

  d) Energy is synonym for other scientific concepts such as momentum, force, and power.

- *Pedagogical aspects of reasoning from data and energy:*

  a) Teachers have shown high commitment towards the designed curriculum. Yet, the two teachers' enactment process was different.

  b) Teachers and students have smoothly treated the less "trouble-making" data: the data that show a vivid pattern. However, when data did not meet students' predictions or when it was anomalous to them, then the dialogue seems to be governed by students pre-existing knowledge.

Discussing the results of the study

Having summarized the previous results, it seems that this study have brought to the surface two of the most complicated fields in science education: reasoning from scientific data and students ideas about energy. According to the recent study findings as well as the literature that I have reviewed, there are two vivid conclusions that confidently could be drawn and they are: a) The evidence that has been reported regarding students' difficulties (i.e. misconception or confusion) about energy is much stronger than a few promising cases. B) This study and relevant literature have also pointed to another line of consistency: learners' informal tools of developing scientific knowledge are likely situated within out-of-school contexts and these contexts have more authoritative influence on their ideas about energy than the formal science.

How could we understand the findings of this study in terms of students reasoning from scientific data and about energy? In order to answer this question, I will integrate the recent results with other findings from literature. To simplify the discussion, I will focus on some interesting contrasts that have been consistency found in this research and the relevant literature

A) Local to global reasoning from data:

Students have shown that they are fluent in terms of local data analysis. For example, they all were able to read local points in a graph or a specific point in a data table. In this regard, locality of reasoning also means focusing on direct observations (the changes in the smoosh factor) without necessarily than connecting that effect with kinetic and gravitational energy. Finding a pattern in data requires, however, the learner to move from local to more general reasoning that implies realizing the relationship between variables that are involved in an investigation. Many previous studies have shown that the more variables an experiment includes, the more confusion students might face (Jeong, Songer, Lee,2007; Leinhardt, Zaslavsky, Stein, 1990; Lubben, & Millar, 1996) While reasoning about gravitational or kinetic energy activities, students came up with a long list of variables that could be influential in both cases. The fact that there are many factors, such as height, mass, speed, isolating these variables one from another is rather a difficult task, particularly when energy is converted from gravitational to kinetic or the opposite.

B) Force-dynamic causation to model-based reasoning:

Some scenarios of this study sounded more accessible to students than others. For example, when they were asked about their predictions about the gravitational energy scenario, most students were able to do that. However, when it comes to more complicated scenarios, such as the spring activity or the fireplace, the number of students who can reason from model-based perspective dramatically decreases. This kind of reasoning requires multi-level of understanding. This includes: realizing the constraints and principles, dealing with multiple representations, making connections among the different parts of the system. In fact, many research groups have found that even students in high school level many not be able to reason that way (Lin & Hu, 2003; Jin & Anderson, 2007). Learners in middle school level have tendency to focus on visible, macroscopic, and natural tendency of scientific phenomena.

It is not clear whether IQWST curriculum designers were deliberately aiming at pushing students towards this kind of reasoning. There is solid evidence in this study that students were able to collect and analyze data through the guided inquiry teaching. They further were able to reason about energy transformation representations, such as ECD and ETD, sufficiently. In a sense, they are partially model-based learners. Anderson's (2007) diagram that illustrates developing models from observations does not work in school and scientists communities in the same way. Thus, force-dynamic causation, especially in a topic such as energy, is not an unusual finding.

The wood in the fireplace and the car on gasoline station scenarios have strongly shown that middle school learners reason about energy from a force-dynamic causation point of view. There are many considerations that should be discussed here. First, unlike the other two scenarios, those two are not directly related to the IQWST energy unit. They rather are general questions that were basically designed to investigate participants'' reasoning about energy. Thus, transforming learners' understating about energy into these scenarios is not expected.

Aikenhead (2004) have insightfully explained why the possibility of transform us very rare, "the transformation of canonical science knowledge into useful everyday knowledge requires that it be deconstructed from its universal context [the energy concepts in the classroom] and then reconstructed according to the idiosyncratic demands of everyday context [such as the car at a gasoline station]." This transformative knowledge, from Aikenhead's perspective, "has agency in other situations, whereas canonical content knowledge found in science courses would seldom have agency." (p.260). I see this process of the "deconstruction" and "reconstruction" of the scientific knowledge is very similar to model-based reasoning.

C) From conceptual change to conceptual integration:

Perhaps participants' worldviews about energy were the most vivid findings of this study in terms of its overlap with the similar literature. Students ideas about energy are powerful, legitimate, and were developed mostly in out-school contexts. Like many other science education researchers (Resnick, 1987; Driver & et.al, 1994; Duit & Haeussler, 1994), I believe in developing these ideas, departing from constructivist point of view, rather than conceptual change perspective. In their outstanding analytical piece about how learners construct knowledge in the daily life settings, Driver and his colleagues stated that:

> As far as people's everyday experiences are concerned, the informal ideas are often perfectly adequate to interpret and guide action. Fires *do* burn down to result in small pile of ash- a widely used way of getting rid of unwanted rubbish. If you want to keep a piano moving across the floor you *do* need to keep up a constant push. It is not surprising that ideas that are used and found useful are then represented in everyday language. Perhaps such as being "as light as air" or something being "completely burned up" both reflect and give further support to underlying informal ideas" (p.8).

This is very similar to children ideas about energy. The car at the gasoline station is a systematic experience that most children see on daily bases. The "gasoline is gone or just get burned" is a common language that may not be simply replaced, but rather advanced. This kind of advancement may be achievable goal through a dialogical process between the "common sense" knowledge and an authority (usually the teacher). According Resnick (1987), there are two conditions for productive negotiations:

providing support and guidance and at the same time listening carefully to the learners. By doing so, "teaching from this perspective is thus a learning process for the teacher and he is the often hard-pressed tour guide mediating between children's everyday world and the world of science" (p.11).

Looking back at the two science teachers who enacted this unit, they indeed were mediating the dialogue between students' world and science world. Through my observations, I was enjoying a different type of teaching science. They went the last mile while listening to their students' ideas. Their willingness to learn science from the energy unit and other resources was noticeable. However, further research is perhaps needed in order to explore their classroom actions and decisions regarding specific findings of this study. Next, I will discuss some of the study limitations.

Study Limitations:

This study has many limitations in terms of its results, data collection methodology, and its context. First, this is a case study that focused only on six participants and therefore its findings may not be generalized. Rather than providing comprehensive results about middle school learners' skills in data analysis and worldviews about energy, it gives an example about that. Perhaps collecting data through additional tools, such as written assessment, and including a bigger sample will provide additional venues for understanding how students from different academic levels reason about scientific data. Furthermore, the results of the recent study were related to the energy activities. The interview questions and scenarios were also consistent with these types of activities. Giving the abstractness and students' difficulties about energy, it might be interesting to pay more attention to more accessible and concrete scientific concepts.

Secondly, the study was conducted in an independent school that has many special characteristics. Examples of these are the considerable flexibility in the school schedule and the length of classes' periods, the number of students in each class, the technological infrastructure, and the general educational policy. These aspects many not be found in other schools. In fact, my participation in IQWST has shown that the context of teaching and learning (e.g., the teachers, learners, and local community) plays a critical role in the process of curriculum enactment. Therefore, the results of this study are associated with its context.

Finally, the study tools were limited to observations and interviews. Again, another valuable dimension might be added if the two teachers who participated in this study were given the opportunity to reflect on their actions and decisions regarding data analysis. My data collection methods did not include interviewing the two teachers for economic and procedural reasons. The goal was collecting sufficient data that provide me with valid sources for answering the research questions. Thus, we have to keep in mind that this research results don't include teachers' strategies of curriculum enactment or teaching materials evaluation. Wilend (2006) reminded us that in qualitative research "data is typically collected with interviews and observations (listening and looking) often as part of some of fieldwork. But not all the information we collect turns to be data" (p.7). In my case, it is true that not all the collected information was used as data, but it seems that using additional methods might enrich the findings of such research.

Implications:

In spite of the previously mentioned limitations, this study has many implications for teaching and learning science, curriculum, and for future research. The results of this study show that middle school learners rely on force-dynamic causation about energy. Although this was not a surprising outcome, especially from middle school learners, science teachers can play an essential role in order to reinforce model-based reasoning. In spite of the fact that classroom observation have shown that the two science teachers were using productive dialogical approach in teaching science, there is no evidence that they were reinforcing model-based reasoning about energy. Students have used a long list of synonyms and concepts to talk about energy such as: momentum, gravity, force, and power. Frequently, learners have used these terms as appropriate language for their force-dynamic causation, particularly when they attempted to correlate informal science with school science (Solomon, 1983a). Perhaps professional development, with more emphasis on content knowledge, can play a significant role in terms of advancing science teachers' pedagogical knowledge that is related to model-based reasoning.

This research findings have also many implications for curriculum materials and curriculum design as well. Many previous studies have suggested that school curricula should include wide range of reasoning from data opportunities (Kanari and Millar (2004); Nicholson, Ridgway, & McCusker, 2007). In school science, learners are often asked to explore situations where two variables covary. The existence of a pattern or a trend is often immediately clear from the data they collect. They are rarely asked to investigate the effect of a variable that does not (in fact) covary with the outcome. Thus, conducting investigations from both types will enhance their reasoning from data abilities. Furthermore, I think that Duit's & Haeussler's (1994) recommendation to integrate science, technology, and society (STS) within the science curricula might be useful in linking the out-of-school knowledge and the formal learning settings, particularly in topics such as energy.

Like most of research in education, this study is an incomplete story. It opened new directions for future investigations. For instance, the following questions remain unanswered and they might be interesting future projects: How do learners from other school contexts, such as public schools, and other grade levels reason about scientific data? Would learners' skills and abilities be different from the recent case if the concept under investigation was other than energy? What are the teachers' considerations and justifications that have shaped their enactment of this energy unit?

Reflection

- *Reflection on the tools:*

What additionally could we learn if students' reasoning from data and their ideas about energy was assessed using written assessment? The main tool that was used for data collection was the interview. It is important to note that these interviews were not identical in spite of using a special protocol. In many cases, I learned from the previous interview. So, I used such an opportunity to extend the dialogue with the next interviewee. In fact, I don't see in this any problem, I rather consider that a legitimate way to learn from my own work. In interviews, we use our authoritative position. We add more questions, seek deeper explanations and justifications, and we also may decide to stop asking more questions. This is not the case in the classroom observations.

Unlike the interviews, observation as a data collection tool takes away most of the researcher authorities. Once you observe, you can't lead the dialogue in spite of the very fact that you are a selective observer. The teacher, his students, and the curriculum materials interact in a complicated social way so that it becomes impossible to predict what might happen after a minute. Classrooms are uncertain environments. Although we design activities that need well-known materials, we may know the teacher's abilities and background, but we hardly know something about learners' and their worldviews about science. Researchers are selectively making their decisions. We decide which group to focus on, which portion of data to pay more attention to it. For somebody else, perhaps the moments that we have ignored are more significant and interesting than what we reported.

- *Reflection on experience:*

There is a unique thing that most of graduate students, particularly those who came from international backgrounds, learn while doing their research: experiencing education of the others (i.e. the American). I did this research in an American school and this experience was another PhD. In addition to that school, I visited many other schools in rural, inner-city, and suburban areas. As a result of these different experiences, I have advanced my own understanding of the meaning of the term "context." I remember how my first experience inside an American classroom was! By that time, I did not feel that there was any "good" teaching or learning. My own vision of teaching and learning was developed through many years of teaching science and math in Palestine. Thus, it was like the glasses on my eyes, filtering what I see. In fact, this unique experience is very important in answering many questions about teaching and learning in different cultures and contexts. Yet, the initial questions about the meanings of teaching and learning are still there; in fact the list is now longer.

Chapter Summary

Students in middle school students draw from a wide range of out-school experience and they legitimately use this discourse to talk about science. In spite of the fact that they can treat scientific data and use models to reason about energy conservation and conversion, they are not necessarily depending on model-based reasoning. Rather, they have tendency to relay on force-dynamic causation. Science teachers can orchestrate dialogical strategies to bridge the out-of-school informal knowledge with the formal school science.

Appendices

Appendix A: Description of the Energy Unit

The energy unit is designed for middle school level students. The entire unit is organized around a driving question (Fortus, 2007).This question is supposed to be "a rich and open-ended question that uses everyday language to connect with authentic interests and curiosities students have about the world" (p.ii). The energy unit driving question is: "Why do some things stop and others keep going?" The 14 lessons of the unit are then organized around three learning sets (LS). Each of these sets emphasizes a specific area of the big driving question and at the same time has some sort of unifying potential for some types of energy. The following table summarizes the three learning sets including their driving questions, the types of energy in each set, and the scientific principles that are addressed by the national standards.

According IQWST designing point of view, learning science has the following aspects:

1. Learners engage in guided-inquiry activities. Each of these activities addresses an interesting idea about energy. Learning science is a social process and thus IQWST curricula gives priority for working in projects through small groups.
2. Students collect, organize, and analysis quantitative and qualitative observations in order to advance their learning about energy types and principles.
3. Learners involve in many design activities, such as designing Rube Goldberg machine, to help them make sense of energy and its conversion.
4. Curriculum materials should be simple, accessible, and attractive for learners. It should be also educative for teachers and their professional development. Technology plays essential role in learning and therefore computers, movies, and other apparatus are used in most activities.

Table 8: The energy unit lessons and activities (Fortus, 2007).

Learning Set	Energy Lessons (types)	Activities	Learning Standards
LS1: *What determines how fast or high an object will go?*	• Kinetic energy • Gravitational energy • Elastic energy	1. Qualitative observations and watching many videos that has something to do with energy. 2. Conducting investigations to learn about the factors that determine kinetic, gravitational, and elastic energy. 3. Building the Energy Conversion Diagrams (ECD).	• Kinetic energy is associated with the speed and mass of an object. • Gravitational energy is associated with an object's and its elevation from a reference point. • Elastic energy is associated with stretching of and elastic object. • Energy can't be destroyed (energy conservation) but can be transformed from one type to another (energy conversion).
LS2: *Why do some things stop?*	• Thermal energy • Sound energy	1. Exploring energy systems, transfer, and conservation. 2. Determining the factors of thermal energy in objects. 3. Exploring sound energy activities. 4. Exploring molecules motion in liquids and solids	• Thermal energy is associated with the temperature of an object. • Sound energy is associated with sound waves. • Atoms and molecules are in motion; increasing (or decreasing) temperature implies changing that motion. • Energy cannot be created or destroyed. Whenever some types of energy seem to appear in a place, another type will sound to disappear in another place.
LS3: *Why do some things keep going?*	• Chemical energy • Electrical energy • Light energy	1. Thermal energy in chemical reactions. 2. Exploring factors that determine chemical energy. 3. Electrical energy transfers through simple circuits, generators, and power plants. 4. Exploring light energy.	• Chemical energy depends on the chemical composition of a substance • Light energy is associated with light waves. • Electrical energy is associated with closed circuits and power sources. • Electrical energy could be produced from other types of energy sources and could be easily transformed into almost any other type. • Electrical circuits are used to distribute energy to different locations.

Appendix B: The interview protocol

A) The Gravitational and kinetic energy activities:

Remind students about the activity in which they dropped different masses (books) from different elevations in order to find the "smoosh" factor. Then show him/her the play-doh cube and how they took the measurements. While introducing the following data table, I'll explain to the interviewee that group "A" dropped 5 different masses (each was dropped three times) from a 10 inches height, whereas group B did the same activity but from 20 inches height.

Table 9: The interview data table

Dropped mass (Lb)	Group A's results Average of "smoosh" [mm] (Height = 10 inch)	Group B's results Average of "smoosh" [mm] (Height = 20 inch)
1	4 mm	4 mm
2	7 mm	11 mm
3	10 mm	13 mm
4	15 mm	13 mm
5	20 mm	25 mm

I would like to focus on the data in this table (give him/her one minute and then start probing the following questions).

1. Why do you think that the class has used 5 different masses? Two different elevations?
2. Do you see any pattern in the data? Explain that to me.
3. How do you connect this data (event) with energy? What kinds of energy are involved in this activity? How?
4. I would like you to draw an ECD for the dropped book at positions 1, 2, and 3. (Identify these positions to be at the beginning of the free falling, the middle, and just before the book hits the play-doh. I will draw a diagram on the board as an example of this scenario).
5. What do you think about group **A**'s data and group **B**'s? If the interviewee stuck here, ask him if he sees any problem (or anything strange or disagreement) with the results. If he identified a problem in the measurements, ask additional questions if we can correct it and how.

6. Assuming that the books were dropped freely (free falling objects), do you think that the previous results (data) will change if the books were thrown? Why? Why not?

B) Chemical Energy and Thermal energy:

Show the following picture of the fire place and introduce to the question by saying that many American families prefer using wood for heating their homes in winter.

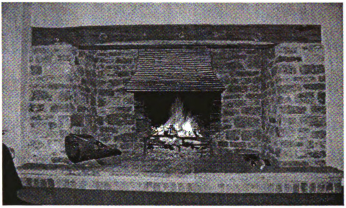

Figure 6: Wood in fire place picture.

1) Do you think that wood has any type of energy? Could you please explain that to me? Where did this energy come from?
2) Could you please explain the energy transformation that happens when we burn wood?
3) Do you see any similarities between burning wood and the chemical reaction activity (remind interviewee about that activity)?

The following graph shows the change in the room temperature as a result of burning two kinds of wood: Oak and Elm wood in the fire place. I would like you to concentrate on the graph and then I'll ask you some questions about it.

4) What will the temperature increase be if we burn 4 logs of oak?
5) Which wood is better for your fire place? Why?
6) Do you see any pattern in the graph? Explain that to me.

Probe with the students to see if they can realize the relationship between the mass of substance (wood) and the heat increase as a result of converting chemical energy into heat.

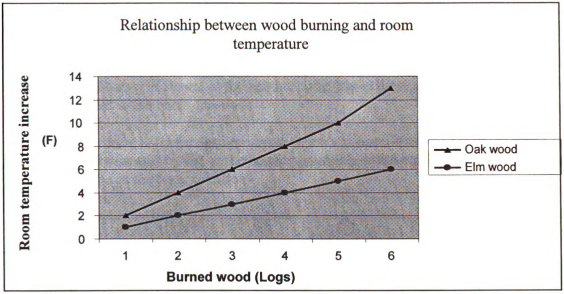

Figure 7: A graph of the Relationship between burned wood and a room's temperature.

C) Elastic energy activity:

Remind students about the activity 4.3 about elastic energy; show him/her the apparatus (springs, stand, and the ruler) and the following picture. Then ask the following questions:

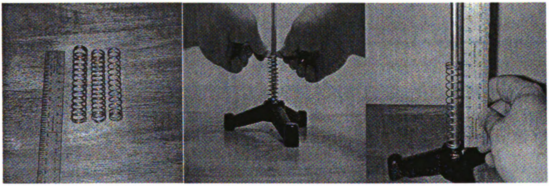

Figure 8: A picture of the elastic energy activity.

1) Why did we use three different springs? What was the difference between them?
2) Why do you think that we compressed the springs for 1 cm at first and then in the second route we compressed it 2 cm?
3) What did you measure? What was the evidence that your group used to differentiate between elastic energies of the three springs?

Imagine that we have 5 different springs (S1, S2, S3, S4, and S5). Each of these springs was compressed for the same distance, say 1 cm, the class then reported the following results about the flown distance for each spring.
Give the interviewee one minute to focus on the graph and then ask start by asking the following questions:

a) According to the graph, which spring has around 38 cm average flown?
b) Could you please describe the graph?
c) Could you please rank the springs from the hardest to the softest?
d) I would like to draw ECD for springs in two positions: once it's compressed, at the middle of the distance of flown, at the heights point (show these position on a diagram on the board as I did in the book question).

I would like to draw ECD for springs in two positions: once it's compressed, at the middle of the distance of flown, at the heights point (show these position on a diagram on the board as I did in the book question).

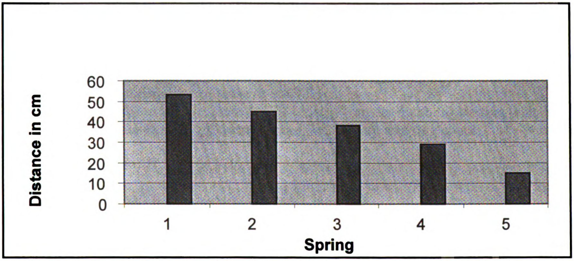

Figure 9: A graph of the relationship between springs types and moving distance

D) A car on a gas station scenario:

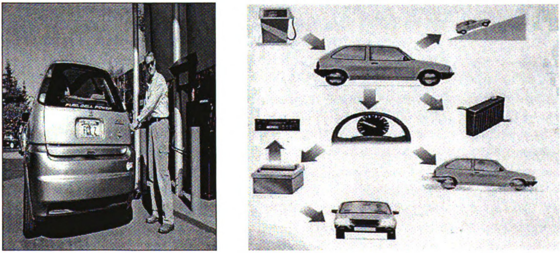

Figure 10: A picture of a car on a gasoline station

I will first show the picture to the left and then I'll tell this short narrative: Your dad filled the tank of his car before traveling from Ann Arbor to the Upper Peninsula in Michigan with 20 gallons of gasoline (around 150 lb). After the trip, he has to fill the tank again because the indicator of the gasoline indicator pointed to E, which means empty. After telling the story, I'll ask the following questions:

1. I would like you to think about where did the gasoline go?
2. Can you think about all types of energy transfers that have been taking place in the car while it's traveling? I'll ask the interviewee more questions whenever he mentions something like KE, GE, light energy, or thermal energy.
3. What are the ETDs, which stands for energy transfer diagrams, that you are thinking about in this case? You may draw anything that represents those?
   If the student's responses were very limited (or irrelevant) in the first stage, I will show him the picture on the left side in order to encourage him/her for extended responses.
   a) What kinds of energy transfer process that are happening here?
   b) Can you explain one of these to me?
   c) I would like to draw a general ETD (energy transfer diagram) starting from the gasoline pump to show all the processes that you are thinking about.

Appendix C: An exemplar sheet about Coding students' response[1]

Table 10: An example of coding students' data analyses skills

Code	Examples of participants' responses on the data analysis skills		
	Reasoning about investigation variables (C1): *Why did we use three different springs?*	**Finding Patterns in Data Table (A2):** *Do you see any pattern in data? Explain your response?*	**Drawing evidence-based argument (C3):** *Explain the evidence that your group have used to differentiae between the elastic energy in the three springs?*
3	To find if the hardness of the spring affected the elastic energy of the spring. These three springs are different in hardness.	Yes, I see that. I think that if you increase the mass, the "smoosh factor" increases, and I think that the 20 inches elevation generally has more "smoosh factor" than the 10 inches	We measured the height of the spring as an indicator for how much elastic energy the spring has because we can't measure the elastic energy directly.
2	To test the difference, the elasticity of the three different kinds (springs). The difference between them is that the material is thicker.	In the first one (G A's data) yeh, because it changes a little bit each time, it stays the same for the 3 lb and for the 4 lb and it does not seem to make sense.	We measured the height like how much it went up to see like which one has most elastic energy and it was the lighter one to the right.
1	To see how each spring have hardness or springiness. The difference between them one was like harder, and one was kind of in the middle, and one was like a lot easier to compress.	NA	The evidence that we used in this case was the different materials and they were harder to compress.
0	Probably to get different results, because if like you use the same ones, you will have the same stuff the whole time.	Well, not really because the first column has the same thing, I don't really think that there is consistency.	NA

[1] The codes were explained in the methods chapter, here I am giving examples of the actual response and their codes. Code 3 (complete response), 2 (almost complete, but something is missed), 1 (the response is incomplete, more than a basic part is missed), and the code 0 (the participant's response is not relevant).

References

Aikenhead, G. S. (2004). Science-based occupations and the science curriculum: Concepts of evidence. *Science Education, 89*(2), 242-275.

American Association for the Advancement of Science (AAAS). (1989). Project 2061: Science for all Americans. New York; Oxford University Press.

Anderson, C. W (2007). Teaching science for motivation and understanding. Unpublished manuscript, Michigan State University.

Ball, T (2008). Debates over the global warming. Retrieved 5-10-2008 from http://www.youtube.com/watch?v=XDI2NVTYRXU

Ben-Zvi, D. & Arcavi, A. (2001). Junior high school students' construction of global views of data and data representations. *Educational Studies in Mathematics*,45, 35- 65.

Blumenfeld, P. C., & Krajcik, J. (2006). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 333-354). New York: Cambridge University Press.

Bogdan, R.C. & Biklen, S. K. (2003). Qualitative Research for Education: An Introduction to Theory and Methods. 4th Ed. Boston, MA: Allay and Bacon.

Brooks, J. G., & Brooks, M. G. (1993). *In search for understanding: The case for constructivist classrooms*. Alexandria, VA: Association for Supervision and Curriculum Development.

Callopy, R. (2003). Curriculum materials as a professional development tool: How a mathematics textbook affected two teachers' learning. *The Elementary School Journal, 103*(3), 287-311.

Chin, C. & Brewer, W. (1993). The role of anomalous data in knowledge acquisition: a theoretical framework and implications for science education. *Review of Educational Researcher.* 63, 1, 1-49.

Chin, P., Munby, H., Hutchinson, N. L., Taylor, J., & Clark, F. (2004). Where's the science? Understanding the form and function of workplace science. In E. Scanlon, P. Murphy, J. Thomas & E. Whitelegg (Eds.), *Reconsidering science learning* (pp. 118-134). London: Routledge, Falmer.

Chinn, C., & Malhotra, B. (2002). Children's responses to Anomalous scientific data: how is conceptual change impeded? *Journal of Educational Psychology, 94(2),* 327-343.

Clark, L. (2008). Debates over the global warming. Retrieved 5-10-2008 from http://www.youtube.com/watch?v=XDI2NVTYRXU

Davis, E., & Krajcik, J. (2004). Designing educative curriculum materials to support teacher learning. *Educational Researcher, 34*(3), 3-14.

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

Duggan, S., & Gott, R. (2002). What sort of science education do we really need? *International Journal of Science Education, 24*(7), 661-679.

Duit, R. (1984). Learning the energy concept in school - empirical results from the Philippines and West Germany. *Physics Education, 19*, 59-66.

Duit, R., & Haeussler, P. (1994). Learning and teaching energy. In Fensham, R., Gunstone, R. (Eds). The content of science; constructivist approach to its teaching and learning (185-200).

Duschl, R.A., Schweingruber, H.A, & Shouse, A.W. (2007). Taking science to school: Learning and Teaching science in grades K-8. Washington, DC: The National Academies Press.

Enyedy, N. & Goldberg, J. (2004). Inquiry in interaction: how local adaptation of curricula shape classroom communities. Journal of Research in Science Teaching. 41, 9, 905-935.

Fortus, D. & Shwartz, Y. (2006). Data gathering, organization, and Analysis (DGOA). Retrieved 7-25-2007 from https://ctools.umich.edu

Fortus, D. (2007). The energy unit overview. Retrieved 7-25-2007 from https://ctools.umich.edu

Gore, A (2008). Debates over the global warming. Retrieved 5-10-2008 from http://www.youtube.com/watch?v=XDI2NVTYRXU

Gore, A. (2006). An Inconvenient Truth: The planetary emergency of global warming and what we can do about it. New York: Rodale.

Gott, R., & Duggan, S. (1996). Practical work: Its role in the understanding of evidence in science. *International Journal of Science Education, 18*, 791-806.

Gott, R., Duggan, S., & Johnson, P. (1999). What do practicing applied scientists do and what are the implications for science education? *Research in Science and Technological Education, 17*, 97-107.

Hatch, J. A (2002). Doing Qualitative Research in Education Settings. Albany, NY: State University of New York Press.

Jeong, H., Songer, N., & Lee, S. (2007). Evidentiary competence: sixth graders' understanding for gathering and interpreting evidence in scientific investigations. *Research in Science Education*, 37 (1), 75-97.

Jin, H., and Anderson, C. W. (2007, July). Developing a Learning Progression for Energy in Environmental Systems. Paper presented at the Knowledge Sharing Institute of the Center for Curriculum Studies in Science. Washington, D. C.

Johnson, J. M. (2002). In- Depth interviewing. In Gubrium, J. & Holstein (Eds.). Handbook of Interview Research: Context and Method. Thousand Oaks, CA: Sage.

Kanari, Z., & Millar, R. (2004). Reasoning from data: How students collect and interpret data in science investigations. *Journal of Research in Science Teaching, 41*(7), 748-769.

Koslowski, B.(1996). *Theory and Evidence. The development of scientific reasoning.* Cambridge, MA:MIT Press.

Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). The development of scientific thinking skills. London: Academic press.

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

Lee, O. (1997). Scientific literacy for all: What is it, and how can we achieve it? *Journal of Research in Science Teaching, 34*(3), 219-222.

Leinhardt, G. Zaslavsky, O. & Stein, M. (1990). Functions, graphs and graphing: tasks, learning and teaching. *Review of Educational Research*, 60(1), 1-64.

Lijnse, P. (1990). Energy between the life-world of pupils and the world of physics. Science Education. 74, 571-583.

Lin, C.Y., & Hu, R. (2003). Students' understanding of energy flow and matter cycling in the context of the food chain, photosynthesis, and respiration. International Journal of Science Education, 25(12), 1529-1544.

Liu, X., & McKeough, A. (2005). Developmental growth in students' concept of energy: Analysis of selected items from the TIMSS database. *Journal of Research in Science Teaching, 42*(5), 493-517.

Lubben, F., & Millar, R. (1996). Children's ideas about the reliability of experimental data. *International Journal of Science Education, 18*(8), 955-968.

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

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, D.C.: National Academy Press.

Nicholson, J., Ridgway, J., & McCusker, S. (2007). Reasoning with data-time to rethink? *Teaching Statistics, 28 (1),* 2-9.

Nordine, J., Fortus, D. & Krajcik, J (2006). The Impact of a Novel Approach to Energy on Middle School Students' Conceptions of Energy. A Paper presented at the annual meeting of the National Association of Research in Science Teaching , San Francisco, California.

Piaget, J., & Inhelder, B. (1971). *The psychology of the child.* New York, NY: Basic Books.

Posner, J., Strike, K., Hewson, p., & Gertazog, W. (1982). Accommodation of a scientific conception: toward a theory of conceptual change. Science Education. 66, 211-227.

Reiser, B. J., Krajcik, J. S., Moje, E. B., & Marx, R. W. (2003). *Design strategies for developing science instructional materials.* Paper presented at the Annual Meeting of the National Association of Research in Science Teaching, Philadelphia, PA.

Resnick, L. (1987). Learning in school and out. Educational Researcher. 16(9), 13-20.

Ridgway, J., Nicholson, J., & McCusker, S. (2007). Teaching statistics-despite its application. *Teaching Statistics, 29 (2)*, 44-48.

Schauble, L. (1996). The development of scientific reasoning in knowledge-rich contexts. *Developmental Psychology, 32*(1), 102-119.

Schneider, R. M., Krajcik, J. & Marx, R. (2000). The Role of Educative Curriculum Materials in Reforming Science Education. In Fishman, B. and O'Connor-Divelbiss, S. (Eds.) Proceedings of the International Conference of Learning Science, Lawrence Erlbaum Associates, NJ.

Shwartz, Y., Weizman, A., Fortus, D., Krajcik, J., Reiser, B. (2005). The IQWST experience: coherence as a design principle. Unpublished manuscript, Michigan State University.

Solomon, J. (1983a). Learning about energy: How pupils think in two domains. *European Journal of Science Education, 5*(1), 49-59.

Solomon, J. (1983b). Messy, contradictory, and obstinately persistent: A study of children's out-of-school ideas about energy. *School Science Review, 65*(231),225-233.

Stake, R. E. (2005). Qualitative case studies. In Denzin, N. K. & Lincoln, Y. S (Eds.). The Sage Handbook of Qualitative Research 3rd Ed. Thousand Oaks, CA: Sage.

Trumper, R. (1990). Being constructive: An alternative approach to the teaching of the energy concept - part one. *International Journal of Science Education, 12*, 343-354.

Trumper, R. (1991). Being constructive: An alternative approach to the teaching of the energy concept - part two. *International Journal of Science Education, 13*(1), 1-10.

Trumper, R. (1993). Children's energy concepts: A cross-age study. *International Journal of Science Education, 15*(2), 139-148.

Varelas, M. (1997). Third and fourth graders' conceptions of repeated trials and best representatives in science experiments. *Journal of Research in Science Teaching, 34*(9), 853-872.

Vellom, R. & Anderson, C. (1999). Reasoning about data in middle school science. *Journal of Research in Science Education, 36(2)* ,179-199.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Cambridge University Press.

Watts, M. (1983). Some alternative views of energy. *Physics Education, 18*, 213-217.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction, 16*(1), 3-118.

Wilend, S.(2005). Qualitative Methods in Educational Research. Unpublished manuscript. Michigan State University, East Lansing. MI.