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Conditions Supporting the Development of Scientific Argumentation in High School Chemistry Classrooms: The Role of Question Prompts and an Interactive Simulation

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CONDITIONS SUPPORTING THE DEVELOPMENT OF SCIENTIFIC ARGUMENTATION IN HIGH SCHOOL CHEMISTRY CLASSROOMS: THE ROLE OF QUESTION PROMPTS AND AN INTERACTIVE SIMULATION

A Dissertation Presented

By

TUGBA KESER

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DEDICATION

To my husband,

Halil Solak

and

to my family,

Fatih Keser, Dursel Keser and Rabia Tugce Keser

for their patience, support and unconditional love.

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ABSTRACT

CONDITIONS SUPPORTING THE DEVELOPMENT OF SCIENTIFIC ARGUMENTATION IN HIGH SCHOOL CHEMISTRY CLASSROOMS: THE ROLE OF QUESTION PROMPTS AND AN INTERACTIVE SIMULATION

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The purpose of this case study was to provide benefit to preservice and inservice science teachers, who have an interest in applying scientific argumentation in their high school chemistry instructions, by investigating role of question prompts and an interactive simulation supporting the development of scientific argumentation. In particular, the study examined the quality of students' arguments changing over time in scientific argumentation when they constructed and defended their arguments using the "Gas Properties" computer simulation. For this purpose, forty-seven11th grade students from four classes first worked in pairs and then, all the pairs returned the classroom for discussion. One pair was selected as a focal group by their chemistry teachers within each class resulting in a total of four focal groups. The chemistry teachers posed the driving question of Part I to familiarize students with scientific argumentation while exploring the effect of gravity on the behavior of air molecules in space. Then, the teachers challenged the students with the driving question of Part II to help students construct and defend more elaborate scientific arguments while comparing the behaviors of air and Helium molecules in space. I examined what type of arguments participants found convincing and also searched which conditions (i.e. challenged by the driving question, counter-arguments, peer question or self-questions, or prompted by representation of investigation, teacher questions, or similar arguments) helped students to improve their arguments in scientific argumentation.

The results depicted that in pair discussions, argumentation was a way of participants' collectively supporting a scientific claim based on evidence from the interactive simulation and trying to agree on conclusions drawn from this evidence. Though, only two focal groups generated the highest quality of arguments with the waxing and waning amount of consensus over time from Part I to Part II. On the other hand, in classroom discussions focal groups tried to win their opponents over to their points of view and to weaken opposing views with making their evidence visible on the interactive simulation, which led four focal groups to produce the highest quality of arguments from Part I to Part II.

Keywords: *scientific argumentation, interactive simulations, gas properties and behaviors*

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CHAPTER 1

INTRODUCTION TO THE RESEARCH PROBLEM

1.1 Statement of Problem

Given that many science concepts are difficult to grasp, a growing number of science education studies are focusing on providing students with activities similar to scientists' work across the science disciplines and concepts (e.g. Wilensky, 2003; Liu, 2006; Andersen, Nobile, & Cormas, 2011; Leinonen, Asikainen & Hirvonen, 2012; Aydeniz, Pabuccu, Cetin & Kaya, 2012). This research suggests focusing on scientific practices as outlined in the Next Generation Science Standards (NGSS). The NGSS (2013) provide an important opportunity to students to actively engage in scientific and engineering practices and to understand disciplinary core ideas. Deepening their understanding of the core ideas through science and engineering practices enables students to think more like scientists who understand the core principles and theoretical constructs of their field, and who use them to make sense of new information or tackle novel problems. Argumentation is considered as one of these science practices to be a way of promoting thinking of learners about several content topics such as global warming (McNeill & Pimentel, 2009; Linn & Eylon, 2006), genetics (Jimenez-Aleixandre, Rodriguez & Duschl, 2000; Zohar & Nemet, 2002), light (Bell & Linn, 2000), sound (Baker, 2003), and properties and behaviors of gases (Aydeniz et al., 2012; Roehrig & Garrow, 2007; Pallant & Tinker, 2004; Leinonen et al., 2012). In this research I deal with one of these content topic "properties and behaviors of gases" in argumentation-based high school classrooms.

The content topic of “properties and behaviors of gases” has been found to be a conceptually difficult content topic for high school students, even for graduate students in physics and chemistry (Wilensky, 2003). Generally speaking, a great number of studies address students’ conceptual understanding and reasoning about the gaseous state of matter, which is a classical and central topic in chemistry and physics. Students’ understanding and reasoning about the gaseous state of matter is the anchoring point for the subsequent learning of advanced topics, such as thermodynamics and adiabatic compression of gases. Yet, students have some difficulties in applying this content taught during early stages of their education in a new context (Leinonen et al., 2012; Beall, 1994; Kautz, Heron, Shaffer & McDermott, 2005; Liu, 2006; Wiebe & Stinner, 2010; Wilensky, 2003). In this section, I discuss difficulties that students may encounter within this particular content area and provide the range of possible learning activities that other researchers offer to overcome these difficulties. In doing so, I attempt to create awareness of the importance of using scientific argumentation and computer representations in the content topic of “properties and behaviors of gases.”

To begin with, students face problems learning the content topic of properties and behaviors of gases in high school science and they convey these problems even into later stages of their education. Leinonen et al. (2012) investigated this issue focusing on what kinds of problems of reasoning university students bring from their high school science education as they enter a thermodynamics course. They conducted a case study with second year-university students whose explanations and reasoning related to adiabatic compression of an ideal gas, which points out the first law of thermodynamics. According to Leinonen and his colleagues, the phenomenon was new to the students, but it was one, which they should have been capable of explaining using their previous upper secondary school knowledge. The students' explanations and reasoning was investigated with the aid of paper and pencil tests and semi-structured interviews at the start of a thermal physics course. In the paper and pencil test, an open-ended question—a slightly modified version of the question devised by Loverude, Kautz and Heron (2002)—was posed to determine students' ability to relate the concept of work to the adiabatic process of an ideal gas. In this question there was a cylinder-piston system, which had a mole of ideal gas and was insulated from the environment. The piston was dense so that the gas could not exit the cylinder. The question asked was "what would happen to the temperature of the gas if the piston was used to compress the gas inside the cylinder?" The aim of asking such a question was to see how students would explain their answers rather than to pay attention to students' finding right outcomes. Leinonen and his colleagues (2012) found that second-year university students accurately used some concepts with various reasoning in their explanations when they responded to this question. But during the semi-structured interviews these students used different concepts to explain their answers in an inconsistent way. For instance, one of the students correctly used the velocity of particles between gas particles when talking about temperature in the paper and pencil test. In his interview, he was asked to explain his thinking. The result of the interview depicted the inconsistency in his micro-level reasoning: he spoke inaccurately about the collisions between gas particles instead of referring to the velocity of particles when explaining the reason for temperature increase.

Leinonen and his colleagues' (2012) research also revealed that a majority of the university students who had learnt about the ideal gas law in high school applied it without realizing the limitation that the situation imposed: all three quantities change:

Ideal Gas Law: P. V= n. R. T

P: Pressure V: Volume n: Number of mole
R: Universal gas constant (8.3145 J/mol K) T: Temperature

Students who used the ideal gas law inaccurately assumed that one of the quantities stayed constant. Typically, students claimed that an increase in pressure was the reason for an increase in temperature, ignoring volume totally when they responded to the open-ended question in the paper and pencil test. During the interviews they realized that there were problems involved in their claims, but they kept using the inaccurate micro level reasoning to explain the phenomenon in this question. For example, another student considered pressure and temperature as directly proportional without dealing with volume. Then, during the interview, the student revealed that he did not realize the problems related to the ideal gas in his explanation earlier. He evaluated and modified his explanation that when the volume is decreased, the pressure increases, as does also the temperature. When the interviewer asked the student if he could explain the phenomenon in terms of particles, he presented an inaccurate explanation that collisions between particles would take place and heat would partially be generated when particles get close to each other.

College students convey the limited understanding of the microscopic properties of the gas laws from earlier stages of their education to higher education. According to Beall (1989), it is very common among college students. In his study 89% of college freshmen were not able to correctly predict the effect that opening a cylinder of compressed gas would have on the gas temperature. Similarly, Kautz et al. (2005) found that many undergraduate science and engineering majors have “flawed microscopic models for the pressure and temperature in an ideal gas” (p. 1). The research results in all these cases showed that college students have difficulty in applying the properties and behaviors of gas molecules that have been taught in earlier stages of their education, explicitly, during high school science. The standard mathematical formalism of the gas laws emphasized in high school curriculum did not cue these students into seeing inaccuracies in their explanations (Leinonen et al., 2012).

On the other hand, teaching the content topic of properties and behaviors of gas molecules in high school science is mostly based upon problem-solving strategies depending on algorithmic techniques often devoid of promoting the use of any reasoning skills (Lin, Hsiu-ju, & Lawrenz, 2000). Teachers tend to place a great emphasis on the memorization of various “Gas Laws” formulas, without trying to embed these formulas in a rich framework of qualitative knowledge (Reif, 1983). But formula substitution to solve contextualized quantitative gas law problems requires developed reasoning skills and conceptual understanding for the qualitative use of direct and inverse ratios (Shayer & Adey, 1981). De Berg’s study (1995) backed up this assumption with a specific finding that the quantitative operations for the pressure-volume law require qualitative comparisons—that as the pressure increases, the volume decreases (Boyle’s law).

$$P_1.V_1 = P_2.V_2 \text{ at constant } T$$

De Berg examined student solutions to problems related to the compression of a given amount of air in a syringe through administering a paper and pencil test. Two modes of questions were asked to 101 college students, which required qualitative knowledge and a quantitative knowledge of the syringe system. In Question 1 two states of compression were represented to students and it was expected that the students would present a qualitative understanding of pressure, volume, and mass of a gas in different states of compression. In Question 2 a similar experimental system was represented as in Question 1 but quantities were not attached to the pressure and volume components. Students were asked to identify the pressure and volume for different situations. De Berg (1995) noted that students were more likely to score correctly in Question 2 if they had scored correctly in Question 1. This finding of de Berg's (1995) study showed that earlier stages of students' education need supportive learning activities to help students develop qualitative understanding of gas concepts and theories.

Contemporary and innovative high school science curricula recommend inquiry-based learning activities to enhance the qualitative knowledge acquisition of properties and behaviors of gases and, laboratory experiments are generally considered to be an essential part of this inquiry (Berg, Bergendahl, Lundberg & Tibell, 2003). For students to develop conceptual understanding of gas concepts and theories, experiments are often done in the inquiry-based chemistry laboratory after tasks were solved during lectures (Bopegedera, 2007). For example, in Robins et al.'s (2009) research to explore students' understanding of the inversely proportional relationship between pressure and volume of a gas in Boyle's law, high school students explored capped syringes, similar to the cylinder-piston system in Leinonen and colleagues' research mentioned earlier. In another activity these students also measured the volume of a balloon at different temperatures to establish the directly proportional relationship between volume and temperature of a gas at constant pressure (Charles' law):

$$V_1 / T_1 = V_2 / T_2 \text{ at constant } P$$

They also monitored a weather balloon to explain the relationships between volume, pressure and temperature as described by the ideal gas law. However, after implementing these experiments classroom observations, student questions, and exam results showed that the students' qualitative acquisition and understanding of the gas laws was somewhat limited. To investigate the difficulty these high school students had in understanding the related gas laws, Robins and his colleagues (2009, p.37) identified a list of five competencies necessary for the gas laws unit:

1. Algebra: solving for unknowns;
2. Units: understanding labels on measurement values;
3. Gas law variables: changes that occur in pressure, volume, and temperature;
4. Plug-in problems: solving problems by inserting known values correctly into given equations;
5. Scientific concepts: explaining relationships between variables as they apply to the gas laws.

The proficiency levels of 63 high school students with respect to each of these five competencies were measured in the post-activity written assessment. The results from this assessment indicated that the students had much greater difficulty answering questions pertaining to units, variables, plug-in problems, and conceptual problems than they did answering those related to algebra. That is, a high level of competency was seen with respect to decontexualized algebra problems, but lowered proficiency was observed as soon as the problems were integrated with conceptual knowledge. Based on these results, Robins and colleagues (2009) argued for the need of supportive and innovative designed learning activities which help students develop a conceptual understanding of gas laws through the use of authentic applications that involve common items such as soda cans, coffee cups, and bicycle tires.

Scientific argumentation can be considered as one of these innovative learning practices to support students as they critically examine real-world problems and issues that they confront in their everyday lives (Norris & Phillips, 1994; Solomon, 1994; Jimenez-Aleixandre & Pereiro-Munoz, 2002, 2005; Zeidler, Osborne, Erduran, Simon & Monk, 2003; Maloney & Simon, 2006). The carefully constructed questions of science educators provide a social context where students elaborate on their ideas and, their peers evaluate the rationality and accuracy of these ideas considering alternative possibilities (Andersen, Nobile & Cormas, 2011; Bricker & Bell, 2008). In such a context, argumentation has the potential to enhance the quality of learning by engaging students in thinking and reasoning (Aydeniz et al, 2012; Chin & Osborne, 2010). But students need resources which provide access to evidence. Andersen et al.'s (2011) study supports this argument. In their study, the posing of a "driving question" and teacher's questions provided a context to prompt students' thinking. However, it was not enough for the students to think deeply about how the ideal gas law affects bike tires in the summer. Students did not mention that their friend should let air out of his bike's tires because the summer temperature is much hotter, which causes the molecules to speed up and pressure to be exerted from the inside of the tire. The findings of this research showed that individual thinking and reasoning can benefit from argumentation to learn. Yet, as stated by some researchers (Kuhn, 1991; Means & Voss, 1996 cited in Bulgren & Ellis, 2012), most young Americans do not have a firm grasp of higher-order reasoning such as that associated with argumentation (Bricker & Bell, 2012).

To ameliorate this situation, computer representations acting as resources to provide access to evidence are essential to support student thinking and reasoning in scientific argumentation (e.g., Andriessen, 2006; Berland & Reiser, 2008; Veerman, 2003; Bouyias & Demetriadis, 2012; de Vries et al., 2002).

To discuss in more detail why students need computer representations as resources for their conversation and reasoning, it will be relevant to mention the findings of another study designed by Roehrig and Garrow (2007). Their study focused on interventions to develop students' conceptual understanding of properties and behaviors of gases through the use of authentic applications involving common items such as soda cans and balloons recommended by Robins et al. (2009). In Roehrig and Garrow's study four chemistry teachers completed the Weather Unit by implementing The Living by Chemistry (LBC) curriculum in a 10^{th} grade classrooms. The LBC curriculum consists of a mixture of learning activities such as lecture, guided practice, hands-on activities, demonstrations and classroom and group discussions. During these activities students were routinely included in the sense-making process and in making meaning of the curriculum activities. They appealed to evidence from their existing knowledge to describe the relationships between variables in Gas Laws, which helped them form links and connections in their minds and develop their understanding of the effect of a treatment under investigation. In some cases students' existing knowledge had some developed conceptions to explain the scientific phenomena under investigation but these conceptions were inconsistent with the accepted scientific concepts presented in science instruction. Roehrig and Garrow (2007) illustrated this at an example. Students discussed what happens to air molecules in a can if some water is added to the bottom of the can, the can is heated and then placed in cold water. Some students reasoned incorrectly even after observing the crushing can in the teacher demonstration and other hands-on activities. Student explanations revealed that teaching scientific concepts through teacher demonstration and hands-on activities were not enough to remove a common incorrect conception that air molecules expand when heated (Roehrig & Garrow, 2007). Similar results were found in de Berg's (1995) research. A significant proportion of students confused density with mass; they said that a syringe had a greater mass when squeezed into a smaller volume. Another study by de Berg (1992) also represented similar finding that many students typically had conflicting conceptions that enclosed air not in compression exhibits no pressure. All these findings—from Andersen et al. to de Berg's research—revealed that some common science classroom learning practices such as scientific argumentation, demonstrations, discussions and hands-on experiments are not enough to help high school students connect the macroscopic representation of gas concepts to either symbolic representations or microscopic representations in their reasoning (Roehrig & Garrow, 2007).

Presenting computer representations as appropriate resources provides access to evidence and to support student thinking and reasoning in scientific argumentation (e.g. Andriessen, 2006; Friedler, Nachmias & Linn, 1990; Veerman, 2003). In many research studies (e.g. Andriessen, Baker & Suthers, 2003; Bouyias & Demetriadis, 2012; Stegmann, Wecker, Weinberger & Fischer, 2007; Baker, 2003; de Vries, Lund & Baker, 2002; Clark, Sampson, Weinberger & Erkens, 2007; Slotta, 2004; Savelsbergh, van Joolingen, Sins, de Jong, & Lazonder, 2004) computer representations are used as a medium of communication in scientific argumentation. Students communicate by typing their arguments in several computer software systems, which help users to perform multitudes of specialized tasks such as communicating and data processing. Typing arguments in the organized medium of these systems scaffolds student argumentation in some way-; "by providing structure to the roles of each student and to the relationships between them in a dialogue, and by offering new and multiple ways of representing and manipulating the structure and content of argumentation" (Andriessen, 2006, p.449) (see next chapter, for an extensive review). However, writing at a distance on the computer has some constraints such as time delays during message transfers and interaction management problems in dialogue turns, which may inhibit effective discussion when compared to face-to-face interactions (de Vries et al., 2002). Although students are more efficient at managing their discussions through face-to face interactions than through computer-mediated written interactions (Bell, Urhahne, Schanze & Ploetzner, 2010), there is a lack of systematic research on scientific argumentation through verbal interactions between students who are working at the same computer in a classroom (see next chapter, for an extensive review). Computer representations, which I dealt with in this study, are designed to support deeper understanding and thinking processes through argumentation (Andriessen, 2006; Baker, 2003). But rather than using computer representations as a medium of communication, in this study I view computer representations as resources for conversation and student reasoning in a scientific argumentation-based activity within the content topic of properties and behaviors of gases. The computer software is a resource for verbal interactions supporting students' arguments about properties and behaviors of gases in scientific argumentation-based high school classrooms.

1.2 Research Questions

I designed a study in which eleventh-grade students use interactive computer representations to construct and defend their arguments about properties and behaviors of gases in scientific argumentation-based classrooms. The following research questions guided the present study:

1. How do interactive computer representations support students in developing arguments?
2. What type of arguments do students use?
3. What type of arguments do students find convincing?
4. What conditions help students to improve their arguments?

To find responses to these research questions I designed a research environment in which four 11th grade focal group students first participated in pair discussions and then, in classroom discussions.

1.3 Significance of the Study: Who Will Find this Research of Value

Two areas of significance are identified in this study:

First, from a practical point of view, this research will have great application and strategic value to several professional groups: science teachers, curriculum designers and computer software designers. Science teachers, who are considering applying computer representations as an integral part of their argumentation-based instructions, will benefit from this research because it will provide them insights into how the use of computer representations can supports students' arguments in scientific argumentation.

This research gives science teachers ideas about when they need to use computer representations in their lessons, how they can discuss abstract concepts through computer representations, and what possible arguments students can come up with in order to explain their answers to questions that their classmates pose or their teacher asks. Curriculum designers can use the results of this research when they design science tasks involving computer representations as instructional resources, and to better understand the value of promoting engaged exploration with computer representations in instructions in order to support mastery of science concepts. Computer software designers can also use the research results in order to design, develop, implement and revise the modules of curriculum driven computer representations that will support students in making high levels of scientific arguments based on empirical evidence.

Secondly, from a scholarly point of view, my research will enhance research on how students' arguments were scaffolded through computer representations in scientific argumentation—an area that has been mostly neglected as my literature review showed (see chapter 2).

1.4 Definitions of Terms

The vocabulary of this research encompasses the following definitions of key words and phrases:

- Scientific argumentation: the discursive practices where two or more individuals construct and critique scientific arguments with the consideration of alternative explanations (Lawson, 2003; Nussbaum, Sinetra & Owens, 2012).
- Scientific argument: a series of propositions used to explain competing theories in the natural or social world and which "should be supported by empirical

evidence, or at least capable of being verified, falsified, or weakened by such evidence" (Erduran, 2008 cited in Nussbaum et al., 2012, p.18).

- Empirical evidence: numerical or non-numerical data, which is collected with students' empirical investigations using computer representations.
- Reasoning (in argumentation): an ability to justify a claim by appealing to existing knowledge on the basis of no or minimal data or by appealing to empirical evidence on the basis of data from computer representations.

1.5 Overview of the Dissertation

In exploring how the use of computer representations supports students' arguments in scientific argumentation, the current dissertation is organized in six chapters.

In Chapter 1 I present the statement of problem, the research questions guiding this study, the significance of this study for some professional segments, and the definitions of terms, which are most often used throughout this study.

In Chapter 2 I review the literature on how scientific argumentation has potential to engage students in the investigative nature of science and scientific thinking by means of its constructive context, how the use of computer representations support students' investigations and their thinking about different content topics in scientific argumentation and what are the difficulties that students may encounter within the content topic of "properties and behaviors of gases" and how these difficulties are overcome using computer representations as resources for verbal interactions in scientific argumentation.

Chapter 3 focuses on two types of argumentation, persuasion and inquiry, which are central for this study. In this chapter I describe my theoretical framework: Walton's argumentative dialogues such as persuasion and inquiry, Vygotsky's zone of proximal development, which leads to some conditions supporting argumentation about scientific and socio-scientific issues, and the role of computer representations in argumentation.

In Chapter 4, I present my research design, how the "Gas Properties" simulation used as a computer representation works and my research methods. The latter includes information about participants, data collection processes, classroom settings and procedure and data analysis procedures.

In Chapter 5, I describe the research results of this study. I analyze how students argue when explaining the behavior of air molecules in space and comparing the behaviors of air and Helium molecules in space by using "Gas Properties" simulation. During these analyses I present what types of arguments students constructed and defended, what types of arguments students found convincing, how the use of "Gas Properties" simulation supported students' arguments in scientific argumentation, and what conditions helped students to improve their arguments.

In Chapter 6, I discuss how types of students' arguments change over time during their scientific argumentation, how students learnt to create convincing arguments using their investigations in scientific argumentation, how students learnt to draw more relevant information from "Gas Properties" simulation to support their arguments during scientific argumentation, and what conditions supported students in constructing and defending more extended and elaborated arguments during scientific argumentation. I also acknowledge limitations of this study.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Introduction

Argumentation is a fundamental discourse practice of science to promote thinking of learners in several content topics (e.g. global warming, genetics, light, sound and properties and behaviors of gases). I focus on how argumentation promotes thinking of learners about a specific content topic --"properties and behaviors of gases"-- when learners use interactive computer representations. Before discussing why I chose students' thinking of "properties and behaviors of gases" topic in more detail, I outline a rationale for how I decided on using computer representations as resources for learners' conversations in scientific argumentation.

2.2 Scientific Argumentation as a Discursive Practice

Scientific argumentation is seen as a discursive practice that involves the evaluation of knowledge claims in light of *empirical or theoretical evidence* to support or refute an explanatory conclusion, model, or prediction in science (Suppe, 1998; Jimenez- Aleixandre & Erduran, 2008). Recently, various authors have turned attention to the importance of argumentation to science education, and Zembal-Saul Munford, Crawford, Friedrichsen and Land (2002, p.439) aligned this importance as follows:

> First, learners can experience scientists' practices that situate knowledge in its original context (Brown, Collins, & Duguid, 1989), as well as provide opportunities to learn about science, not merely science concepts (Driver, Newton, & Osborne, 2000; Osborne, Erduran, Simon, & Monk, 2001). Second, learners' understandings and thinking can become more visible (Bell & Linn, 2000), representing a tool for reflection and assessment (Abell, Anderson, & Chezem, 2000; Sandoval & Reiser, 1997; Zembal-Saul& Land, 2002). Finally, argumentation can support learners in developing different ways of thinking (Kuhn, 1991, 1992, 1993) and facilitate science learning, taking into

> consideration the role of language, culture and social interaction in the process of knowledge construction (Pontecorvo, 1987).

Backed by these ideas, argumentation is a critically important discourse practice for students to construct new meanings within the context of science classrooms (Ohlsson, 1995; Roschelle, 1992). When argumentation is seen as a more or less explicit attempt at confrontation, Andriessen, Erkens, Van de Laak, Paters & Coirier (2003) distinguished three types of requirements for classifying part of a discourse as argumentative. First, argumentation minimally involves a participant stating a position, and another participant questioning it. Second, participants do not accept a particular piece of information and try to convince each other of their own viewpoints in argumentation. Third, argumentation can be resolved by an (explicit or implicit) acceptance of the defended position, or the alternative position.

When students state their positions in scientific argumentation, they construct arguments that consist of claims, evidence, and reasoning. According to McNeill and Krajcik (2007), in order for a statement to be classified as a claim in an argument, individuals need to offer answers to a scientific question. That is, these answers are assertions grounded in data/evidence that are intended to account for the phenomena under investigation (Zembal-Saul et al., 2002). For evidence, a statement needs to include data or information directly drawn from the investigation to support the claim (McNeill & Krajcik, 2007). Evidence can assume multiple forms (e.g., graphs, numerical data, and field notes) (Zembal-Saul et al., 2002). The reasoning component consists of a justification that shows why the data count as evidence to support the claim (McNeill & Krajcik, 2007). In the social context of argumentation, students are expected to provide justifications for their choice among different plausible options using evidence. When students solve problems and reason about their choices, their justifications are based on theory or evidence (Kuhn, Garcıa-Mila´, Zohar, & Andersen, 1995). Justifications are coded as *theory-based* when they involve students' prior theoretical beliefs on the basis of no or minimal data or they are coded as *evidence-based* when justifications involve instances of data. Instead of differentiating theory and evidence, Berland and Hammer (2012) thought that these two concepts are closely connected with each other. That is, students' theories sensitive to context foster their engaging with data and critically attending to alternative ideas. This concern will be discussed in more detail next chapter.

This study focuses on students' engaging in high levels of argumentation that include making a claim, collecting data, considering evidence, putting forward an argument with justifications and examining the reasonableness of alternative perspectives. For such students to progress to the more advanced argumentation, students have to explain their reasoning underlying their decision when supporting or challenging an idea (Stahl, 2002a; Koschmann, 2002, Andriessen et al., 2003, Andriessen, 2006). However, students have some difficulties in their reasoning to produce better-developed arguments and explanations. Sadler (2004) discussed these difficulties in socio-scientific argumentation and Cavagnetto (2010, p.338) emphasized them as follows:

> (a) Students often make unjustified claims and struggle to recognize opposing arguments during argument construction in socio-scientific contexts, (b) students do not commonly use scientific evidence to inform their personal decision making, (c) students' content knowledge influences reasoning ability in contexts associated with the particular content, and (d) students are not very competent at analyzing and evaluating arguments.

As a way to address these difficulties, children need to develop the ability to reason, to evaluate alternatives, and to weigh evidence competently in scientific argumentation (Maloney & Simon, 2006). Maloney and Simon (2006) proposed that the curriculum and learning environment should provide opportunities for children to develop (a) analytical skills to make judgments about the reliability of scientific evidence; (b) an ability to make judgments about the validity and strength of conclusions. When designing a context for scientific argumentation, the inclination of students towards engaging with contexts and their ability to see evidence as central to the justification of an explanation, to access evidence, either from their own experience or from a resource, and to recognize its absence in the explanations provided by others, needs to be taken into account (Simon, Richardson, Amos, 2012; Osborne, MacPherson, Patteson & Szu, 2012b). For instance, McNeill and Pimentel (2009) used this approach in their research. They selected two video clips from YouTube as resources for evidence that provided different perspectives on climate change. Then, from analyzing the discourse in the three classrooms they classified the data as scientific evidence, personal evidence, or other evidence to further capture the nature of the data students used. McNeill and Pimentel (2009, pp.210-211) defined these three types of evidence as follows:

> Scientific evidence was any data that scientists use to investigate this phenomenon, such as glaciers melting, sea levels, air temperature, water temperature, or species disturbance. Data were categorized as scientific evidence regardless of whether students obtained the information from one of the two videos or from another outside source such as a previous science class or a news program. Personal evidence was information from students' everyday lives, such as comments about weather patterns during their lifetime. Other evidence was information or data that were not data scientists would use nor was it a personal

experience of the student, such as discussing nonscientific information from the media.

From these definitions it is challenging to distinguish scientific evidence from personal evidence at some points since scientific evidence “from another outside source” such as a news program can be information “from students’ everyday lives” referring to personal evidence. On the other hand, Berland and Reiser (2011) used the term of “empirical evidence” rather than scientific evidence when analyzing students’ written explanations in the What Will Survive unit. The data were provided to students in a form of graphs of population fluctuations or of food webs on computer representations such as the NetLogo computer simulation. When students presented evidence in a way that was similar to the original data and used numbers and numerical descriptions in evidence to make clear comparisons, Berland and Reiser called this empirical evidence--data directly drawn from the investigation to support a claim.

As can be inferred from the discussions of McNeill and Pimentel’s (2009) and Berland and Reiser’s (2011) studies above, appropriate resources such as computers and video clips are valuable to provide access to evidence and to support student thinking and reasoning of learners in scientific argumentation (e.g. Andriessen, 2006; Friedler et al., 1990; Veerman, 2003; McNeill & Pimentel, 2009). In this study I considered computer representations as resources not only to collect evidence for scientific argumentation but also to foster the quality of argumentation, to enhance individual knowledge acquisition and the quality of student reasoning and to challenge students to externalize their reasoning (e.g., Andriessen et al., 2003; Jermann & Dillenbourg, 2003).

2.3 Computer Representations in Scientific Argumentation

Engaging students in classroom discussions around the use of computer representations in curriculum-related activities improves students' understanding of science concepts (e.g. Mercer, Littleton & Wegerif, 2004; Wegerif & Mercer, 1996) and promotes scientific reasoning in science classrooms (e.g. Andriessen, 2006; Bouyias & Demetriadis, 2012; de Vries et al., 2002; Veerman, 2003; Berland & Reiser, 2008). When computers are used to represent and manipulate information and data in multiple ways (Krajcik, Blumenfeld, Marx & Soloway, 2000; Clark, Stegmann, Weinberger, Menekse, Erkens, 2008), they become vehicles through which people interact with the subject matter (Norman, 1990, 1993). From the literature (e.g. Suthers, 1995; Suthers, 2003; Collins & Ferguson, 1993; Roschelle, 1994), the use of computer representations in argumentation can be classified as follows:

1. Computer representations as a medium of communication in argumentation
2. Computer representations as a formal record of arguments in argumentation
3. Computer representations as resources and guides for verbal interactions in argumentation

2.3.1 Computer Representations as a Medium of Communication

In several studies computer representations are designed as communicational channels to support argumentation by typewritten interactions (e.g., Andriessen et al., 2003; Bouyias & Demetriadis, 2012; Stegmann, Wecker, Weinberger & Fischer, 2007; Baker, 2003; de Vries et al., 2002; Clark et al., 2008; Slotta, 2004; Savelsbergh, van Joolingen, Sins, de Jong, & Lazonder, 2004) (i.e., CASSIS, VCRI, CONNECT, WISE, CoLAB). During typewritten interactions individuals are encouraged to propose, support, evaluate, and refine their ideas and arguments (Clark et al., 2008). To illustrate with a concrete example, CASSIS environment developed by Weinberger, Stegmann, Fischer & Mandl (2007) engages students in discussions of short problem cases from different locations using a customized asynchronous text-based discussion board. Within the comment creation interface of the CASSIS discussion board, three students in each group construct and exchange their arguments and then enter the subject line and the body of text messages through collaboration scripts. The scripts for the construction of single arguments visualize individual components (i.e., a claim, grounds, and possible qualifications) of a simplified Toulmin model (Toulmin, 1958) (discussed in greater detail later in chapter 4) and focus on the salient issues. Visualization of arguments on these scripts might lead to sufficient elaboration of new and complex concepts and theories that students might not otherwise address (Clark et al., 2008). Then, these scripts structure dialogical exchange through Leitão's (2000) specific argument–counterargument–integration pattern in typewritten interactions. Thus, computer-supported collaboration scripts can facilitate argumentative knowledge construction in online discussions.

In spite of the benefits of visualization of arguments in typewritten interactions, writing at a distance on the computer has some constraints such as time delays and the loss of nonverbal clues (such as intonation, facial expressions and gesture), which hamper the communicative flow and make co-constructing meaning and knowledge more difficult in argumentation (e.g., Andriessen et al., 2003, Sandoval & Millwood, 2007). Therefore, students' written work typically lags behind their ability to communicate verbally in scientific argumentation (Berland & McNeill, 2010).

2.3.2 Computer Representations as a Formal Record of Arguments

Verbal argumentation has almost exclusively been studied within contexts of collaborative inquiry or problem solving including computer representations as a formal record of arguments or resources and guides for conversation (i.e., BGuILE, Belvedere, CoVis, CSILE, SenseMaker, and WebCamile). Besides facilitation of coordination and negotiation, verbal argumentation may also allow immediate feedback on argumentation and thus, facilitate co-construction of argumentation sequences. For instance, the BGuILE environment scaffolds middle school students as they work collaboratively to make comparisons in The Galapagos Finches. Each student collects data about the animals and conditions as part of scientific inquiry and constructs an explanation that justifies the gathered data. According to the explanation-driven inquiry principle, which is the first strategic design principle of BGuILE, students' explanations should develop rational, causal relationships explaining the data as evidence in relation to natural selection (Clark et al., 2008). Students present their evidence using ExplanationConstructor which helps students record and review their own work as a form of electronic journal embedded in the BGuILE environment (Sandoval & Reiser, 2004). This written form facilitates students' elaboration of their own explanations, evidence, assumptions and results in argumentation (Resnick, Salmon, Zeitz, Wathen & Holowchak, 1993). Students, then, compare and critique other students' findings and explanations that involve new and complex knowledge and concepts, and they collaboratively resolve possible differences among explanations through verbal argumentation environments.

In another study by Bell and Linn (2000), the SenseMaker tool within the WISE environment allows middle school physical science students to construct and edit their arguments using a graphical representation on the computer. Individual students support their claim “light goes forever until absorbed” or “light dies out” incorporating evidence from the World Wide Web for arguments. As students add new evidence and elaborate their arguments, they make visible their understanding of the evidence and the scientific ideas involved within the topic in their written argument representations. Then, SenseMaker promotes the collaborative exchange of ideas in a group. Students in the group communicate and compare the strengths and weakness of competing ideas, recognize any inconsistency or faulty reasoning, evaluate the evidence that supports or refutes the claims and generate a shared argument that are more viable. In the extension of these processes, they compare their argument with arguments constructed by other groups through verbal argumentation environments.

As noted from the description of Bell and Linn’s (2000) study above, another rational and critical approach in verbal argumentation is collaborative construction of arguments in computer-based learning environments. Students work together at a single computer with specific tasks in scientific argumentation such as to identify the relevant problem information within complex problem cases and to create an appropriate solution strategy. Then, they collaboratively construct representational artifacts for their emerging knowledge in a persistent visual medium of computers, viewed by all participants. For instance, another computer representation, namely Belvedere, is designed to support pairs of secondary school children’s learning of critical inquiry skills in the context of science (Suthers, Toth, & Weiner, 1997). Belvedere involves rich representations intended to enable students' collaborative construction of arguments by visualizing respective claims, relevant evidences, and possible qualifications (Fischer, Bruhn, Grasel & Mandl, 2002; Kirschner, Buckingham Shum & Carr, 2003; Suthers & Hundhausen, 2001). These representations provide a diagrammatic environment for collaborative construction of "evidence maps" (Suthers, et al. 1997; Suthers & Weiner, 1995), which relate data and hypotheses via the evidence. The evidence maps support students' discussions by making some knowledge (i.e., data, prior knowledge, theories and the connections between them) more salient in the computer representations of the students' explanations so that other students notice differences in their explanations and want to discuss them (Clark et al., 2008). By showing a reference point on evidence maps, students elaborate their own arguments and critique each other's arguments in light of the evidence and work toward consensus through scientific argumentation.

2.3.3 Computer Representations as Resources and Guides for Verbal Interactions

In my research, rather than being a medium of communication or a formal record of the argumentation process, I come to view computer representations as resources and guides for learners' conversations and reasoning (Suthers, 1995; Suthers, 2003; Collins & Ferguson, 1993; Roschelle, 1994; Wilensky, 2003). These types of computer representations specifically refer to computer simulations which may be useful for helping students to visualize theoretical and conceptual facts in science events (Gilbert, 2005; Lindgren & Schwartz, 2009). More specifically, computer simulations may allow students to explore aspects of the subject matter through collecting evidence for their arguments and, thereby, the simulations increase the potential persuasiveness of students' arguments (Oestermeier & Hesse, 2000). The research findings support the above statement. For example, in Wilensky's (2003) study (also discussed in greater detail later next chapter), three students working as a group used the GasLab simulation that represents the particle nature of matter to develop understandings of the Kinetic Molecular Theory. They decided to verify Boyle's law that changing the volume of the box in the simulation would lead to an inverse proportional change in the pressure of the gas. When they made several suggestions and created a "monitor" to display the pressure in the box, they were face-to-face with the challenge of a phenomenon under investigation that the pressure in the box was fluctuating wildly. Up to this challenge, a student from the group generated an argument to compare the box in a GasLab simulation with real boxes. Her claim to account for this phenomenon was that the number of particles in the box was not as many as it should have been in a real box. In her argument, the evidence included data directly drawn from the investigation with the GasLab simulation that its box only had 8000 particles while real boxes full of gas had many more particles in them. Her reasoning component consisted of a justification that because the number of particles was not large enough, it was hitting a lot less times at each tick on the GasLab simulation. According to Wilensky (2003), her ability to make her reasoning visible on the simulation increased the persuasiveness of the student's "law of large numbers" argument by other students and helped the group get one step further on the way to verifying Boyle's law.

In previous work I have also invested a significant amount of effort into supporting high school students' arguments of "properties and behaviors of gases" with a dynamic computer representation (e.g. Wilensky, 2003; Pallant & Tinker, 2004). At the core, my study is concerned with the creation of an artifact that encourages pairs of students to identify strong pieces of evidence for their positions from their experiments with a computer simulation, discard others, and then compare and argue for their consensus with other student-pairs. When confronting the discrepancy between their position and the alternative, students may determine salient components and relationships in their evidence from the computer simulation to persuade others to change a particular position.

2.4 Promoting Students' Thinking of "Properties and Behaviors of Gases"

As noted by Gabel (1999), many of science concepts such as atoms and molecules are abstract and might be inexplicable without the use of analogies or models in science classroom activities. Computer representations used as an integral part of these activities may support the learning of these abstract science concepts with specialized experiments not feasible in the classroom environment (Finkelstein, et al., 2005; Hennessy, Deaney & Ruthven, 2006; Rogers, 2004). As an example from the literature, Pallant & Tinker (2004) developed the Molecular Workbench, a two-dimensional molecular dynamics computer simulation, to satisfy the need of animating and simulating real world processes in science classrooms. Middle and high school students discovered the behaviors and properties of gases as well as solids and liquids both in hands-on activities on the powerful dynamic molecular models of the Molecular Workbench. Then, pre- and post-tests and semi-structured interviews were conducted to investigate students' ability to transfer their understandings to both new representations and new situations. When compared to pretest scores, significantly higher posttest scores were in evidence that showed that middle and high school students acquired fairly robust conceptual understanding of gas states of matter through guided explorations of the dynamic molecular models of Molecular Workbench. It is also noteworthy to state that in pre- and post- test comparisons the high school students overall did better than the middle school students on the same questions, but not significantly. Then, students were interviewed in groups of three to measure the transfer of their understandings based on the quality of student reasoning about atomic-level phenomena and their manifestations at the macroscopic level. During the interviews, students accurately recalled arrangements of gas states of matters in the Molecular Workbench models, their knowledge of the motion of particles and the relative proximity of particles in gas states in order to make a decision. Student explorations of a two-dimensional molecular dynamics computer simulation appeared to lead to a good understanding of connections between atomic-scale events and macroscopic scale-observations. This research shows that a computer simulation may resolve the difficulty that high school students have when they make sense of abstract or unseen science concepts such as gas atoms and molecules. But it does not inform about how a computer simulation eliminates the difficulty that these students have when they articulate their reasoning about scientific events requiring the use of these concepts in science classroom discussions.

CHAPTER 3

THEORETICAL FRAMEWORK

3.1 Introduction

Countries increasingly need well-educated graduates who are capable of analytical and critical thinking to evaluate what they learn and express clearly what they know both in their speech and in their writing (Osborne, MacPherson, Patterson & Szu, 2012b; Sawyer, 2006). To respond this need, the field on argumentation in science learning contexts has received growing attention within the science education research community since the 1980s. In this regard, an increasing number of studies have been focusing on the argumentation practices of students in science learning contexts (e.g. Driver et al., 2000; Jiménez-Aleixandre et al., 2000; Kelly & Takao, 2002; Zohar & Nemet, 2002; McDonald & Kelly, 2012). In this chapter I will provide these studies as a theoretical framework to address the four overarching research questions that guide this proposed study. To gain an understanding of how interactive computer representations support students in developing arguments, I will begin the chapter with theoretical justification for why I consider argumentation as persuasion and inquiry to be of significance to science and science education. Then, I will provide examples from research which introduce different interventions involving computer representations to support argumentation in science education. At the end, I will finish the chapter with a framework which has been applied to analyze scientific arguments in science education contexts.

3.2 Argumentation as Persuasion and Inquiry in Science

Argumentation is seen as a social process that lies at the heart of science and is central to the discourse of scientists (Druker, Chen, & Kelly, 1996; Driver et al., 2000; Osborne, Erduran, & Simon, 2004a). Scientists take action to understand the natural world by presenting two or more competing theoretical interpretations of a phenomenon in scientific argumentation (Jimenez-Aleixandre et al., 2000). *Scientific argument* is used to explain these competing theories in the natural or social world and it should be supported by empirical evidence, or at least capable of being verified, falsified, or weakened by such evidence (Nussbaum, et al., 2012). *Scientific argumentation*, on the other hand, is the discursive practices where two or more individuals construct and critique scientific arguments with the consideration of alternative explanations (Lawson, 2003 cited in Nussbaum et al., 2012). Hence, argumentation entails "the coordination of evidence and theory to support or refute an explanatory conclusion, model, or prediction" in science (Erduran & Dagher, 2007, p.403). Commitments to a theory emerge from these argumentative discourses of scientists when scientists evaluate the potential validity of the theoretical interpretations of the phenomenon by weighing evidence (Driver et al., 2000; Latour, 1987; Latour & Woolgar, 1986).

Backed by these ideas, scientific argumentation can be regarded as an accumulation of cyclical processes of producing evidence, generating explanations, and conducting evaluations (Duschl, Schweingruber, & Shouse, 2007). Within these processes, recognizing the interdependence of theory and data in the evaluation of evidence and explanations is an essential feature of science. Scientists gather a lot of relevant data from their experiments or observations and provide a logic and justification for why the data count as their evidence to support their theories. This evidence is then used as a resource in developing logical arguments to justify an idea and convince other scientists of its merits in argumentative dialogues (Latour & Woolgar, 1986; Traweek, 1988).

According to Walton (1998), argumentation has six types of dialogue that scientists often engage in when drawing on evidence-based justifications: Persuasion, negotiation, deliberation, inquiry, information-seeking, and quarreling. Although all categories of Walton's dialogue may appear in science classroom discourses, I discuss two of them in particular because they are of the importance to my study, which I will explain later in this section: *persuasion* and *inquiry*. According to Walton, *persuasion* is often more like a debate, in which different scientists try to win people over to their points of view and to weaken opposing views with evidence and reasoned argument. Jimenez-Aleixandre & Erduran (2008) gave Darwin's theory of evolution as a prototypical instance of the task of persuading audiences, composed both of scientists and of the general public. In accordance with his theory, that the species living on Earth descended from other species instead of having being created all at a time, Darwin's strategy to persuade the audiences of his argument was based on a number of observations with breeds of pigeons for meaningful variation (Darwin, 1969). He showed that the discrete differences among breeds are linked by smaller, continuous differences among sub-breeds. Within breeds and sub-breeds, the traits which differ most between the breeds are often the most variable. This proves that naturally-produced variation has right properties needed to allow selection to occur, and for change to occur gradually, over many generations. Most paleontologists criticized

Darwin's assumption asserting that there ought to be a considerable number of true transitional structures preserved in the fossils but they found themselves facing a situation in which there were only gaps in the fossil record, with no evidence of transformational intermediates between documented fossil species (Morris, 2001). Therefore, while scientists have been attempting to filling in the gaps in the fossil record with so-called missing links, Darwin's theory is still at the heart of contemporary debates.

At the other end of my concern, there is another, very important type of argumentative dialogue that Walton (1998) calls *inquiry.* Aristotle and Descartes (cited in Walton, 1998) conceived of scientific argumentation as a form of inquiry, the goal is for the participants to collectively establish or demonstrate scientific claims based on evidence and to try to agree on conclusions drawn from this evidence (Walton, 1998). For instance, a body of independent scientists from Intergovernmental Panel on Climate Change (IPCC) was charged with proving periodic assessments of climate change using their observations of nature (Corner, 2012). Crucially, this was a cyclical inquiry form of argumentation to account for all of the available evidence (Berland & Hammer, 2012) and as more evidence became available, the views of these scientists in the debates on climate change shifted from the role of human activity in climate change toward endorsing the reality of anthropogenic climate change (Nussbaum et al., 2012). Pachauri and Reisinger (2007) declared that the discussion between scientists resulted in an agreement drawn from the evidence--"most of the observed increase in globally-averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" (Corner, 2012, p.202). As inferred from this instance, in the form of inquiry, rather than being a debate between opposing parties in scientific community, argumentation is a way of making judgments in a cumulative fashion with the waxing and waning amount of building consensus over time (Solomon, 2008).

Argumentation often times involves a shift between persuasion and inquiry forms of argumentation when scientific controversies and debates help the scientific community explore and evaluate alternative claims (Nussbaum et al., 2012). As scientists benefit from persuasion and inquiry in argumentation practices such as collaborative development of arguments and critical scrutiny of scientific knowledge claims with available evidence (Kolsto & Ratcliffe, 2008), the extent to which students work in these practices of argumentation is important to develop their thinking in the contexts of scientific and socio-scientific issues (Ratcliffe & Grace, 2003; Maloney & Simon, 2006).

The National Research Council recommends argumentative discourse where students engage in cognitive processes that typify scientists' thinking: ''asking scientifically oriented questions, giving priority to evidence in responding to questions, formulating explanations from evidence, connecting explanations to scientific knowledge, and communicating and justifying explanations'' (NRC, 2000, p. 23). Science educators should focus their efforts on helping students learn how to participate in the practices of argumentation where they explore the same and different viewpoints (Lawson, 2003) so that they begin to understand how evidence is used to reach consensus. Only if these forms of argumentation is specifically addressed in the curriculum and experienced through tasks regarding science and socio-scientific issues, will students gain the skills to participate in argumentation practices (Osborne et al., 2004a).

3.3 Argumentation as Persuasion and Inquiry in Science Education

Engaging students in persuasion and inquiry forms of argumentation practices provides them with opportunities to participate in core aspects of scientific disciplines, and indeed to examine the deep assumptions and foundations of these disciplines (Bricker & Bell 2008). The inquiry form of argumentative dialogue, which may foster the joint construction and the individual acquisition of knowledge, is likely to occur in collaborative learning when two or more students are working together to solve an issue (Berland & Reiser, 2008). Within the context of inquiry, students most often are asked to generate explanations by evaluating evidence for competing mechanisms of a phenomenon (Cavagnetto & Hand, 2012). They discuss, evaluate, and debate the processes and products and reach consensus regarding how to best explain the phenomenon under study. Thus, students work together to identify and collaboratively construct an explanation that supports a specific point of view and that best fits the available evidence and logic.

On the other hand, in persuasive form of argumentative dialogue students explore different viewpoints and they use evidence to persuade each other to change a particular viewpoint (Maloney & Simon, 2006). While they construct explanations about a scientific phenomenon under study (Southerland et al., 2005), the goal of persuasion requires that students articulate why their classmates should believe these explanations coordinating theory and evidence (Berland & Reiser, 2008). In other words, to engage in critique and evaluation of each other’s explanations, students should have an ability to see evidence as central to the justification of this explanation and recognize its absence in the explanations provided by others (Osborne et al. 2012b).

Most of science education researchers have examined inquiry and persuasion not as separate forms of argumentative dialogues but as a single practice. For example, Berland and Reiser (2008) treat the knowledge building process, as it is apparent in the inquiry and persuasion forms of argumentative discourses, without differentiating or defining these forms of communication. According to their analysis, students consistently use evidence to make sense of phenomenon and articulate their understandings through scientific explanations in the process of developing shared understandings of the phenomenon under study. While they in turn are challenged by other explanations, they consider and reconcile competing ideas from their peers and work to convince others of scientific accuracy of their explanations.

On the other hand, students may not be inclined to discuss the provided information in every practice. From this perspective, assessing provided information critically on its meaning, strength or relevance depends on the type of classroom task and how they are engaged in this task (Veerman, Andriessen & Kanselaar, 2000; Baker, 2003 cited in Veerman, 2003). That is, generating effective argumentation in educational situations requires students to initiate and maintain a shared focus of the task and agree on the overall goal and descriptions of the current problem-state (Roschelle & Teasley, 1995 cited in Veerman, 2003). In order to stimulate and promote a shared focus of themes and problems in argumentation, students' interactions with the task need to be taken into account (Clark et al, 2007).

3.3.1 Conditions that Support Argumentation

As Golder (1996 cited in de Vries et al., 2002) pointed out, one does not argue with anyone, about anything without any reason. Argumentation both in inquiry and persuasion forms requires appropriate argumentation conditions in which students are encouraged to question, justify, and also to evaluate their own and others' arguments (Duschl & Osborne, 2002). At the core, researchers have attempted to create rich contexts that differently emphasize the value of these conditions to enable dialogical argumentation to take place. Drawing on these research designs, I found a number of specific argumentation conditions that *challenge* and *prompt* students' thinking and reasoning to construct and defend their arguments of a scientific phenomenon in the literature as follows:

Condition 1: The topic needs to be debatable (de Vries et al., 2002).

Condition 2: A "driving question" about topic must be posed to give a focus to scientific argumentation (Krajcik, Czerniak, & Berger, 2002; Berland & Hammer, 2012; Krajcik, Blumenfeld, Marx, Soloway, 2000) and students must hold competing viewpoints on the answer of the driving question in the given task (Chin & Osborne, 2010; Berland & Reiser, 2008).

Condition 3: Appropriate external supports as scaffolds (i.e., teacher's questioning, peer's questioning and self-questioning, diagrammatic representations of arguments) are needed to encourage students to construct and evaluate arguments and to participate in argumentation (McNeill & Pimentel, 2009; Chin & Osborne, 2010; Bell & Linn, 2000; Simon, Erduran, & Osborne, 2006; Jimenez-Aleixandre, Bugallo-Rodriguez, & Duschl, 2000).

Condition 4: During construction and evaluation of arguments, students need to consider competing viewpoints using appropriate evidence and reasoning. Evidence, which students use to argue, includes information from their existing knowledge or information from different instructional resources. Activities should involve appropriate resources (i.e., computer representations, video clips) that provide evidence to help students reason argumentatively.

I will explain these conditions in more detail below.

Condition 1:

Teachers and researchers must create environments that provide students with an authentic reason to fully engage with scientific argumentation. For these environments they first choose a controversial topic which leads to a discussion. Engagement in thinking about the pros and cons of this topic enhances the quality of students' reasoning which involves making arguments to defend their positions (Jimenez-Aleixandre et al., 2000). For example, it is relatively more difficult to provoke and organize argumentation about co-constructed scientific notions which allow for the reinforcement and deepening of knowledge than about contentious scientific topics such as the use of nuclear power or genetic engineering in schools (e.g., Resnick, Salmon, Zeitz, Wathen, & Holowchak, 1993; de Vries et al., 2002; Jimenez-Aleixandre et al., 2000).

Condition 2:

Argumentation always occurs in a context where learners exchange views (Kolstø & Ratcliffe, 2007) and have opportunities to interpret and critically examine multiple, apparently conflicting perspectives (de Vries, Lund, & Michael, 2002; Berland

& Hammer, 2012). A "driving question," which involves no right or wrong answer, gives context to scientific ideas and asks students to generate explanations through the evaluation of evidence for competing mechanisms for a phenomenon (Cavagnetto & Hand, 2012).

Condition 3:

The majority of students need some form of guidance to structure their arguments in scientific argumentation and this guidance can be provided by scaffolds during the construction and elaboration of arguments as follows:

Scaffold 1: Writing prompts

Scaffold 2: Teacher's prompts

Scaffold 3: Peer's prompts

Scaffold 1: Writing Prompts

The structural support provided by a paper-based mode of visual representation of different argument components (claim, data, evidence, reasoning) can make it easier for students to articulate high-quality arguments and counter-arguments and, facilitate the development of their argumentative dialogue ((Berland & Reiser, 2008; Ravenscroft, 2007; Ravenscroft, Wegerif & Hartley, 2007; Andriessen, 2006; Yeh & She, 2010). In the published studies to date, various authors have presented this structural support with different argument frameworks such as claim, evidence and reasoning argument framework to enable students to be engaged in argumentative discourse (e.g., Toulmin, 1958; McNeill & Krajcik, 2007; McNeill, Lizotte, Krajcik & Marx, 2006). Then, they judged the quality of scientific arguments generated by students using these frameworks. I will mention different argument frameworks that are created for different contexts in the literature next chapter.

Scaffold 2: Teacher's Prompts

All students are not equally engaged in every practice of argumentation because of their level of motivation and cognitive engagement. Osborne and his colleagues (2012b) mentioned that one approach to promote student engagement in argumentation is to ask students to explain why an explanation might be wrong or why the interpretation of evidence is flawed. Different from teaching by telling, teachers can provide explicit support to the interactions between students with questioning strategies (Martin & Hand, 2009). Traditionally, teachers' questions have involved a limited number of correct answers to look for specific student responses (Lemke, 1990). These questions lead students to waiting for teachers to evaluate their contributions, serving very different role in classroom discussions (Chin, 2007). Instead of being sole authoritative voice in student-student interactions, teachers need to take on the role of mediator to support students to evaluate potential viability of theories, weight evidence and offer rebuttals. In this regard, McNeill and Pimentel (2009) found that when the teacher asked open-ended questions with many possible answers, these questioning strategies encouraged students to share their ideas, expand their justifications, elicited student thinking, and connected their ideas to the ideas of their peers in a substantive manner.

Related to supporting students' engagement in scientific argumentation, another approach is to put their explanations in opposition and to place students in the role of critic for another's arguments (Berland & Reiser, 2008) such that they are in positions to persuade the opponent by identifying and challenging weaknesses in his/her argument (e.g., Walton, 1989; Bell & Linn, 2000; Hatano & Inagaki, 1991; Osborne, Erduran, & Simon, 2004a). This means "students need to learn how to *challenge* weaknesses in alternative explanations" (Duschl, 2007, p.161). To engage in critique and evaluation of alternative explanations, students should have an ability to see evidence as central to the justification of an explanation and recognize its absence, incompleteness or contradiction in the explanations provided by others (Osborne et al. 2012; Maloney & Simon, 2006).

Scaffold 3: Peer's Prompts

Students often have difficulties with using evidence to construct and analyze arguments and counterarguments on their own (e.g., Kuhn, 1992; Berland & Hammer, 2012; Jimenez-Aleixandre, Bugallo-Rodriguez, & Duschl, 2000; Kelly, Druker, & Chen, 1998; Duschl et al., 2007). A variety of challenging or prompting questions (i.e., "Is there evidence to support this claim?" or "Is it flawed?" or "What are the limits of the evidence?" or I "Is the interpretation offered justified?") asked by their peers, support students' articulation of evidence-based arguments while they engage in high levels of argumentation (Osborne et al., 2012, p.10). Chin and Osborne's (2010) classroom activity can be taken as a prototypical instance of supporting scientific argumentation through students' questions. Their analysis reveals that the presence of a puzzling observation experienced by students stimulates the generation of questions posed to the self or others and, these questions potentially provide critical support for critical thinking about competing claims and evidence, and support for eliciting the construction of arguments and counterarguments. To ask these kinds of productive questions, students should know how to pose appropriate questions about the phenomenon under discussion to guide their thinking, to become aware of what they do or do not know, to challenge claims, to compare the strengths and weakness of competing ideas, and to formulate alternative explanations or potentially more extended and elaborated arguments from one another (Duschl et al., 2007). Multiple opportunities to practice in different argumentation contexts may enhance the chances of successful student questioning.

Condition 4:

In exploring the driving question, students take a position and access evidence either from their own experience or from instructional resources (Simon, Richardson & Amos, 2012). First, if students have sufficient content knowledge being sensitive to context, they experience differences of belief that they care to solve, and feel they can solve and then, they argue about science (Sadler, 2004; Berland & Hammer, 2012). Second, different instructional resources (i.e., cartoons, stories, video clips, computer representations, a report of a science experiment undertaken by students) providing access to evidence in that context can facilitate students' reasoning to support a specific claim, thereby potentially increase the persuasiveness of their arguments (e.g., Oestermeier & Hesse, 2000; Keogh & Naylor, 1999; Naylor & Keogh, 2000; Goldsworthy, Watson & Wood-Robinson; 2000; Clark et al., 2007; McNeill & Pimentel, 2009). I will return to considering students' use of evidence from existing knowledge or evidence from instructional resources in their arguments in more detail in an upcoming section.

3.3.2 Arguing with Reasoning and Evidence in Argumentation

Argumentation is analyzed as a discursive practice, which is essential to develop student reasoning (Vygotsky, 1981; Garcia-Mila & Andersen, 2008). The essence of argumentation is based on zone of proximal development which has been defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978, p86). As can be inferred from the definition, a critical feature of addressing zone of proximal development is involving students in social practices (Bulgren & Elis, 2012), where two or more minds construct and critique an argument through a series of claims, counterclaims and rebuttals (Kuhn & Udell, 2003; Nussbaum, 2002; Andriessen, 2006). The act of constructing claims and then explaining or justifying these claims with warrants in strong arguments promotes student thinking and reasoning (Berland & Hammer, 2012; Szu & Osborne, 2012). Thus, reasoning occurs as an argument intended to prove one's own point of view in discursive practices before becoming internalized by the individual (Vygotsky, 1978; Wertsch, 1985).

In addition, recent research have shown that children have the ability at least at nascent form to generate and evaluate arguments even with little or no argumentation instruction (Berland & Hammer, 2012) and they can critically and independently examine claims and statements that they confront in their everyday lives (e.g. Norris & Phillips, 1994; Nussbaum et al., 2012). But, Bricker's ethnographic research presented that youth's everyday argumentation practices and their perceptions of these practices are quite different from argumentation in a school setting (Bricker & Bell, 2008). They found that everyday argumentation relies much more heavily on reasons situated in the realms of conventions and stories instead of scientific evidence placed in the structure of scientific argument. Therefore, it might not be enough to simply embed learner-associated ways of talking, problem solving, and acting from everyday argumentative practices into science curriculum and instruction.

Argumentation practices in a school science environment focus on students' understandings about the role of evidence in scientific investigations and require their providing evidence for the conclusions they draw in their own science practices. In addition to empirical evidence acquired from an instructional resource in scientific investigations, students' reasoning in their arguments rests on their existing knowledge on the basis of no or minimal data in school science argumentation.

a) Reasoning about Evidence from Existing Knowledge

Students' ability to reason in scientific argumentation is highly dependent on their existing conceptual knowledge that they bring to a context to support a theory (Rumelhart & Norman, 1981). Their existing knowledge is constructed from experience with concrete objects and events in everyday life and from prior schooling. This knowledge contains both a sense of deep structure and a sense of surface structure and, students can reason abstractly using this knowledge that is similar in form to that of experts (Smith, diSessa & Roschelle, 1993). As an illustration, during the discussion on the simple question "how the bicycle's frame is supported- why does it not fall to the ground?" students do not simply accept the obvious fact that bicycle frames do not fall to the ground (Smith et al., 1993, p.128). Instead, based on their existing knowledge, they propose hypothetical reasoning such as the effect of the spindliness in a bicycle spoke that may support the hub and frame. Thus, Smith et al.'s research supports the fact that students' reasoning does not only depend on potential observations, but also depend on existing knowledge and experiences (Veerman, 2003).

Since new understandings are constructed by the interaction of currently available knowledge with a new knowledge, the literature on learning in science typically discusses these understandings under the headings of the nature and grounds of students' knowledge. If students have existing knowledge being sensitive to a context, they feel they can solve problems and then, they can argue about science (Berland & Hammer, 2012). To illustrate with a concrete example, consider the case that a teacher read a story about invasions from outer space and initiated a discussion on whether or not there really is life in outer space and then, she was puzzled with the question that a boy asked "Does all water have germs in it?" (Duckworth, 1996) The teacher didn't know what the question meant and didn't know how to answer it, however, through a series of insights and questions, the teacher figured out the reason underlying this question: The student had existing knowledge acquired from some authoritative source that there was ice on Mars and when sun shone on that ice, it would melt. According to him, this would mean that there was water on Mars, if all water had germs in it, there would be germs in that water on Mars. Since germs are alive, this would support the theory that there was life in outer space. Both this study and the study from Smith et al. (1993) mentioned before show that when a complex fabric of physical relationships, potential observations, and interventions mediate students' thinking; student reasoning can be abstract in the same sense that expert reasoning is abstract.

On the other hand, students come to classrooms with incorrect or partially correct existing knowledge. In other words, students' existing knowledge has some developed conceptions to explain some of the scientific phenomena but these conceptions may be inconsistent with the accepted scientific concepts presented in science instructions (Smith et al, 1993). For instance, Maurines (1998 cited in de Vries et al., 2002) found that high school students have potentially conflicting conceptions about sound, which are often shown to be persistent even after teaching. These students can use the naïve conception of "force causes motion and that motion naturally fades away" (diSessa, 1996) to describe sound as a material object created and put into motion by a source. This finding highlights the need for the adaptation of these conceptions towards scientifically accepted notions through scientific practices such as argumentation and explanation in the domain of science (de Vries et al., 2002).

This adaptation is called conceptual change in the literature and may take place by adding notions to existing conceptions or by changing existing conceptions; that is, enrichment or revision (Chi, Slotta, & de Leeuw, 1994; Vosniadou, 1994). Conceptual change is fostered by argumentation in science classrooms by externalization of existing conceptions. During argumentation, other students who disagree with these conceptions may in turn explain aspects of the problem that are anomalous to the existing conceptions and propose a new notion for the solution of the problem (Weinberger et al., 2007 cited in Bouyias & Demetriadis, 2012). When confronted with the discrepancy between their point of view and the alternative, students may consider both sides of issue (Nussbaum & Sinatra, 2003) and drop false points of view or modify their beliefs on a claim eliminate misunderstandings or co-construct new knowledge (Baker, 1999).

Thus, attempting to dissolve conceptual differences in arguments and to resolve conflicts in the dialectical sense of argumentation supports students' conceptual change (Baker, de Vries & Lund, 1999 cited in Andriessen, Erkens, Van de Laak, Paters & Coirier, 2003).

To illustrate these points mentioned above, I will consider a detailed case study by Chin and Osborne's (2010) who detected conceptual change when students made decision on the correctness of two graphs (graph A and graph B) in argumentation. These graphs was representing temperature as decreasing below 0ºC for ice and increasing beyond 100ºC. The only difference between the two graphs was that while graph B had two flat portions corresponding to 0ºC and 100ºC, graph A did not. To facilitate students' construction of arguments, Chin and Osborne explicitly taught a structure for argument and subsequently asked students to apply this structure. They also gave question prompts to help students generate questions regarding puzzling aspects of a scientific experiment. Students, aged 12-14 years, first constructed their arguments and then, posed their own questions using these prompts in groups to predict the shape of the graph showing the change in temperature with time when ice was heated to steam. These questions constituted a starting point leading them to notice the given data in the graphs in some detail and to address any points of disagreement that they had in their arguments. Thus, scaffolding the talk that incorporated questioning and argumentation in a group setting helped students to apply reasoning skills at the core of scientific thinking and to engender conceptual change.

Specifically, a student, Devi, in one of these groups, drew her own graph C that was similar to graph B except that it did not show the horizontal portion at 0°C and she initially thought that the temperature should rise continuously without stopping at 0ºC. She, then, challenged other students' thought asking the following questions during the discussion: "But how come when it reaches 0°C, it takes quite a long time for it to start changing its temperature? Couldn't it start melting straight away?" (p.264). Upon making her existing conception obvious and accessible to the group members and discussing it further with them, she did successfully revise her thinking in direct relation to the alternative proposition offered to her and showed the conceptual change as below (Chin & Osborne, 2010, p.264):

> I've changed my mind to believe that graph B is actually correct because as the evidence states, and as Amy and Val have argued that while the temperature is constant at 0°C, energy is being stored and used. So therefore the temperature has to remain constant in order for the energy to be fully used and melt the ice… and break the bonds between particles…. Therefore, I admit defeat and say that graph B is correct.

As seen in the excerpt above, Devi accepted that the temperature should be constant at 0°C in order for the energy to be fully used to melt the ice.

In another instance from the same research, a student, Jiahao, produced richer and more productive argument involving the applicable conditions of graph A. He initially disagreed with his group members and believed that graph A was correct but after several rounds of questioning and reasoned argumentation about his choice of graph A with his peers, he decided to change his existing conception and choose graph B as the correct answer. He also posed a challenge to his group members by considering the applicable condition of graph A in his reasoning when the ice was thrown into an incinerator at the very high temperature: "[If] the ice is actually being thrown down into an incinerator, perhaps, then I think the answer will be graph A. But in these circumstances, I think it's graph B because the evidence statements state that there will be no temperature change when there is bonding [bond] breaking of particles" (p.260).

These two cases above support a view that holding opposing viewpoints and having disagreement in ideas between students may reinforce the acquisition of knowledge on argumentation (Kuhn, 1991). If students can achieve to make complex, high quality arguments in science courses, they are more likely to engage deeply with the content and thus, experience conceptual change (Nussbaum et al., 2012).

b) Reasoning about Evidence from Instructional Resources

Toulmin and colleagues define reasoning as a central activity in the generation and evaluation of claims with available evidence to support arguments (Bricker & Bell, 2012). Student reasoning can be developed with designing argumentation activities that provide a context where students are able to use each other's ideas to negotiate a shared understanding of a particular phenomenon in the light of new information as well as existing knowledge (Abell, Anderson & Chezem, 2000; Andriessen et al., 2003; Boulter & Gilbert, 1995; de Vries et al., 2002; Veerman, 2003). But most teachers lack time to fully design their own argumentation activities or have low pedagogical design capacity for argumentation associated with lack of experience, and they need procedural guidance which is developed by curriculum designers to support them.

Osborne and his colleagues (2004a) identified nine argument-based interventions that involve different evidence resources to engage students in argumentation: table of statements, concept map of student ideas, a report of a science experiment undertaken by students, competing theories-cartoons, competing theories-story, competing theories-ideas and evidence, constructing an argument, predicting, observing, and explaining, designing an experiment. In some of these argument-based interventions evidence is provided in a written form and students make arguments based on the evidence (Cavagnetto & Hand, 2012). In other argument-based interventions, students collect data, show it as evidence and generate arguments based on this evidence as a consequence of their investigations (Sampson & Clark, 2006). All these argument-based interventions in science classrooms offer multiple perspectives on students' arguments and the diversity of these argument interventions certainly illustrate a clear movement by the science education community to improve students' reasoning. To extend the classification of these argumentation-based interventions, I will append three more argument-based interventions from the literature to this list: "Competing theories- video", "Competing theories-pictorial representations" and "Competing theories-computer representations" and I will deal with one of them, "competing theories-computer representations," in more detail throughout this paper as described below.

Competing theories- videos: McNeill and Pimentel (2009)'s classroom activity can be taken as a prototypical instance of this kind of scientific argumentation intervention. In their research high school students observed two short video clips which presented different perspectives on global climate change. Neither video clips provided a strong model of scientific argument for climate change. After watching the videos, students wrote arguments for whether or not the earth's climate is changing on their investigation sheets. In these arguments they showed evidence from their existing knowledge or new information provided in the video clips and, articulated their reasoning for why that evidence supports their claims. Then, students shared their arguments in classroom discussions. McNeill and Pimentel designed this classroom activity to promote student voice and support students' understanding of the social nature of science in argumentation.

Competing theories- pictorial representations: Azevedo, Martalock and Keser (2014) have contributed to this kind of scientific argumentation intervention by analyzing the Inventing Graphing (IG) activities of diSessa, Hammer, Sherin and Kolpakowsky (1991). In general, IG activities seek to engage sixth grade students in designing and refining pictorial representations that progressively approximated Cartesian graphing. diSessa and his colleagues examined meta-representational competence as it is apparent in a discourse practice. Then, Azevedo et al. (2014) differentiated and defined the modes of communication and, treated description, explanation and scientific argumentation as separate categories in these discourse practices. While in scientific argumentation activities students often discuss two opposing theories (e.g. McNeill & Pimentel, 2009; Jimenez-Aleixandre et al., 2000), in the IG activities students argue over their own two or more created competing- but not necessarily a clear opposition between viewpoints- theories in the form of the desert motion pictures of a motorist. For Garcia-Mila and Andersen (2008), these are implicit theories that are constructed from experience with concrete objects and events in everyday life and from prior schooling, but this construction is unconscious. In diSessa et al's study since students had worked on programming simulations in which the motion of the graphical object, a Logo-like turtle, involved segments of motion at constant speed before the IG discussions, their initial pictorial representations that formed their competing theories often came from previous students' computer work.

After the students designed and redesigned a static motion picture as they worked in group discussions, they presented their designs for peers' comments and gave reasons why one design was preferred to another directly addressing each other's material contributions, which sustained students' argumentative exchanges.

Competing theories-computers representations: While the world is changing constantly, the current science curriculum still employs static representations overmuch (Wilensky, 2003). The disjunction between the world of dynamic experience and the world of static school representations stands as one source of student alienation from scientific theories and concepts in traditional curricula (Bertalanffy, 1975; Stroup, 2002; Wilensky, 1997b). To deal with this alienation, computer representations are used as interactive tools for student interactions which involve making observations, criticizing evidence or arguments, making predictions, and reaching conclusions (Slotta, 2002). I will discuss the place of computer representations in scientific argumentation in greater detail in an upcoming section.

3.3.3 The Role of Computer Representations in Argumentation

Along with the beginning of the computer age, a great deal of high-quality research has been done to add insight on how computers assist student learning in science and mathematics classrooms (e.g., Maor, 1991; Metz & Hammer, 1993; Linn & Hsi, 2000; White & Frederiksen, 2000). Curriculum designers and researchers use computers to create learning environments that place learners in control of their own learning (e.g., Linn & Hsi, 2000). They integrate existing learning activities that are already components of standard curriculum with the new activities that involve the use of computers. Some well-known examples of computer-assisted learning environments such as BOXER computer microworld (Metz & Hammer, 1993; diSessa & Abelson, 1986), ChemSense (Mihalchik, Rosenquist, Kozma, Kreikemeier & Schank, 2008) and ThinkerTools (White & Frederiksen, 2000) are utilized in learning science to contribute to a high degree of learner involvement and to promote a deeper conceptual understanding in learners. These learning environments, when customized or designed specifically for use in scientific argumentation, can be a part of educational packages that scaffold the construction of arguments (Bricker & Bell, 2012). In this section of the paper, I will mention how the use of computer representations supports one of the learning environments referring to argumentation in science classrooms.

Engaging in learning environments involving computers fosters the development of learners' higher -order intellectual skills such as reasoning, metacognition and creativity (Bracewell et al., 1998). Among these intellectual skills, I will restrict myself to the skill that focuses on students' reasoning about science concepts through computer-assisted reflection and discussion in face-to-face and network situations. Students argue from different positions presenting their reasoning for a particular standpoint on computers when they are challenged in their own thoughts (Maloney & Simon, 2006). When they negotiate the meanings of science concepts, partner's request for clarification or explanation might stimulate students to think and rethink their ideas and then, to support these ideas with arguments (Gijlers & de Jong, 2009). Reasoning tends to occur as a result of this exchange of statements and counter-statements (Pilkington & Parker-Jones, 1996). For instance, as part of his dissertation research Bell created argument-building software called Sense Maker to make students' thinking visible in groups when they construct their arguments about two different theories:

"light goes forever until it is absorbed" and "light dies out as you move further from a light source" (Bell & Linn, 2000, p.798). Sense Maker software scaffolded middle school physical science students' abilities to coordinate evidence with theory when facilitating these students to utilize the entire evidence corpus that were thought to support their chosen theory (Bricker & Bell, 2012). They argued like scientists using Sense Maker software as a tool in their learning about how to build Toulmin style structural arguments as well as their conceptual understanding about the science of light (Bricker & Bell, 2012). These students communicated and compared their different ideas in groups by revealing their particular conceptions and their own knowledge perspectives to construct a group argument. At the end of their argument construction work, each group presented their argument to the class and then responded to the questions from their classmates. Thus, the externalization of ideas and thoughts in argumentation raised students' awareness of their own ideas and of alternative explanations (Gijlers & de Jong, 2009).

As can be noticed above, providing students with scaffolding tools such as computer representations in argumentation-based learning environments reinforces students' reflections and makes it easier for them to articulate their reasoning (Sawyer, 2006). Some of the special roles that computer representations can fulfill by the virtue of their distinctive features:

- a safe environment to practice making real-world decisions,
- a means of representing the operation of a real-world process or system over time,
- the focusing point of discourse and action (de Vries et al., 2002, p.70), and

- the medium for student interactions (de Vries et al., 2002, p.70).

I will respectively deal with these features below.

First, computer representations can be a safe environment to practice making real-world decisions. Students can practice making decisions which closely resemble those which scientists in their field must make (Pilkington & Parker-Jones, 1996). They can construct their own hypotheses to check and see what extent these decisions fit their experiments. If their hypotheses do not fit and they do not understand the situation, they may try another hypothesis. However, sometimes because of time limitation, dangerous experiences or inadequate equipment, they have not the chance to try many experiments. Computer representations enrich active learning environments and provide a safe alternative to dangerous, difficult, costly, time consuming or specialized experiments not feasible in school laboratory, by means of animating and simulating real world processes such as motion, photosynthesis, diffusion, or bonding atoms (Hennessy, Deaney & Ruthven, 2006; Rogers, 2004). For example, the PhET group at the University of Colorado at Boulder developed a computer simulation to illustrate the trajectories of a tank shell, a baseball, a pumpkin, a piano, and even a person which are blasted out of simulated cannon by using an implicit goal of hitting a target (Wieman & Perkins, 2006; Lindgren & Schwartz, 2009). The quantities of default setting parameters (e.g., mass, initial speed, angle and diameter) for each object can be changed by curious learners. While this kind of experiments may relatively seem trivial, they are needed to encourage students' elaborative thinking in classroom discussions (i.e., "would a piano and a baseball shot out of the cannon at the same velocity really travel the same distance?" Lindgren & Schwartz, 2009, p.425).

Second, the computer representations can be used as a means of representing the operation of a real-world system or process over time. This role of the computer specifically refers to computer simulations which may be useful for helping students to visualize theoretical and conceptual facts in science events (Gilbert, 2005). Highly dynamic and interactive visualizations on the computer simulations enhance student learning of abstract scientific concepts that involve large-scale or unobservable levels (Clark et al., 2012). For example, this distinctive benefit of computer representations was observed in Finkelstein et al.'s (2005) research. Finkelstein and his colleagues conducted research with two groups of undergraduate students who performed laboratory experiments with the computer simulation or with the real equipment. The students built a simple circuit and thereby predicted, observed and reconciled its behavior as resistors or light bulbs were added or rearranged, and finally developed methods to measure resistance in multiple ways in these circuits. The difference between CCK (The Circuit Construction Kit) simulation circuits and real circuits was that the explicit use of moving electrons along the wires in CCK simulation provided the visual representation of current flow and current conservation which were otherwise hidden. As a result of this study, CCK simulation circuits mediated students' understandings of these hidden concepts, and a high fraction of students who used computer simulations in lieu of real equipment performed better on conceptual questions in the assessment related to current and voltage than their counterparts who used real components.

Simulations may be the only way to visualize, and hence gain an understanding that how systems of many interacting elements change and evolve over time and how large-scale patterns can arise from local interactions of these elements (Wilensky, 2003; Pilkington & Parker-Jones, 1996). They represent a dynamic system in such an apparently simple way that learners may understand based on superficial observations (Chiu & Linn, 2014). Since simulations scaffold students by hiding the complex ways in which variables interact over time, they "purify" phenomena for observation. They make a considerable contribution to the visualization of structure in phenomena and processes that are traditionally "invisible" to students if they are too small (bacterial reproduction), too big (tectonic shifting), too fast (chemical reactions), or too slow (evolution) (Lindgren & Schwartz, 2009). By demonstrating the invisible deep structures beneath surface changes, dynamic visualizations on computers have a great potential to support students learn science content that involve these phenomena or processes (Ardac & Akaygun, 2004). For instance, Papageorgiou, Johnson and Fotiades (2008) considered this feature in their investigation that whether or not the use of the software simulations helps 6th grade students understand particulate explanations for evaporation process below boiling point. Two matched classes were involved in a short intervention for this investigation. One class was taught using software simulations, the other was not. Twenty-four students were interviewed individually before and after the intervention and asked to explain what happens to a drop of ethyl alcohol after being put on the table and left for a few minutes until it has completely evaporated. In pre-intervention only two of them talked about ethyl alcohol particles leaving and turning to the gas state and one of them described the action of the particles of alcohol as forced by the air movement. Half of the students gave explanations at the macroscopic level where heat was seen as the main agent like "the drop of ethyl alcohol is dried due to the heat from surroundings” or “the air and the heat from the sun dry the drop” (Papageorgiou et al., 2008, p.177). Other students simply observed the disappearance of ethyl alcohol or said that the surface of the table would absorb this liquid alcohol. After that, all students from two matched classes were involved in an intervention. During the intervention, one of the classes incorporated software simulations and the other relied on more traditional static representations. Both groups made progress, but there were indications that the software helped for more sophisticated explanation of evaporation phenomenon. While five of the students using the software simulations gave sophisticated explanations involving a distribution of energy amongst particles of alcohol in post-intervention, many of the students using static representations did not. Papageorgiou and colleagues stated that the simulation might have made a particular impression and, consequently, the students used this sophisticated idea of the distribution of energy in their explanations. Thus, the students began to use particle ideas to account for the disappearance of the liquid in evaporation but some ideas like the surface of the table absorbs alcohol stayed most persistent not to change.

If we assume that language and images are conducive to the imaginative construction of human minds, computer simulations are also supportive visual tools to prompt student minds to expected imaginative construction in science learning. If the learner can directly manipulate objects and observe the effect, imaginative construction becomes easier, and through this construction, abstract reasoning in the domain becomes possible (Pilkington & Parker-Jones, 1996). For example, in Wilensky’s (2003) research, imaginative construction was facilitated by the multi-dimensional world of GasLab simulation. Before using this simulation, Harry, a high school physics teacher had long been intrigued by the behavior of a gas in a sealed container, had thought that when the collisions between particles were head-on and completely symmetric in a one-dimensional world, average speed would stay constant. After he discovered broken symmetry between two particles on GasLab, he reasoned that when two particles do not collide head-on each time in the multi-dimensional world of GasLab simulation, collisions cause particle speed distributions to become non-uniform.

However, Harry did not achieve this abstract reasoning at once. Wilensky (2003) showed that conceptual changes were also seen in the reasoning of Harry in this case study. In one of his experiments, Harry created a collection of particles of equal mass randomly distributed in GasLab and then, he suddenly noticed that one of his statistics, the average speed, was going down. He, thus, felt the need to further explore the behavior of the gas particles in the model in order to get a more visual understanding of the gas dynamics. During this further exploration he started with the assumption that momentum is conserved inside the box. He reasoned that since mass is constant, this means the average velocity as a vector is constant, the average velocity's magnitude, the average speed, should be constant. However, just as he observed, the average speed decreases. Harry was puzzled by this observation because he knew that the particles change their speeds when colliding with other particles. This puzzlement then elicited *a self-question* posed by Harry to himself, which subsequently led to a self-explanation or monologic argument. He *challenged* his thinking by asking himself "But the collisions between particles are completely symmetric – why does one particle change speed more than the other (p.12)?" To answer these questions, Harry conducted further modeling experiments that focused on only two particles that repeatedly collided in fixed trajectories. Then, he discovered that two particles did not behave the same way each time. They collided at different angles to the line that connected their centers each time, that is, their trajectories may not be symmetrical. The discovery of broken symmetry led him to see his faulty reasoning and *change his conception* regarding average speed, in his words (Wilensky, 2003, p.11):

> [I] screwed up the mathematics – the magnitude of the average vector is not the average speed. The average speed is the average of the magnitudes of the vectors. And the average of the magnitudes is not equal to the magnitude of the average.

Thus, Wilensky's study showed how the unexpected observations induced the individual generated puzzlement which elicited a self-question. These questions subsequently led to self-explanations or monologic arguments.

Third, the computer representations can be used as the focusing point of discourse and action because knowing what to focus on in an object or a system under observation helps students easily pay attention. There are many more features of the object or system that students encounter in their investigations and teachers cannot make certain in a predetermined way what understandings students will construct from their practical work with this object or system (Driver & Bell, 1986). This means that teachers need supporting tools in science classrooms to engage all students in the observation of intended features of the object or the system in their investigations. As an example, the computer representation such as the Envisioning Machine software (Roschelle, 1992) serves as an assisting tool to set students' insight on manipulating intended features of an object or a system under observation, allowing students genuine interactivity within a debate. This software offers a direct manipulation graphical simulation of the concepts of velocity and acceleration. Students construct their own hypotheses actively and they check to see what extent they fit their experiments on the EM software. If their hypotheses do not fit and they do not understand the situation, they may try another hypothesis. Collaboration between students using the EM is studied as a process that leads to convergent conceptual change. Conceptual change is analyzed as it emerges from the combination of utterances and gestures in relation to the EM. Thus, the computer display is viewed as a social tool for achieving the joint construction of a common interpretation in argumentation (de Vries et al., 2002).

Computer representations designed appropriately for use in scientific education can also isolate specific situations from the complexity of reality. Although distance from a real situation may create a problem (Baser, 2006), simplification facilitates students to jointly focus on and discuss the important aspects of scientific events (de Vries et al., 2002; Krajcik, Blumenfeld, Marx & Soloway, 2000). Knowing what to focus on in these particular events makes it easy to ask questions for learners as well as to explore particular events, to initiate processes, and to probe conditions (Tao & Gunstone, 1999; Zacharia & Anderson, 2003). For instance, in another case study conducted by Wilensky (2003), GasLab, a computer-based modeling environment, offered opportunities for high school students to observe different molecules speeded across the screen, bouncing off a containing "box" and colliding with each other and changing speeds in the content of statistical thermal physics. In student discourse, GasLab led one of the students to puzzlement with his observation "that slow molecule just sped up real fast when it hit the other one. Why does it do that?" (p.1). The others agreed with his puzzlement and they all started to suggest computer experiments, explore and analyze the interactions of large number of simulated molecules that could help them answer this question. Using the GasLab toolkit in their experiments afforded more direct engagement with the ideas, models and thought experiments that are central to the study of statistical mechanics. They did quite sophisticated reasoning about this advanced content in their discourse.

Computer representations are seen as appropriate resources for conversation and reasoning in a specific form of discourse which is scientific argumentation across various communities of science education research (e.g., Berland & Reiser, 2008; Suther, Toth & Weiner, 1997). For example, the SenseMaker tool acting as a computer representation within the WISE environment encourages students' using their reasoning to analyze the conflicting piece of evidence in terms of their meaning and their relevance to students' claims (Bell & Linn, 2000). Students identify stronger pieces of evidence for their position from their experiments discarding others (inquiry form of argumentation), and then, compare and argue for their position with another pair using the evidence they keep, leading to increase the persuasiveness of students' arguments (persuasion form of argumentation).

Besides, students are more likely to generate strong arguments and attend and respond to counter-arguments providing evidence when it is evidence they can see rather than being a list of written evidence statements that is asked them to evaluate (Bernard & Lee, 2010). For example, Bernard and Reiser (2011) recount six-grade students' using evidence in the form of graphs generated by a NetLogo simulation (Wilensky, 1999) to support and *challenge* competing claims, with little instruction. These students identified evidence and counterevidence for one another's claims by working with a computer simulated ecosystem while exploring interactions between organisms in a food web. Visualization of evidence on the NeLogo environment led students to successfully construct not only arguments but also counterarguments to challenge other's ideas.

Fourth, the computer software and representations can be used as the medium for student interactions. Most of studies in the literature recently utilized from this feature of the computer to support argumentation by typewritten interactions (i.e. Andriessen et al., 2003; Bouyias & Demetriadis, 2012; Stegmann, Wecker, Weinberger & Fischer, 2007; Baker, 2003; de Vries et al., 2002; Clark et al., 2007; Slotta, 2004; Savelsbergh, van Joolingen, Sins, de Jong, & Lazonder, 2004) (e.g., CASSIS, VCRI, CONNECT, WISE, CoLAB). The computer environment provides learners with a means to represent their ideas and arguments in a persistent medium, where these ideas and arguments become more salient and viewable by all participants and a likely topic of argumentation in part of a shared context (Suthers, 2003). The medium of this learning environment incorporates both asynchronous and synchronous online discussion interfaces that can potentially promote and support interactions between students (Clark et al., 2007). In synchronous online discussion all participants are co-present while in asynchronous online discussion non-co-present participants asynchronously discuss over a period of days or weeks (Pilkington, 2004). Synchronous discussion allows more immediate feedback on argumentation due to co-presence and thus, facilitates co-construction of argumentation (Pilkington, 2004; Pilkington & Walker, 2003). On the other hand, asynchronous online environment allows participants time to construct and evaluate textual arguments and facilitates individual knowledge construction (Clark et al., 2007). The instructional approach of both types of online discussions is based on computer-supported collaboration scripts (Stegmann et al., 2007). These scripts provide a set of input text fields or related prompts to support the construction of complex and well-conceived arguments and high-quality argumentation (Clark et al., 2007). For instance, the CONNECT software used as the medium of communication in de Vries et al.'s research (2002) was designed to facilitate certain types of joint interactions between fifteen 11^{th} grade students in the network situation. Students individually wrote an interpretation of a sound phenomenon in a text and then, collaboratively discussed their own texts across the network using CONNECT. The CONNECT interface has the function of representing the positions of both participants and the elements under discussion. When students were asked to judge both their partner's and their own text to write a common text describing the sound phenomenon, they produced a great proportion of domain-related communicative acts relating to explanation and argumentation types of interactions, such as verifications, explanations, justifications, and evaluations.

On the other hand, some types of interactions between students might be obstructed instead of being facilitated when using text-based nature of computer representations as communication mediums (de Vries et al., 2002). For example, one of the disadvantages of the task of discussing and writing at a distance on the computer is that writing may inhibit discussion as seen in the CONNECT environment. Students' dialogues in the CONNECT environment showed communicational burdens that hindered students' participation in argumentation. Even though de Vries and her colleagues provided shortcuts for the students to use in managing their interactions in this computer-mediated learning environment, the interactions revealed the burden of dialogue turns needed for interaction management. Furthermore, the burden of executing task actions themselves such as adding phrases to common text, took time away from dialogue. de Vries and her colleagues (2002) states whereas these communicational burdens have limited effects on argumentative interactions between students, there can be important differences in interactions depending on the activity that is carried out.

All in all, as mentioned in previous chapter, in this study, rather than being a medium of communication or a formal record of the argumentation process, I come to view computer representations as resources for conversation and reasoning (Suthers, 2003; Collins & Ferguson, 1993; Roschelle, 1994). Finding that the literature lacked systematic research on this variable in scientific argumentation, I undertook a program of exploring the hypothesis that information made salient by a computer representation may have facilitative effects on students' construction and defense of their scientific arguments during argumentation. Therefore, I propose a design strategy for addressing the social interactions inherent in scientific practices of argumentation involving a computer representation when students constructed and defended their arguments about properties and behaviors of gases. The following research questions guided the present study:

1. How do interactive computer representations support students in developing arguments?
2. What type of arguments do students use?
3. What type of arguments do students find convincing?
4. What conditions help students to improve their arguments?

CHAPTER 4

RESEARCH DESIGN AND METHODOLOGY

4.1 Introduction

The purpose of this dissertation study was to examine how the use of interactive computer representations supported students in developing arguments in argumentation-based chemistry classrooms when students constructed and defended their scientific arguments by using a computer simulation. For this purpose, it drew on a research approach that first explored what type of arguments students constructed and defended in argumentation-based chemistry classrooms. Secondly, I attempted to investigate what types of arguments students found convincing in argumentation-based chemistry classrooms. Then, I examined what conditions helped students improve their arguments in argumentation-based chemistry classrooms.

During this research, students were prompted to discuss their findings from their investigations with a computer simulation in order to solve some scientific questions within the context of scientific argumentation. More specifically, students were encouraged to provide evidence from this simulation and to state their reasoning though using that evidence in their scientific arguments. Finally, I sought to validate the improvement in the quality of their arguments by analyzing and comparing student arguments between the two contexts of scientific argumentation.

4. 2 Research Design

Using computers in argumentation-based chemistry classrooms promotes student thinking and reasoning by making sense (or making meaning) of chemistry concepts and theories. In most studies computational media is designed as a communicational channel to support scientific argumentation by typewritten interactions (e.g. Andriessen et al., 2003). However, students' written argumentation typically lags behind their ability to communicate verbally (Kantor & Rubin, 1981), which underlines the importance of engaging in a context of verbal argumentation rather than focusing solely on written products (Berland & McNeill, 2010). Verbal argumentation between students who are working together at a single computer may afford students opportunities not only to learn scientific content but also to enhance the quality of arguments (Suthers, 2003; Andriessen, 2006). As my literature review demonstrates, there is a need of research designs in which students use computers as a source of their arguments. Therefore, rather than a medium of communication or formal record of the argumentation process, I view computers as resources (stimuli and guides) to promote scientific arguments of students in this research.

To glean understanding and knowledge about the change in the quality of students' arguments over time in scientific argumentation, the research strategy I intended to use is a *qualitative case study approach*. Case study is used for a detailed account and analysis of a specific case (i.e. an event, process, organization, group, or individual; Johnson & Christensen, 2000) drawn from a class of similar phenomena (Rossman & Rallis, 2003). Thus, it seeks to explain a larger phenomenon through close examination of this particular case (Rossman & Rallis, 2003). In this study, I investigated a larger phenomenon of how the use of computer representations would support students' arguments in scientific argumentation when analyzing a specific case of how interactive computer representations support 11th grade students in developing arguments. I propose that during their scientific argumentation the quality of 11th grade students' arguments will change over time when they construct and defend their arguments using evidence from the "Gas Properties" computer simulation (e.g., without gravity and cold, heavy molecules slow down, but they are still able to move, which would allow the chamber of the simulation to increase in size.) To verify my hypothesis, I particularly examined the types of scientific arguments students constructed and defended while they acted and interacted with the "Gas Properties" simulation in an argumentation-based learning environment. Throughout this process, this specific case also makes it possible for me to:

- Explore the types of scientific arguments students found convincing (e.g. scientific arguments with empirical evidence consisting of numerical data collected from the Gas properties" simulation or scientific arguments with empirical evidence consisting of non-numerical data collected from the "Gas Properties" simulation).
- Investigate the conditions that helped students improve their scientific arguments (e.g., students articulate their arguments when they are challenged by the driving question teacher asked, students elaborate their arguments when they are challenged by a peer's question).
- Validate the support of computer representations on the quality of scientific arguments (e.g. using Table 4.5 to analyze the quality of students' argument)

4.3 How does the "Gas Properties" Simulation work?

As suggested in Cavagnetto (2010), a number of argument interventions are guided by the notion that it is best to learn making scientific argument by embedding argumentation within investigative tasks. The Physics Education Technology (PhET) project at the University of Colorado has developed a series of highly interactive computer simulations in order to teach science concepts and provide students with animated feedback in investigative learning tasks (Finkelstein et al, 2005). In this study, I borrow one of PhET's simulations, the "Gas Properties" (Gas Properties, n.d.), where empirical observations of the behaviors of gas molecules at macroscopic terms can help students develop their conceptual understanding and reasoning of the behaviors of gas molecules at microscopic level in the content of Kinetic Molecular Theory of gases.

The "Gas Properties" simulates the behavior of gases in a closed system and provides an open workspace where students can manipulate the parameters of "pressure," "temperature," "volume," and "number of gas molecules" (which are called "gas in chamber" in the simulation) (Fig.4.1). The pressure and temperature parameters are represented with their own units such as Atm and Kelvin, and they can be measured by a barometer and a thermometer in the simulation. Although volume cannot be measured exactly in the "Gas Properties" simulation, the increase or the decrease in the volume parameter can readily be perceived by looking at "a small guy" moving back and forth on the left of the chamber or by using a ruler which is in the "measurement tools" option of the simulation. Pressure, temperature, volume and the number of gas species can be manipulated by the users' pumping a handle on the screen. When one of these parameters is varied by the users, the effect of this change in this parameter can be observed on other parameters in the "chamber" of the simulation. For instance, when the users pump the handle many times to increase the number of gas species, the simulation shows how gas species move faster, making the lid of the chamber pop off with the increasing pressure and temperature.

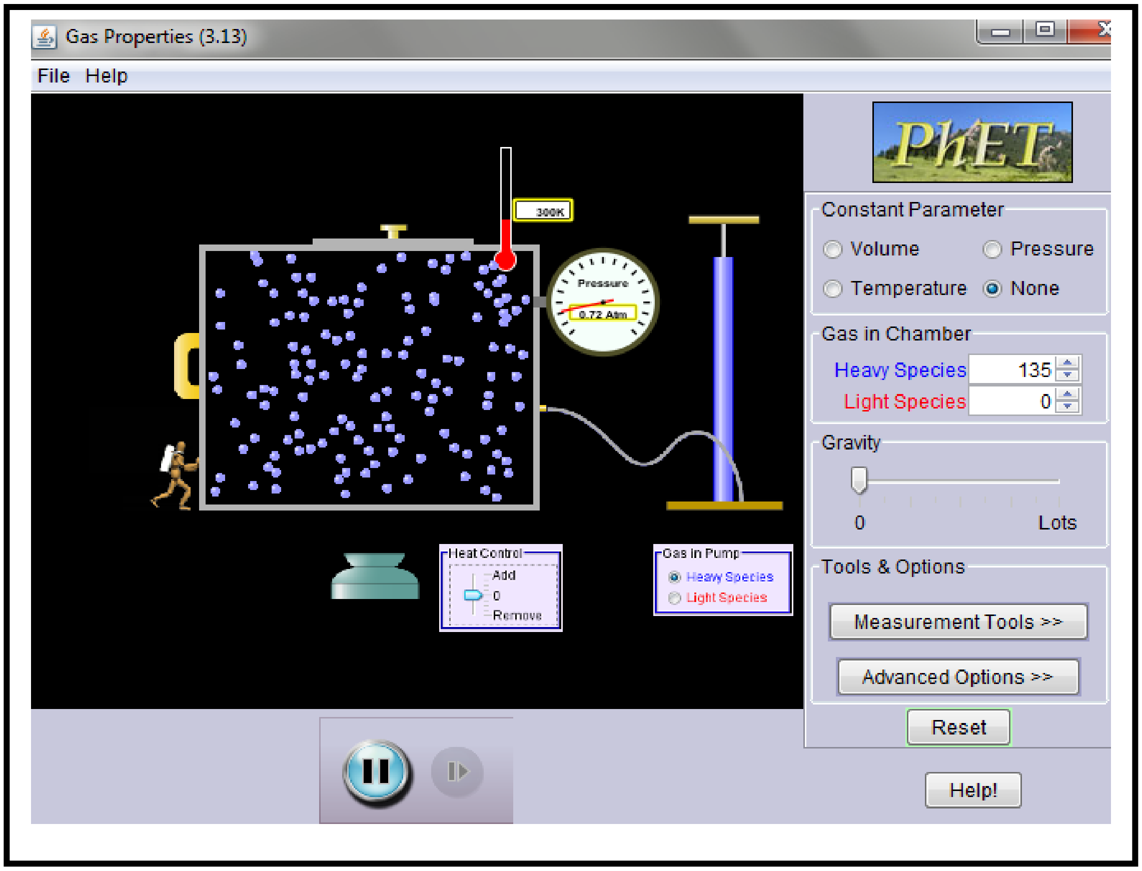


Figure 4.1: (Color) Screenshot of the PhET's "Gas Properties" Simulation.

The "Gas Properties" simulation enables a much larger and younger segment of society to engage with the powerful ideas of chemistry and physics. This simulation is designed mainly to teach the basic concepts of Kinetic Molecular Theory such as the combined gas law (P.V=n.R.T), Boyle's law (inverse proportion between P and V at constant T), Charles's law (direct proportion between V and T at constant P) and Gay-Lussac's law (direct proportion between P and T at constant V) to students from elementary school levels to university levels. In these laws, P is the absolute pressure of the gas, V is the volume, n is the number of moles of gas, R is the universal gas constant (8.3145 J/mol K) and T is the absolute temperature. For example, when students keep constant volume in the "constant parameters" box of the "Gas Properties" simulation and increase temperature by adding heat into the chamber, the simulation shows the increase in pressure and helps students make sense of Gay-Lussac's law:

$$P_1 / T_1 = P_2 / T_2 \text{ at constant } V$$

The "Gas Properties" simulation also supports students to develop conceptual understanding about a subtopic: the effects of gravity on the behaviors of heavy and light gas molecules. Students can follow both heavy and light gas molecules' actions with "heavy gas species" and "light gas species" options on the simulation. Heavy gas molecules are represented with big blue balls moving slower than small red balls, which represent light gas molecules. When students increase the gravity in the simulation, the pressure of the heavy gas molecules decreases more than the pressure of the light gas molecules. Gravity pulls down heavy gas molecules more than light gas molecules because of increasing molecular weight and makes them move slower than light gas species. Thus, the "Gas Properties" simulation provides an opportunity to students to explore the difference in the pressure, volume and temperature of heavy and light gas species by changing gravity.

4.4 Research Methods

4.4.1 Participants

Forty-seven leventh grade students (16-18 years old) who had experience interacting with computers were identified through *purposeful and convenience sampling* (Patton, 1990) to ensure that scientific argumentation could be observed in this study's entirety. Students were drawn from two Western Massachusetts High

Schools in a broad spread of average income areas. This research study took place in four 11th grade chemistry classes because of:

- *The Place of "properties and behaviors of gases" in Kinetic Molecular Theory topic of High School Chemistry Curriculum:* According to Massachusetts Curriculum Framework for Science, Technology and Engineering (2006, p.70), "explaining the behavior of gases and the relationship between pressure and volume (Boyle's law), volume and temperature (Charles's law), and pressure and temperature (Gay-Lussac's law)" and "using the combined gas law to determine changes in pressure, volume, and temperature" should be in the learning standards of a high school chemistry course. In two high schools that I selected for my study these learning standards appear in 11th grade chemistry curriculum. When the research began, 11th grade students had some prior knowledge of gaseous state of matter but they had not undertaken any activity to investigate the behaviors of gases with changes in pressure, volume and temperature or they had not been taught about Kinetic Molecular Theory. Otherwise, if students had well-established knowledge and consensually agreed-upon answers, there could be little for them to discuss or argue about.
- *Student Readiness to participate in Scientific Argumentation:* Because the progression of this study necessitates having prior knowledge about ratio and proportional relationships to understand the relationships between the combined gas law parameters, it involved high school students who had "used concepts of ratio and rate to solve problems" and "developed

understanding and applied proportional relationships" in their middle school mathematics classes (Massachusetts Curriculum Framework for Mathematics, 2011, p.49 and p.55). Furthermore, that significant changes in students' abilities to coordinate theory and evidence take place during the years of early adolescence (Kuhn, Amsel, & O'Loughlin, 1988), which purposely made me decide on 11th grade students who could use evidence from the "Gas Properties" simulation to justify their claims in scientific argumentation.

Eleventh grade classes selected for this study led to achieve diversity in both student ability and enactment. They were mixed ability with similar average performance across subjects and this variety increased the likelihood that students' answers would demonstrate a range of ways that students could engage in this practice. I made students work in pairs in some parts of the activity, with each other and with the teacher during group discussion. One pair in each class was selected as a focal group to identify students' interactions with the "Gas Properties" simulation. These focal group students' interactions were followed during classroom discussions to assess their interactions with other students.

Focal-Group Discussions: During the group discussions, participants were divided into pairs across all four classes, and one pair of students was selected as a focal group by their chemistry teachers from the middle of the ability range within each class. The sample was constructed in this way to make it as representative as possible of students in elective and compulsory chemistry education. In addition, teachers were asked to select students who were prepared to talk with each other and with them. The discussions were conducted during the courses and they served as a means of pair checking. The group format permitted a more in depth exploration of the ideas with all participants present. The group discussions also provided a brainstorming place for dialogue about investigations among 11th grade students. Three female and five male students participated in these four focal group discussions as follows (Table 4.1):

Table 4.1: Focal Group Participants[1]

Focal Group	Name	Gender	Age	Ethnicity	Teacher	Chemistry Course
FG1	Andy	Male	17	Hispanic	Mr. Core	Compulsory
FG1	Jane	Female	17	Hispanic	Mr. Core	Compulsory
FG2	Sean	Male	18	White	Mr. Core	Compulsory
FG2	Ally	Female	17	Hispanic	Mr. Core	Compulsory
FG3	Simon	Female	16	White	Mrs. Simpson	Elective
FG3	Kelly	Female	17	White	Mrs. Simpson	Elective
FG4	Chris	Male	17	White	Mrs. Simpson	Elective
FG4	Justine	Male	18	White	Mrs. Simpson	Elective

According to their oral and behavioral expressions, all of these students were quite interested in the activities.

4.4.2 Data Collection

In this study I had four focal groups and two driving questions. Each group discussed the questions first within groups and then, with other groups in their classes during Part I and Part II of the scientific argumentation. I videotaped 16 sessions with four focal groups during discussions within their groups and with other groups during the four activities of both Parts. Table 4.2 presents analyzed minutes of videotaped data

[1] All the names of participants in this dissertation are pseudonyms.

for each group when the groups were playing with the "Gas Properties" simulation and/or discussing about the tasks in the activities of each Part.

Table 4.2: Analyzed Focal Group Recordings

Parts of Scientific Argumentation	Part I		Part II	
Activities in Parts	Activity I: Focal group discussion within group	Activity II: Focal group discussion with other groups in class	Activity I: Focal group discussion within group	Activity II: Focal group discussion with other groups in class
Videotaped Data for FGs	30 minutes	30 minutes	30 minutes	30 minutes
Analyzed Videotaped Data for FG1	15 minutes	13 minutes	14 minutes	12 minutes
Analyzed Videotaped Data for FG2	15 minutes	12 minutes	16 minutes	14 minutes
Analyzed Videotaped Data for FG3	14 minutes	12 minutes	15 minutes	16 minutes
Analyzed Videotaped Data for FG4	10 minutes	11 minutes	13 minutes	12 minutes

I used the following data sources:

- Videotape recordings of scientific argumentation when four focal groups constructed their group arguments in pairs.
- Videotape recordings of scientific argumentation when four focal groups defended their group arguments in classes.
- Related Document (or Artifact) as "Our Argument" worksheet recordings of four focal groups' scientific arguments when they constructed their arguments in pairs (Appendix C).

4.4.3 Classroom Settings

In order to evaluate how the quality of students' arguments changed over time during scientific argumentation, and when students construct and defend their arguments using a computer simulation, two chemistry teachers (Mrs. Simpson and Mr. Core) implemented the "Gas Properties" simulation with their classes in the chemistry laboratories. All 11th grade students did computer-assisted laboratory activities when their daily courses required the use of computers. Mrs. Simpson is a white female American with eight–year experience teaching high school science, including biology and chemistry. Mrs. Simpson completed a bachelor's degree in biology and a master's degree in education. Her school is a public school with a curricular focus on math and science as well as social sciences. Students are from different rural districts around the school. Mrs. Simpson was teaching in three 11th grade chemistry classes and two of them participated in this study. These classes were elective courses with 25 11th graders enrolled (14 females, 11 males, 11 ethnic minorities). Mrs. Simpson also had an experience working with projects for the university faculties prior to this study, but she had not implemented scientific argumentation-based activities during the school year before starting this study.

Mr. Core is a white male American with 2 years experience teaching chemistry, after working as an environmental scientist. Mr. Core earned bachelor and master's degrees in environmental science and a master's degree in education. He conducted research with the university faculties in different projects. Mr. Core teaches at a charter school that values its emphasis on curiosity and project-based inquiry and its preparation of students to matriculate into competitive colleges. Mr. Core's students, 32 eleventh graders (18 females, 24 males, 29 ethnic minorities) from two classes, were enrolled in chemistry but they had not participated in argumentation-based chemistry activities with Mr. Core during the school year before starting this study. Mr. Core learned about this study from the university faculty and was excited about including it in his curriculum for the first time.

Prior to the activities, Mrs. Simpson and Mr. Core were briefed on the approach to the lessons so that some uniformity was provided in the way they carried out the activities. The teachers read the research method that described the instructional moves that could be used to prompt students' reasoning such as asking students to give reasons or evidence or to sum up the argument so far and challenging students by presenting counterarguments that they did not considered. The research method also acknowledged that while students asked gas related questions such as why the pressure of gas molecules is higher in space and why the temperature of the gas molecules is higher on earth, the teachers would not give away factual information or explanations relating to the behaviors of gases. They would answer with another question, hint or prompt which aimed at helping students to find the answers for themselves, through their own reasoning.

The teachers dedicated different amounts of time to the activities because of the different duration of their courses (three days for Mrs. Simpson's students, four days for Mr. Core's students), but both teachers successfully intertwined the students' experimental work with scientific argumentation in their lessons. One video camcorder per focal group (two students) discussion in each classroom was set up throughout each activity to record students' interactions with the simulation, with each other and the teacher. Then, this camcorder was used to record these focal group students' interactions with other students in whole-classroom discussions. Mrs. Simpson led eight videotaped discussions with two focal groups throughout the three consecutive days and Mr. Core led eight videotaped discussions with two focal groups throughout the four consecutive days. As it was possible to observe every classroom day, the progress that focal group students made about their arguments in these days could be observed effectively.

During the activities, I and teachers mentored the students in designing and conducting original experiments with unknown outcomes to yield insights into the properties and behaviors of gas molecules that scientists investigate widely in the content of Kinetic Molecular Theory of gases. In particular, students addressed the driving questions posed by the teachers as unanswered questions of how the behavior of cold air molecules changes from Earth to space, and how the behavior of Helium molecules is different from the behavior of air molecules in space. They responded to these questions constructing and defending their arguments using the "Gas Properties" simulation. Thus, while students learnt gas concepts in their chemistry courses, they had the opportunity to engage in science practices enabling them to think more like scientists.

The author as a participant-observer became familiar with both class environments and observed activities related and unrelated to the scientific argumentation. Of special interest were students' arguments, students' efforts to engage in scientific argumentation practices and interactions among students and teachers. I largely maintained the participant-observer stance (e.g. taking notes, managing taping equipment) throughout the data collection, occasionally conducting brief dialogues as students worked through the lessons and helping the teacher respond to a student question, when necessary. The teachers' informal management style allowed me for easy movement around the classrooms to get a closer view of pairs at their work and interact causally with them, including posing questions (e.g., How did you decrease the volume of the balloon? How did you decide to decrease the gravity? How did you decide to observe the changes in the system?). Thus, this research helped me document how students construct and defend their arguments.

4.4.4 Entry to the Classrooms

During the course of my fieldwork, prior to conducting this study in the classrooms, I requested and received proper permission(s) from appropriate administrators and chemistry teachers at both high schools. I explained the premise of my research and what I needed from each high school in the way of assistance in requesting participants. Once preliminary permission to conduct the research was given by the administrators and chemistry teachers, I submitted an application to the University's Institutional Review Boards (IRBs) to receive authorization to conduct this study. Each high school's IRB involved several documents related to the research project. The human subject review questionnaire (Appendix A), a summary description of the research, the consent of parents/guardians (Appendix B) and official acceptance of the research proposal from the University of Massachusetts, Amherst were provided as background for obtaining their approval to enter the classrooms and conduct the data collection.

Once permission to conduct this study at the high schools was granted by the University's Institutional Review Board, I submitted the summary description of the research and the consent forms to the parents/guardians in each class. Volunteer participants and their parents/ legal guardians chose for me to observe signed a letter of informed consent, which explained the purpose, risk, and rights of the participants in this study. Only students whose parents/ legal guardians gave consent were selected as focal groups in each class. During videotaping of the whole class discussion, my camcorder only focused on focal group students and I did not videotape students whose parents/ legal guardians did not provide consent for videotaping. Throughout the research, pseudonyms replaced each participant's name and the name of teachers in an effort to maintain confidentiality.

4.4.5 Procedure

In designing this study, my intent was to investigate how students constructed and defended arguments related to the behaviors of different gas molecules under different conditions (e.g., with gravity and without gravity), using the "Gas Properties" simulation in scientific argumentation-based classrooms. I initially thought that it would make sense to first introduce the participants to the nature of problems, and then to possible solutions during scientific argumentation. However, given the complexity of the issues in the problems, especially 11^{th} grade students who had not been taught the behaviors of gas molecules and used the "Gas Properties" simulation in their chemistry classes yet, I thought it best to start with something tangible. That is, I first let students to have experience with the "Gas Properties" simulation and to have idea about the behaviors of gas molecules in the simulation before scientific argumentation. Then, they proceeded to increasingly more complex realm, which was scientific argumentation. Therefore, the classroom activities in this study were divided into two phases: Pre-Scientific Argumentation and Scientific Argumentation.

Pre-Scientific Argumentation: This phase lasted about *one-hour* in each class. Within this activity I explored how the focal group students' participated in group and whole-class discussions while they acted and interacted with the "Gas Properties" simulation in their regular learning environment. The characteristic features of the first activity were students' familiarizing themselves with the "Gas Properties" simulation, investigating the behavior of gas molecules through the "Gas Properties" simulation and establishing a relationship between the system in the "Gas Properties" simulation and the real world phenomena.

Pre-Scientific Argumentation began with working in pairs at computers to familiarize students with the "Gas Properties" simulation because they had not used this simulation in their courses before. Pairs discussed what they noticed on the simulation and took notes on blank pieces of paper in the first 15 minutes of Pre-Scientific Argumentation. Their notes served as a group memory and as a reminder to the participants of their previous ideas to elaborate on them when focaling on answering the teacher's subsequent questions. For instance, while pairs were still working at the computer, the teacher posed question 1 with additional questions (A1-F1) to support pair discussions and to promote their exploration of the "Gas Properties" simulation.

> Question 1: What do you notice in this simulation? Play the handle on the simulation and observe the behavior of gas molecules. Keep constant pressure, temperature and volume respectively and observe how the gas molecules behave.
>
> A1: How does the pressure vary with time?

B1: What visual cues are associated with an increase in pressure?
C1: Why does the volume vary with time?
D1: What do you notice in the simulation if you pump the handle seven times?
E1: How many different ways can you find to blow the top off the chamber in the simulation?
F1: There is a guy on the left of the chamber in the simulation. If you move this guy right to compress the gas molecules inside the chamber, what happens to the temperature of the gas? Why?

Thus, these questions provided insights to the students about how the change in selected variables affects other variables in a closed system involving gas molecules.

After the first 15 minutes of Pre-Scientific Argumentation, the teacher handed out the “Group Worksheet (Gas Properties)” (see Appendix C) to the pairs to support their investigations in an organized way for the next 20 minutes. The pairs experienced designing their own investigations using the “Gas Properties” simulation. They identified their own questions and they wrote their predictions to these questions on the worksheets. Then, they used the “Gas Properties” simulation to make observations and to discuss their observations with each other. Thus, they gained knowledge of how they could design their investigations to search for the most appropriate responses to their questions on the simulation.

At the end of Pre-Scientific Argumentation, after pair discussions, the teacher told the pairs to stop using the “Gas Properties” simulation and to share their findings from all their experiments with their classmates. Then, the teacher showed an actual balloon in the classroom discussion and asked question 2 with additional questions (A2-C2) to all pairs in order to help them begin to establish a relationship between the behavior of gas molecules in the chamber of the “Gas Properties” simulation and the behavior of air molecules in the actual balloon. These questions were essential to the integration of all their ideas obtained from the “Gas Properties” simulation with the ideas from their everyday experiences with an actual balloon. This classroom discussion took about 25 minutes.

> Question 2: Okay. What can be the similarities and differences between the action of the air molecules in an actual balloon and the action of gas molecules in the chamber of simulation?
>
> A2: What are air molecules doing in the balloon?
> B2: The gas molecules in the chamber of the “Gas Properties” simulation are applying pressure on the walls of the chamber. How is that similar to or different from what the air molecules are doing in the balloon?
> C2: If I compress the balloon, what will happen to the air molecules inside the balloon? Can you explain it using the “Gas Properties” simulation?

Scientific Argumentation: This phase comprised Part I and Part II and each of these Parts lasted about 1 hour in each class. Within these Parts, I investigated how the use of computer representations supported students’ arguments in scientific argumentation when they constructed and defended their group arguments using the “Gas Properties” simulation. Then, when analyzing and comparing their arguments during these two Parts, I validated the improvement in the quality of the focal group students’ arguments.

The characteristic features of Part I and Part II in Scientific Argumentation, which were taught by the respective teachers, were taking positions on a scientific question, constructing scientific arguments and defending these scientific arguments using the “Gas Properties” simulation. Having the same characteristic features in each Part was aimed at supporting students in developing scientific arguments.

4.4.5.1 Part I - Arguing to explain the behavior of air molecules in space

The course objective of Part I was students' exploring the effect of the gravity on the behavior of gas molecules, using "Gas Properties" simulation in a scientific argumentation-based classroom.

At the beginning of Part I in the four classrooms, the teacher posed question 3 as thought experiment when showing the same balloon from Pre-Scientific Argumentation to the class. Students neither worked in pairs nor used the "Gas Properties" simulation when answering this question in 10 minutes. Therefore, I anticipated that their reasoning underlying their answers to the question 3 would be based on their prior knowledge or their experiences with the simulation in Pre-Scientific Argumentation.

> Question 3: Last week you did experiments using the "Gas Properties" simulation and then, you compared the similarities and differences between the behavior of air molecules in an actual balloon and the behavior of gas molecules in the chamber of the "Gas Properties" simulation at the end of the course. I have the same actual balloon in my hand and if I put this balloon in a refrigerator, what happens to the balloon? Why?

After that, the teacher posed the driving question 1 of Part I to familiarize students with scientific argumentation when discussing the effect of gravity on the behavior of gas molecules. S/he wrote this question with a number of claims ranged from option A to option C on the boards of her or his classroom and asked students to choose which the best claim was. S/he conducted a straw poll of students to find out how many of them thought "it gets the same size", "it gets bigger" or "it gets smaller."

> Driving Question 1: If we put an actual balloon in a fridge and then, take this balloon into space away from the Earth, what may happen to this cold air-filled balloon? Why?
>
> A) It stays the same size.
> B) It gets bigger.
> C) It gets smaller.

Then, to achieve the goals of constructing scientific arguments and defending these arguments using the “Gas Properties” simulation, all students first worked in pairs in Part I - Activity I and then, all the pairs returned the classroom for discussion in Part I - Activity II. Thus, these two activities helped me to satisfy my curiosity about my research questions.

Activity I - Constructing Scientific Arguments using the “Gas Properties” simulation: In this activity, students paired up to work on the above driving question using the “Gas Properties” simulation in 20 minutes and one video camcorder captured the dialogue between a pair in each class. When students responded to this question in pairs, they were encouraged to take a position on one of the options under the driving question and to design their investigations based on the position they defended as a group. Then, they were supported to collect data using the “Gas Properties” simulation to show it as evidence in their constructed scientific arguments.

Some additional questions (C1-1 –C1-5) below were also be posed by the teacher to prompt students’ construction of completely explicit arguments if needed.

> C1-1: If we let out air molecules from a balloon in space, will it keep its spherical-like form?
> C1-2: What will happen to the air pressure inside the balloon in space?
> C1-3: Why do you think the air pressure inside the balloon increased/ decreased?
> C1-4: What will happen to the air temperature inside the balloon?
> C1-5: If this balloon was filled with the hot air, what would happen to this balloon into space away from the Earth? What makes you think that?

The teacher distributed and went through the “Our Argument” worksheet (see Appendix D), telling the students that their task was to decide whether the balloon gets smaller, bigger or the same. This worksheet helped the pairs construct not only a scientific argument that they would defend but also a counterargument that other pairs could present in the following classroom discussion.

Activity II - Defending their Scientific Arguments using the "Gas Properties" Simulation: The pairs defended their arguments for the driving question 1 in the classroom discussion at the rest of Part I, which was videotaped. The teacher asked students to choose a representative who would present their arguments to the class. The teacher also explained to the students that they should have provided reasons and evidence for supporting their arguments or challenging other arguments being made by other students.

4.4.5.2 Part II - Arguing to compare the behaviors of air and Helium molecules in space

The course objective of Part II was students' investigating the similarities and differences between the behaviors of heavy and light gas molecules in an environment without gravity, using "Gas Properties" simulation in a scientific argumentation-based classroom.

To save participants' time, the "Gas Properties" simulation was opened and ready for use before the students began their interactions with the computers in Part II. Then, the Part II started with classroom discussion on the following warm-up questions 4 and A4-C4 the teacher posed about two balloons. The students just discussed their answers with each other in classroom in 10 minutes.

> Question 4: Okay. I have two balloons in my hands: one is flying, other one is not flying. If you could zoom in really far inside a balloon, what do you think the gases inside would look like?
>
> A4: What are the similarities and differences between the behaviors of the gases in two balloons? You can use the "Gas Properties" simulation if you want.

B4: Do these balloons have the same pressure?

C4: If I put them in the refrigerator, how do the gases inside these two balloons behave?

While the classroom discussion proceeded, the teacher challenged the students with another driving question. Within this driving question 2, three alternative theoretical accounts of the relationship between the pressures of Helium and air were presented, and students decided on which of the three given options under question is the most appropriate. The teacher wrote this question with three alternative claims ranged from option A to option C on the boards of their classrooms and conducted a straw poll of students to find out how many of them thought option A, option B or option C as their claim.

Driving Question 2: There are 2 balloons at the same place of the space. They are identical in size and material. One balloon is filled with air and the other balloon is filled with Helium. The balloons have the same number of molecules. How does the pressure of the air balloon compare to the pressure of the Helium balloon in space?

A) The pressure in the air balloon is equal to the pressure in the Helium balloon.
B) The pressure in the air balloon is less than the pressure in the Helium balloon.
C) The pressure in the air balloon is greater than the pressure in the Helium balloon.

Then, to accomplish the goals of constructing scientific arguments and defending these arguments using the “Gas Properties” simulation, all students first worked in pairs in Part II-Activity I and then, all the pairs returned the classroom for discussion in Part II- Activity II. Thus, these two activities performed by the same pairs from Part I facilitated my examining my research questions in more detail.

Activity I - Constructing Scientific Arguments using "Gas Properties" simulation: Students worked on the driving question 2 in the same pairs from Part I, using the "Gas Properties" simulation and "Our Argument" worksheet (see Appendix D) in 20 minutes and one video camcorder captured the dialogue between the same pair from Part I in each class. Pairs designed and carried out investigations based on the position they defended as a group and they collected data using the "Gas Properties" simulation to show it as evidence when constructing their arguments.

My expectation in this activity was that students' engaging in group discussions with each other for a different driving question would help them construct more elaborate scientific arguments, this being identifiable in protocols. The teacher also posed some additional questions (C2-1- C2-4) below to promote pair discussions if needed.

> C2-1: How does the pressure in the Helium balloon compare to the pressure in the air balloon in the room?
> C2-2: Do you think the air outside the balloons can apply pressure to these balloons? If so, how do you think it does it?
> C2-3: How do the number of air molecules in the air balloon compare to the number of He atoms in Helium balloon? What makes you think that?
> C2-4: How does the average speed of the Helium molecules compare to that of the air molecules? How do you know that?

Activity II - Defending their Scientific Arguments using the "Gas Properties" Simulation: After pair discussions, the pairs' arguments on the answers to driving question 2 were discussed in the classroom as the rest of this day's activity. The teacher asked students to choose a representative who would present their scientific arguments to the class. During this classroom discussion, I paid close attention to the scientific argumentation focusing on how the focal group students articulated and elaborated their scientific arguments relating evidence to claim when defending their arguments.

4.5 Scientific Argument Frameworks in Argumentation

To date, a significant body of argumentation literature has focused on Toulmin's framework, which is Toulmin's Argument Pattern (TAP) (e.g., Erduran et al. 2004; Jiménez-Aleixandre et al., 2000) to analyze student arguments because of its domain generality and relative simplicity. Toulmin (1958) developed a framework, which has been applied mainly to fairly simple arguments in conversations. This frame involves data, claims, warrants, backings, rebuttals and qualifiers, which are field-invariant features of arguments.

Erduran (2008) defines claim as "an assertion put forward publicly for general acceptance (p.57)." Data is a generic term, which refers to all kinds of evidence that might be used by an arguer to support a claim. *Existing knowledge and research findings in empirical or theoretical statements* might be used as evidence when justifying factual and causal claims in science-related arguments (Kolsto & Ratcliffe, 2008; Wood, 2000). Warrants play a central role in justification by connecting data with claims in arguments (Garcia-Mila & Andersen, 2008). According to Toulmin (1958), warrants are not explicit in most adult arguments and in such cases these arguments contain implicit warrants. Qualifier marks limited certainty of the claim and is usually constituted by a modal adverb such as "perhaps" or "probably" (Stegmann et al., 2007). Bricker & Bell (2012) point out the following example from Toulmin (1958/2003) to show Toulmin's Argument Pattern (p.97): "Harry was born in Bermuda [D] so presumably [Q], Harry is a British subject [C] unless both his parents were aligns/he has become a naturalized American/… [R]" and "a man born in Bermuda will generally be a British subject” [W]. As Bricker and Bell indicated, warrant can be backed by noting that the warrant is reasonable because of legal provisions, statues, and so on.

Despite its use as a framework for defining argument, the application of TAP to the analysis of classroom-based verbal data has yielded difficulties such as what counts as claim, data, warrant and backing (Erduran, 2008). To respond to these difficulties, different education studies used some form of modified version of Toulmin’s argument framework. Sampson and Clark (2006) identified five versions used for the assessment of arguments in scientific and socio-scientific issues (e.g. Sandoval, 2003; Kelly & Takao, 2002; Takao & Kelly, 2003; Lawson, 2003; Zohar & Nemet, 2002). In this research I reviewed some modified versions of argument frameworks mainly used for the analysis of arguments in science education (Table 4.3). These analytic frameworks are tools created for specific issues to investigate specific questions in specific contexts (Clark et al., 2012).

Table 4.3: The Category of Analysis of Scientific Argument Frameworks (Examples)

Toulmin (1958)	Sandoval (2003)	Zohar & Nemet (2002)	de Vries, Lund & Baker (2002)	McNeill & Pimentel (2009)
Data	Data	Explicit Conclusion	Thesis	Claim
Claim	Articulation (Stated Claim)	Justification	Defense	Evidence
Warrant	Evidence	Concession	Concession	Reasoning
Backing			Compromise	
Rebuttal	Warrant (Data to Support Claim)	Implicit Conclusion	Attack	
Qualifier		Opposition	Outcome	
		Counter opposition		

Sandoval (2003): In his research, Sandoval (2003) explored high school students' ideas about a problem of natural selection among finches on a small Galapogos island. Groups of students constructed written explanations involving *articulation of causal claims* about natural selection and evaluation through a technology-supported curriculum (finches investigation environment and ExplanationConstructor). To construct their explanations, they collected data from several sources. *Data* included "rainfall amounts, seed types and amounts, finch predator data, and several kinds of physical (e.g., weight, beak length) and behavioral (e.g., foraging, mating) data about the ground finches (p.14)." Students copied particular data from finches investigation environment in to ExplanationConstructor, linked this data to specific causal claims and justified the relevance of that data as *evidence.* To justify particular claims students gave warrants as reasons. During the analysis of student arguments, Sandoval distinguished these warrants from warrants in Toulmin's scheme. The warrants were more like Toulmin's idea of backing because they came from the data that students looked at to be the source of judgments of warrants.

Sandoval analyzed the quality of students' arguments by scoring from zero to four. If no causal claims were made, explanations received zero as articulation score. If complete natural selection explanations were articulated, these explanations were scored four. Sandoval analyzed written explanations of high school students with respect to their articulation of causal components and warrants for the problem couched within the theory of natural selection. For my study there are two challenges in how Sandoval analyzed his research. First, Sandoval analyzed students' written explanations obtained at the end of the group discussions. He did not inform about how students articulated, extended and elaborated their explanations before presenting them in written forms at the end of the group discussions. Secondly, groups articulated their explanations in a collaborative way, but they did not discuss their written explanations with other groups. The account below can be shown as the result of these challenges (Sandoval, 2003, p.42):

> Students did not go as far as one might wish. They did not, for example, hold the lack of confirming data for claims of advantage to be, effectively, counter evidence. This could be because students did not see a lack of data as problematic, or took aggregate data showing trait differences as defacto evidence for the trait's advantage.

In this study I do not use Sandoval's framework to analyze students' arguments because of two reasons. First, this framework provides a way to analyze written explanations as an end product in group discussions. In my research I would like to examine the extension and elaboration of articulated explanations within verbal group discussions. Secondly, written explanations are the product of inquiry type of dialogues within the groups, which means that students collectively establish scientific claims based on evidence and try to agree on conclusions drawn from the evidence. I anticipate that this type of dialogue is observable within pair discussions in my research and I might have used Sandoval's framework during the analysis of pair discussions. Yet, this framework would not be enough to analyze persuasion type of dialogue in my research while pairs try to win other pairs over to their points of view with counter-evidence in classroom discussions.

de Vries, Lund & Baker (2002): As stated in fourth representation feature of computers above, de Vries and her colleagues designed the CONNECT software as the medium of communication to investigate 11^{th} grade students' explanation, argumentation, problem resolution and management types of dialogues about a sound phenomenon across the network situation. de Vries et al. coded a dialogue as argumentation on CONNECT interface if they could identify a clear disagreement in the dialogue. Then, they analyzed these dialogues with six categories in their framework: thesis, attack, defense, concession, compromise and outcome. If a statement involves a proposal, it is categorized as thesis in argumentative context. The category of attack states reasons against a particular position while the category of defense states reasons for a particular position. Students show concession in the dialogue if they admit the partner is right. Compromise is a category, which proposes an idea unifying two conflicting interpretations. The category of outcome is seen in the dialogue when students discuss the outcome of an argumentative sequence.

Different from Sandoval (2003), de Vries et al. (2002) categorized the statements of students throughout argumentative dialogue using their framework. Each category of statements except thesis may contain evidence in these dialogues. However, de Vries et al.'s framework does not specifically involve evidence, which is very important part of the analysis of my research. That is, de Vries et al. do not categorize evidence independent from other categories in their framework and do not explicitly analyze source and types of students' evidence in their research. Therefore, using de Vries et al.'s framework for the analysis of scientific argumentation is not convenient in my current study at all.

Zohar & Nemet (2002): Zohar and Nemet designed the Genetic Revolution curriculum to investigate the ninth grade students' learning that took place following the implementation of this unit and its effects on both biological knowledge and argumentation skills. Students' discussions related to two dilemmas were audiotaped, transcribed and analyzed by using the classification system modified from TAP framework. Zohar and Nemet collapsed the data, warrants and backings into one single category of justifications in their framework and this involves some criteria for classifications of justifications: no consideration of scientific knowledge, inaccurate scientific knowledge, non-specific scientific knowledge and correct scientific knowledge (Erduran, 2008). They emphasize that students' arguments should include at least one relevant justification, which consists of a piece of knowledge and good arguments include multiple justifications. Zohar and Nemet also define explicit conclusions as explicitly stated ideas and implicit conclusions as not explicitly pronounced ideas in response to the question. Implicit conclusions are followed from the line of discourse. Students' arguments also have the categories of concessions and oppositions, which involve the agreed or disagreed expressions of students with other students. Zohar and Nemet describe another category, counter oppositions, with an example in their research. Counter opposition was shown as the opposition of a student ("No. You are wrong." (p.52)) to his peer's opposition, ("This is not true. You are definitely wrong." (p.52)).

Zohar and Nemet created their framework for a particular issue involving modern technologies in genetics to investigate students' moral value decisions in a specific context of human genetics. They do not accept decisions as arguments that include a conclusion with no justifications. Erduran (2008) argues that this framework does not evaluate the accuracy of the claim itself; therefore, it works better when used to analyze arguments generated in the context of socio-scientific issues rather than in the context of scientific issues. She also emphasizes that in socio-scientific arguments, claims can be made from multiple perspectives but in scientific arguments, claims are explanatory conclusions or descriptive frameworks. As Osborne et al. (2012) emphasized, developing a repertoire of generic frameworks that can be used in scientific and socio-scientific contexts is the real challenge for argumentation field.

McNeill & Pimentel (2009): The argument structure developed by McNeill and Pimentel in the content of global warming is a more digestible version of Toulmin's structure for most scientific contexts (Cavagnetto & Hand, 2012). In McNeill and Pimentel's framework, in order for an utterance to be classified as a *claim*, a student needs to offer a conclusion about whether or not he believes the climate is changing. An utterance is classified as *evidence* if it includes data or information that the student is using to argue for whether or not the climate is changing. McNeill and Pimentel then classified evidence as scientific evidence, personal evidence and other evidence to further capture the nature of the data students used. Scientific evidence can take a number of forms including traditional numerical data, observations, and facts that are revealed in discussions (Berland & Reiser, 2008). In their research, students obtained scientific evidence from one of the two videos or from another outside source such as science class or a news program. If an utterance is classified as *reasoning,* which consists of a combination of Toulmin's warrant and backing, it provides either a justification for why the student's evidence supports his claim, or a theory or mechanism for why global warming is or is not occurring. Cavagnetto and Hand (2012) criticize that reasoning is undervalued in this framework because this characterization suggests that reasoning occurs only a defined point of inquiry rather than throughout as a critical aspect of entire process.

After considering the divergent foci of the various frameworks in above studies, I decided on using McNeill and Pimentel's (2009) framework in the analysis of my study. Their framework involves types of evidence in students' statements but not focus on source of evidence, which is very important during the analysis of students' arguments in my study. Berland and Reiser (2008) explain it in more detail. According to them, the logical connections between evidence and claims can also be inferences and the distinction between inferences and evidence is a key to inquiry process. That is, students' explanations can include ambiguous statements in which explicit evidence drawn from data and inferences drawn from evidence were not clearly distinguishable. Although students' responses are coherent and consistent with the available data, it is difficult for their audiences to determine which parts of their explanation were based directly on their scientific evidence that students found in their research and which were inference they made. Berland and Reiser (2008) proposed two general strategies to differentiate between inferences and evidence in students' written arguments: explicitly referencing the data and, presenting data in form that is similar to the original source (p.42). In the first one, by citing data source such as "The charts of cactus, Portulaca, and Chamae all show… (p.42)" or referencing the evidence "the graph shows that. . . (p.42)" students make apparent that information comes from their research rather than their own inferences and mark the information as evidence. In the second one, presenting the evidence in a form that is similar to that of the original data source is a strategy that helps readers to identify the students' claims and evidence and, subsequently, to evaluate whether the evidence supports the claims. The second strategy enables students to engage in a discourse in which students evaluate one another's perspective because they become familiar with the data. Because the second strategy is coherent and consistent with the strategy, which should be in my study, the second one will be my focus. I assume that students' referencing data in a manner similar to the original source would help their audiences to be convinced that the available evidence supports the claim. Berland and Reiser argued the importance of this second strategy with an example in which students presented the supportive evidence and reasoning in a written form of argument. This written argument involved five sentences focusing on the potential causes of removing an invasive species (the sea lamprey) from the Great Lakes. Berland and Reiser (2008) identified the first sentence as a claim, and the following three sentences as evidence identified by using numerical data and the last three sentences as reasoning that clarified the logical connections between the evidence and claim. In this argument students provided the actual numbers to describe the data in a form that is closer to the original data and this strategy allows readers to have access to all information used in the comparison and to construct a relatively clear picture of the relationships in the dataset even though the readers are unfamiliar with the context. Thus, presenting data in a similar form to that of the raw data (e.g. numbers) in arguments gave an opportunity to the readers to differentiate between evidence and inferences drawn from that evidence and, increased the persuasiveness of arguments for these readers. I assume that presenting data in a similar form to that of the raw data also provides an opportunity to the pairs to persuade their opponents of their claims in my study and I will return to this issue in more detail in an upcoming section.

4.6 Data Analysis Procedures

After the data collection stage, I utilized a spiral analysis to analyze my research data (Creswell, 1998). According to Creswell, qualitative researchers move in "analytic circles" (p. 142) rather than in linear paths as they collect, organize, and analyze data. Hence, for the fine-grained analysis of collected data in the videotape recordings of all target pairs in focal group and classroom discussions, I first transcribed the tapes of all focal group and classroom interactions and then identified meaningful discourses among the students. I read and reread the discourse transcripts as a means to see the story unfold before I began breaking it down into parts. Then, I noted sections of the text (words, phrases, sentences, etc.) that reflected student statements in connection with the research questions.

I described, classified, and interpreted the data in the transcripts of eight classroom and eight focal group discussions (one-pair in each class). To do so, I first assessed and analyzed the types of constructed and defended scientific arguments during the students' pair and classroom discussions in Scientific Argumentation - Part I and Part II. For this purpose, I modified my coding scheme for argument structure from McNeill and Pimentel's (2009) categorical aggregation in which claims, evidence and reasoning structure serves as a more digestive version of Toulmin's argument structure. In order for an utterance to be classified as *a claim* in my research, it should be one of the options ranged from option A to option B under the driving question1 and driving question 2 in Scientific Argumentation - Part I and Part II. *Evidence* utterance includes data that student used to support their claims. In my research I called evidence as *empirical evidence* because it comprised data collected with students' empirical investigations using the "Gas Properties" simulation. Different from McNeill and Pimentel's categorical aggregation, I also coded and classified data component as numerical or non-numerical data depending on whether or not they were represented numerically. Thus, *reasoning* in my coding scheme for argument structure includes a justification that showed why this numerical or non-numerical data is counted as empirical evidence to support their claims (Berland & Mcneill, 2009). Table 4.4 shows coding schemes for argument structures with examples.

Table 4.4: Coding Schemes for Argument Structure

Code	Examples
Claim	Claim A: The balloon stays the same size. Claim B: The balloon gets smaller.
Empirical Evidence comprising Non-Numerical Data	Evidence 1A: The size of the chamber in the simulation is still the same. Evidence 2A: The pressure decreases.
comprising Numerical Data	Evidence 1B: The pressure does not rise and it stays the same range of .55 [atm] to .65 [atm]. Evidence 2B: The pressure decreases from .36 [atm] to .24 [atm].
Reasoning	Reasoning A: Because there is just no gravity. Reasoning B: Because the space is extremely cold.

Based on the coding scheme for argument structure that I created above, I attempted to explore what type of arguments students used in this research. Considering this coding scheme I categorized scientific arguments constructed and defended by students in scientific argumentation. That is, I created four different types of scientific arguments to examine their argument structures (Fig. 4.2.)

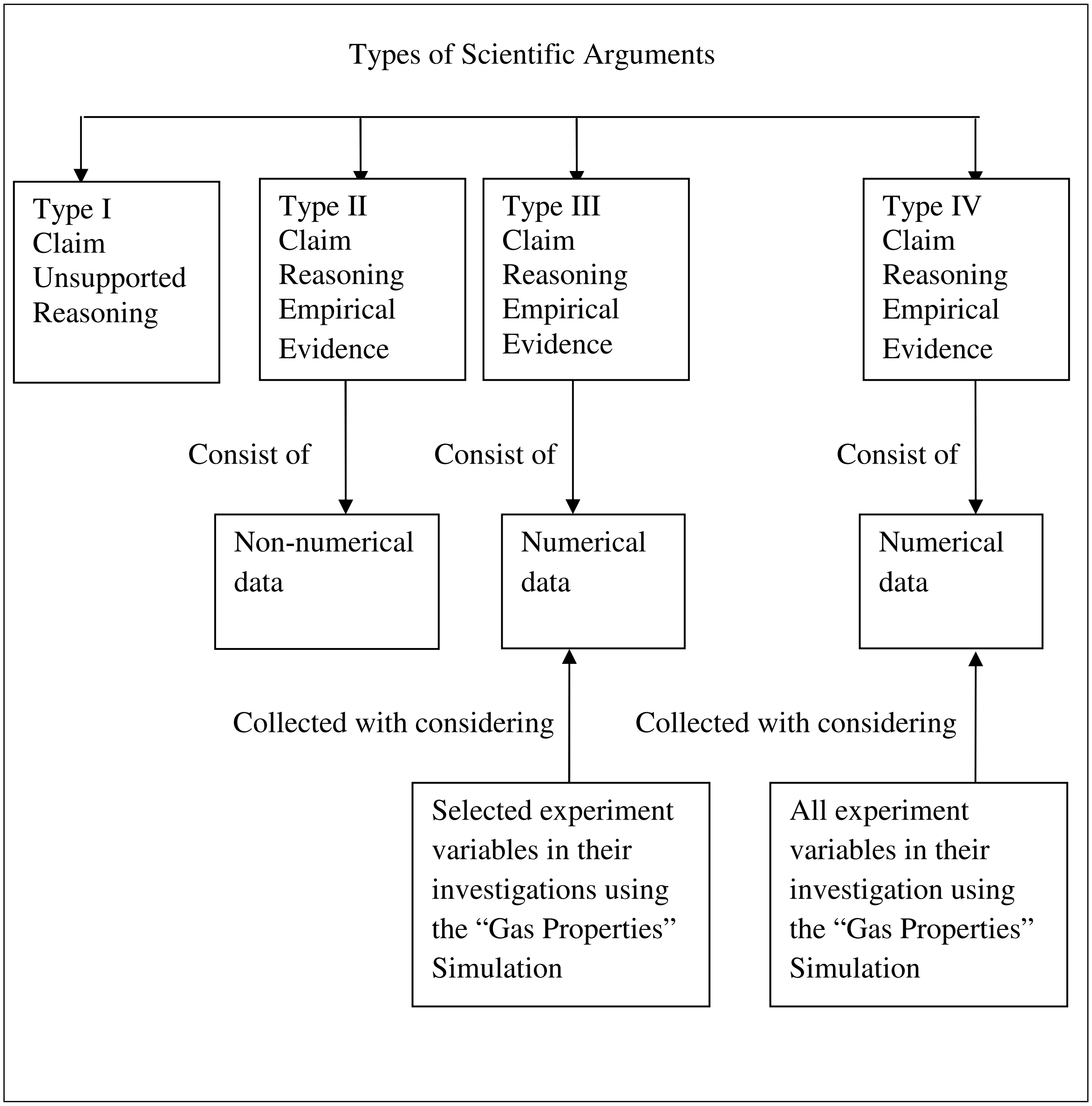


Figure 4.2: Argument Structures in Different Types of Scientific Arguments

By creating different types of arguments I was interested in the quality of arguments judged on whether students used reasoning and empirical evidence consisting of numerical or non-numerical data related to the claim that they defended. That is, I assessed the quality of different types of scientific arguments through the examination of the processes of student arguments. I divided the processes of student arguments into four levels of complexity along a continuum: Type 1, Type 2, Type 3 and Type 4, with the most complex (Type 4) reflecting the depth of argument when claim, reasoning and empirical evidence consisted of numerical data collected with considering all variables in investigations using the "Gas Properties" simulation, and with the least complex (Type 1) representing a limited argument when an argument involved a simple claim or a simple claim with unsupported reasoning. Thus, to make distinctions among four types, I developed an analytic framework (Table 4.4), which focused on the quality of four types of scientific arguments produced by students during scientific argumentation. Using this framework, I determined the improvement in the quality of their scientific arguments from Part I to Part II.

Table 4.5: Analytical Framework to Assess the Quality of Scientific Arguments

Type of Scientific Argument	Description	Examples
Type 1	A simple claim without reasoning and evidence or A simple claim with unsupported reasoning but no evidence.	The cold air-filled balloon gets bigger in space. The cold air-filled balloon gets bigger in space because if there is air in the balloon and space is without gravity, the balloon will get larger and explode.
Type 2	One or more claims with reasoning and empirical evidence comprising non-numerical data collected from the “Gas Properties” simulation.	The cold air-filled balloon gets bigger in space because the pressure is going up in the simulation.
Type 3	One or more claims with reasoning and empirical evidence comprising numerical data that is collected with considering selected experiment variables in investigations using the “Gas Properties” simulation.	The cold air-filled balloon gets bigger in space because zero gravity leads the pressure to go from .45 atm to 2.0 atm in the simulation.
Type 4	One or more claims with reasoning and empirical evidence comprising numerical data that is collected with considering all experiment variables in investigations using the “Gas Properties” simulation.	The cold air-filled balloon gets bigger in space because zero gravity and 200 ºK lead the pressure to go from .45 atm to 2.0 atm in the simulation.

In this case study analysis another objective was to formulate a detailed description of changes in the quality of students’ arguments together with a detailed description of the case and its setting (Creswell, 1998). Hence, in order to build the case, while the quality of students’ arguments changed over time, I examined what type of arguments they accepted and found convincing. When watching videotape recordings, I also determined students' acceptance of a specific argument by using some courses of actions which were used to illuminate the particular task-related interactions:

- Participants explicitly stated that they agreed with their peers or they were convinced in focal groups or classes.
- Participants stopped to request additional information that peers provided, particularly through gesture and facial expressions (e.g., Schiffrin, 1994). For example, they who were convinced leant back and shut their mouths to say nothing (e.g., De Vito, 2002).
- According to Helweg-Larsen et al. (2004), head nodding points out understanding, agreement, and a desire for the other person to continue speaking. Participants nodded their heads to express that they agreed with their peers or they were convinced in focal groups and classes.
- Participants did not insist on supporting a claim in their utterances, they changed their minds and collected empirical evidence from the "Gas Properties" simulation to support another claim in focal groups and classes.
- Participants stopped doing their experiments and finding and providing more empirical evidence from the "Gas Properties" simulation to support a claim within focal groups.
- Participants stopped discussing and they wrote their arguments on their worksheets within focal groups.

When students showed one of these actions within group or in classroom discussions, I identified type of arguments which were enough convincing for students.

I also searched for what conditions (i.e. challenged by the driving question or counter-argument, teacher's question, peer's question or prompted by representation of investigation or similar argument) helped students improve their arguments in scientific argumentation-based classrooms. When challenged or prompted by these conditions, participants articulated their arguments and elaborated these articulated arguments. I first identified the types of the articulated arguments in focal group and classroom discussions. Participants elaborated these articulated arguments when they collected numerical data and non-numerical data from the "Gas Properties" simulation throughout their discussions. To determine a specific condition facilitating the improvement of participant arguments, I analyzed the types of elaborated arguments changing throughout the discussions. Thus, this kind of data analysis assisted my exploration of how the quality of students' arguments changed over time when students constructed and defended their arguments using a computer simulation.

During the analysis of articulated and elaborated argument types, I also included utterances from students other than focal group students in classroom discussions. I did not analyze these utterances to determine types of arguments constructed and defended by other students. I only included these utterances to present specific conditions that other students' having similar or counter- arguments, questions and similar or different representations of investigations prompted or challenged focal group students to articulate or elaborate their arguments when all students attempted to convince each other in classroom discussions.

The "Our Arguments" worksheet also facilitated my analysis of focal groups' arguments. When focal groups built consensus on their group arguments, they recorded these arguments as their conclusions on the worksheets. I first determined the types of recorded arguments. Then, I examined how focal groups used these arguments to defend their claims and how the quality of these arguments improved throughout classroom discussions. Thus, I used the “Our Argument” worksheet as a way of triangulating my dialogue data findings.

After data analysis stage, I presented the research results in a form that best represented my data. The research results were reported with presenting excerpts in which students constructed and defended different types of scientific arguments at a variety of challenging or prompting conditions and in which students found different types of arguments convincing. Throughout the presentation of the results, pseudonyms were be used for each subject, within quoted material, and in any reference to specific individuals. Thus, this research results showed me how he use of computer representations supports students in developing arguments in scientific argumentation-based classrooms when students construct and defend their arguments using a computer simulation. The following chapter presents the case study results.

CHAPTER 5

RESULTS

5.1 Part I - Arguing to explain the behavior of air molecules in space

The topic of group and classroom discussions in Part I was mostly based on a driving question specifically phrased by Mr. Core and Mrs. Simpson:

> If we put an actual balloon in a fridge and then, take this balloon into space away from the Earth, what will happen to this cold air-filled balloon? Why?
>
> a) It gets the same size.
> b) It gets bigger.
> c) It gets smaller.

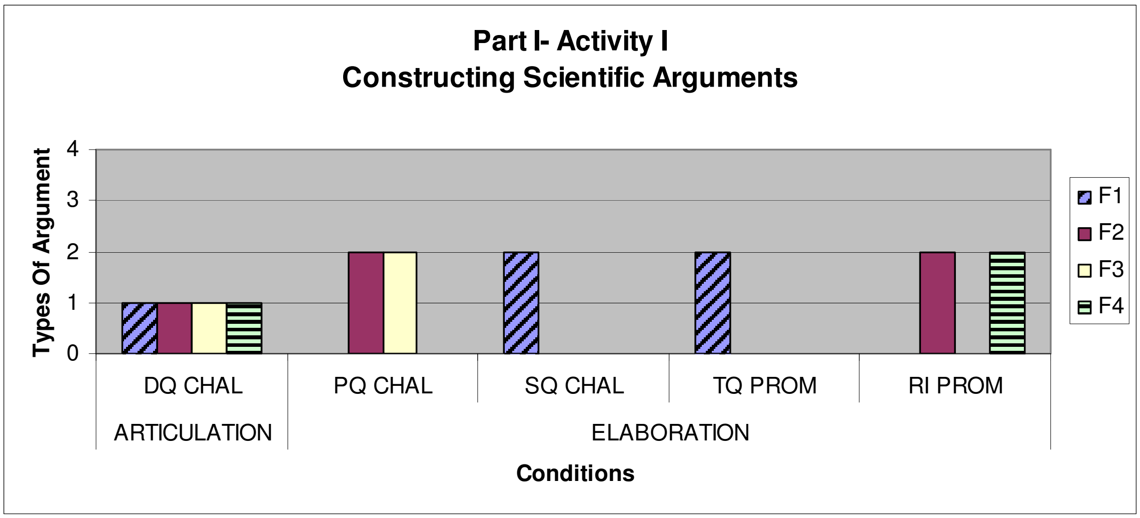
The teachers, Mrs. Simpson and Mr. Core, wrote this question with a number of claims ranged from option A to option C on the boards of their classrooms and asked students to choose which the best claim was. They conducted a straw poll of students to find out how many of them thought “it stays the same size”, “it gets bigger” or “it gets smaller.” Twenty-one students supported the claim that the balloon stays the same size, twenty students raised their hands for the claim that the balloon gets bigger and other sixteen students voted for the claim that the balloon gets smaller. Then, to achieve the goals of constructing scientific arguments and defending these arguments using the “Gas Properties” simulation, all students first worked in pairs in Part I - Activity I and then, all the pairs returned the classroom for discussion in Part I - Activity II. Thus, these two activities helped me to investigate the following research questions:

1. How do interactive computer representations support students in developing arguments?
2. What type of arguments do students use?
3. What type of arguments do students find convincing?

4. What conditions help students to improve their arguments?

5.1.1 Activity I - Constructing Scientific Arguments using the "Gas Properties" simulation

In this activity the focal group students from four classrooms attempted to construct their arguments in order to defend them in Activity II (Figure 5.1).



DQ: Driving question	PQ: Peer Question	SQ: Self-question
TQ: Teacher question	RI: Representation of Investigation	
CHAL: Challenging	PROM: Prompting	

Figure 5.1: Constructing Scientific Arguments in Part I- Activity I

Students initially identified their claims and *articulated their Type 1 arguments when challenged by the driving question* Mr. Core and Mrs. Simpson posed. In these initial arguments Jane, Sean, Simon and Chris only appealed to their *unsupported reasoning* to support their claims. Students did not use evidence from Pre-Scientific Argumentation, which had involved the investigation of gas behaviors using the "Gas Properties" simulation. Hence, the lack of shared evidence made it difficult for the focal group students to engage in a discourse in which they evaluated each other's inferences in light of alternatives.

After that, focal group students engaged in the practices of designing and conducting their experiments using the "Gas Properties" simulation in order to justify their claims with empirical evidence. During these practices, they gathered and combined a wide range of scientific data from the simulation to determine what would happen to a cold air-filled balloon in space. The data they collected largely took a form of *non-numerical data* in this Activity I. The focal group students reasoned about these data to generate their *empirical evidence* and *elaborated their arguments* with this empirical evidence *when challenged by a peer's question or a self-question* or *when prompted by a teacher question and representation of investigation (the visual created by the simulation).* When analyzing participants' arguments, I did not directly evaluate their arguments for accuracy.

Findings: Mr. Core and Mrs. Simpson formed students into pairs in their own classrooms and initiated the group discussions with the same driving question. Pairs pondered this question till the end of their group discussions. They were asked to construct completely explicit arguments using the "Our Argument" worksheet (see Appendix D) and running the "Gas properties" simulation in 20 minutes. They recorded their observations so that they generated their data and reasoned about their data in order to make a reasonable choice between three claims in their pair discussions. I selected one of these pairs as my focal group students in each class to engage in their discussion. While one of students in each focal group manipulated the "Gas Properties" simulation, the other student wrote their group argument on the "Our Argument" worksheet. The focal group students learnt to make a reasonable choice between claims judging their empirical evidence when *building evidential reasoning-based consensus* on their constructed *Type 2 arguments* in this activity.

Condition I: Articulation of argument when challenged by the driving question

Jane (FG1 student) and Sean and Ally (FG2) in Mr. Core's classrooms raised their hands for option A as their claim that a cold air-filled balloon stays the same size in space. Andy (FG1 student) in Mr. Core's classroom and Simon (FG3 student) and Chris and Justine (FG4 students) in Mrs. Simpson's classrooms supported option B as their claim that a cold air filled balloon gets bigger in space. Kelly (FG3 student) in Mrs. Simpson's classroom voted for option C as her claim that the balloon gets smaller. Table 5.1 presents this data below.

Table 5.1: Focal Group Participant Claims in Part I

Participant	Focal Group	Claim
Jane	FG1	Option A: A cold air-filled balloon stays the same size in space
Sean	FG2	
Ally	FG2	
Andy	FG1	Option B: A cold air filled balloon gets bigger in space.
Simon	FG3	
Chris	FG4	
Justine	FG4	
Kelly	FG3	Option C: A cold air filled balloon gets smaller in space.

Some of these focal group students declared their *reasoning* for why they chose their claims at the beginning of their group discussions but they did not present any *evidence* from their previous experiences with the "Gas Properties" simulation. Encountering this kind of situation recruited the assumption that just providing computer-assisted experiments in an activity may not ensure students' use of scientific inference from these experiments in upcoming activities. For example, Jane, FG1 student, supported her claim just by recourse to *reasoning in her Type 1 argument* as follows:

Excerpt 1-FG1

1 Jane: I think that the balloon gets the same size because space is extremely cold. So, it might not affect the cold air-filled balloon if it is cold.

2 Andy: Is it [balloon] cold in space?

3 Jane: It is a kind of cold up there.

Jane made her *claim* “the balloon gets the same size” and presented her *reasoning* “space is extremely cold. So, it might not affect the cold air-filled balloon if it is cold” without any evidence. This type of explanation was also seen at the beginning of FG2 discourse. Sean and Ally chose option A as their *claim* that a cold air-filled balloon gets the same size in space. Sean simply *articulated his Type 1 argument* underlying this choice and he proposed his *reasoning* which was unsupported with empirical evidence.

Excerpt 2-FG2

1 Sean: I really said [option] A because there is no gravity in space.

2 Ally: Gravity doesn’t cause a change [in a cold air filled balloon]. The gravity is only like how much pressure there is.

3 Sean: No, gravity is pulling them [air molecules in a balloon] off.

As seen in excerpt above, Sean (turn 1) articulated his *reasoning* “there is no gravity in space” and Sean’s reasoning *challenged* Ally’s thought consisting of a conflicting conception “the gravity is only like how much pressure there is.” Accordingly, Ally rebutted this reasoning by saying “gravity doesn’t cause a change.”

Thus, the activities in FG1 and FG2 started with very interesting dialogues in which Jane's and Sean's sharing their claims with *unsupported reasoning* but no evidence did *not* seem enough *convincing* for Andy and Ally to defend these claims in classroom discussions later.

Another focal group student who responded the driving question just presenting reasoning in his *Type 1 argument* was Simon from FG3. Simon and Kelly disagreed on the claim that the balloon gets bigger in space and Simon (turn 4) logically phrased his *reasoning* "if there is air in balloon and space is without gravity, the balloon will get larger and explode" in excerpt 3-FG3.

Excerpt 3-FG3

1 Kelly: What about if we put it [balloon] in a spaceship? All the way up, it is going to the space.

2 Simon: No, but the question is if we release air-filled balloon in space, what would happen? The question is not how the balloon goes in space? Will it keep its shape? Yes or no? What is our position? It gets bigger?

3 Kelly: Actually, I'm saying it would get smaller.

4 Simon: No, it will get bigger because if there is air in balloon and space is without gravity, the balloon will get larger and explode.

5 Kelly: But what is the evidence we're going to say for our position. Put your evidence.

As can be inferred from the dialogue above, Kelly was puzzled with Simon's claim since Simon's argument without any evidence was *not* sufficient for Kelly (turn 5) *to convince* their peers in classroom discussion. In the rest of their group discussion Simon and Kelly tended to search for evidence to back up their claims.

Similar case was also observed between FG4 students. Chris (turn 3) mentioned option B as his claim that the balloon gets bigger in space and he supported this claim with his *reasoning* "when we take it into space, the molecules expand and push against the wall of the balloon" in his *Type 1 argument*. Chris's argument was not involving evidence and Justine (turn 4) believed that they need to do experiment with the "Gas Properties" simulation that would lead them to find empirical evidence.

Excerpt 4-FG4

1 Chris: I think we have a progress already.

2 Justine: Yeah. I don't think it [balloon]'s gonna be smaller though.

3 Chris: I don't think it will though either. I think it will be bigger because when we take it into space, the molecules expand and push against the wall of the balloon.

4 Justine: We need to do experiment.

Justine was not sure about option B as their claim that the cold air-filled balloon gets bigger in space. Chris's argument did not seem enough convincing to Justine, which resulted in Justine (turn 4)'s proposition that they need to do experiment. This pointed out that focal group students began to be aware of the significance of evidence to construct sophisticated argument. Thus, they would make sure of this argument obtaining empirical evidence from the "Gas Properties" simulation.

Following similar focal group dialogues in all excerpts above, all focal group students seemed to be *challenged* by the driving question and they were willing to put forward their arguments with evidence. Therefore, they began to design and carry out experiments based on the idea they defended as a group, and they willing to construct more elaborate arguments consisting of *empirical evidence* from the "Gas Properties" simulation.

Condition II: Elaboration of argument when challenged by a peer's question or self-question

Focal group students followed up by constructing more elaborate arguments, making use of data from their investigations with the "Gas Properties" simulation. When designing their investigations, they proposed the different scenarios depending on the possible conditions in space. As an illustration, consider the following excerpt 5-FG2 in which Sean and Ally attempted to observe the behavior of heavy species[2] first at lots of gravity[3] and then, at zero gravity[4]. They randomly pumped 470 heavy species at lots of and then, at zero gravity into the chamber of "Gas Properties" simulation and the following interaction appeared between the focal group students.

Excerpt 5-FG2

1 Ally: There we go. Okay (Ally pumped 470 heavy species into the chamber of the simulation at lots of gravity.)

2 Sean: Because all the gravity, does this actually, cause them [heavy species] to move faster and as more pressure. The pressure is fluctuating.

3 Ally: Ohh, no. As there is a lot though.

4 Sean: Okay. What are we doing next?

5 Ally: Let me do another one.

6 Sean: Why? Why do you just call that?

7 Ally: I don't want in number. Here we go.

---

[2] Heavy species referring to gas molecules have more molecular weight than light species on the "Gas Properties" simulation.

[3] Highest amount of gravity shown in the "Gas Properties" simulation

[4] The lowest amount of gravity shown in the "Gas Properties" simulation

8 Sean: Okay. Go for.

9 Ally: And then, now what gravity? (She did not wait to hear Sean's response to her question.) Yeah, they [heavy species] just start going all over there [in the chamber at zero gravity].

10 Sean: But there is actually more [heavy species] at the bottom [of the chamber] though.

11 Ally: Yeah.

12 Sean: Because they [heavy species]'re gonna be like this and this (he pointed out the behavior of heavy species in the chamber of the "Gas Properties" simulation at lots of and then, at zero gravity.) I think that it [zero gravity] will expand them [heavy species].

13 Ally: Why do you think that they're going to expand?

14 Sean: As there is no gravity, it [chamber]'s gonna expand. I don't know. I also think that it [chamber] will be the same. (He observed the behavior of heavy species at zero gravity in the simulation again.) It [chamber] is still the same, yeah. So, our evidence points out our claim. So, it [balloon] stays the same because there is just no gravity… Ohh, it's cold.

As can be seen in the excerpt above, Sean and Ally were trying to establish a relationship between the heavy species in the chamber of the "Gas Properties" simulation and the air molecules in an actual balloon. They discussed the effect of gravity on the behavior of heavy species to understand the effect of gravity on the behavior of air molecules. They first observed heavy species at lots of gravity and they saw that the amount of pressure for heavy species was fluctuating far from zero on the barometer shown in the simulation. Ally (turn 3) called this amount as "a lot" and she (turn 7) did not tend to express it with a number. Then, when they reduced the gravity from lots of to zero in the "Gas Properties" simulation, they observed that the heavy species which had concentrated at the bottom of the chamber at lots of gravity were spread all over the chamber. This observation led Sean (turn 12) to think that zero gravity would expand heavy species but Ally (turn 13) *challenged his thinking by asking* him why he believed that heavy species were going to expand at zero gravity. Upon this challenge question, Sean (turn 14) faced a dilemma between option A (the balloon gets the same size) and option B (the balloon gets bigger) and he more carefully observed the size of the chamber to find *empirical evidence.* As his evidence consisted of *non-numerical data* that the size of the chamber was still the same at zero gravity, Sean's *Type 2 argument* became progressively more *elaborate by his peer's question,* which was only seen once in FG2 discussion.

Similar case was also seen in FG3 students' discussion. Kelly (turn 1, turn 7 and turn 9) *challenged Simon's thinking by asking him* why he thought that heavy species would expand and what heat led these species to expand. Kelly's questions arising from her puzzlement set the stage for Simon's *elaboration of his argument* with *empirical evidence*. To respond to these questions, Simon led his group to design an experiment and collect data. He pumped 300 heavy species at lots of gravity and the species concentrated at the bottom of the chamber on the "Gas Properties" simulation. After increasing temperature and decreasing gravity, he observed that all species spread out in the chamber. Making his thinking visible and finding empirical evidence on the "Gas Properties" simulation gave him a concrete way of convincing Kelly.

Excerpt 6-FG3

1 Kelly Why do you think that they would expand?

2 Simon: I'm saying like when you take it [balloon] out of freezer.

3 Kelly: And you're putting it in space. So, it is still cold.

4 Simon: No, it gets still cold but.

5 Kelly: Right now you're moving it from having gravity to no gravity. There is no gravity, right?

6 Simon: Exactly so it's cooling, umm, so, it is going to expand a little bit once you take it out.

7 Kelly: Why do you think that it would expand?

8 Simon: Because of the heat before you put it out of space.

9 Kelly: What heat?

10 Simon: Watch you take it.

11 Kelly: No, you're taking from fridge just to space.

12 Simon: No, this is certainly like. This is air if it is cold right? So, the freezer is cold with gravity on earth. That's the balloon [he's pointing out the chamber] and that's the air [he's pointing out heavy species in the chamber]. It [chamber] is cold. So, that's cold, that's hot (he's increasing heat in the chamber to simulate the behavior of air molecules when the balloon was taken out of refrigerator.) The gravity pulls the molecules [heavy species] down (he's simulating the behavior of air molecules when the molecules were out of refrigerator on earth.) And without gravity they're (he's showing how air molecules in the balloon would behave in space. The heavy species molecules spread out in the chamber.)

13 Kelly: Oh yeah it was a process like when you took it out of freezer, the temperature was risen and then, it's going to space. So, it would expand.

14 Simon: Right.

To justify option B as his claim in his *Type 2 argument*, Simon appealed to *empirical evidence* based on *non-numerical data* collected from the "Gas Properties" simulation. He (turn 12) first highlighted a scenario which was referring to the moment once the balloon was taken out of refrigerator on earth before putting it outer space. Then, he showed this scenario on the simulation. After pumping heavy species into the chamber at lots of gravity on the simulation, he increased the temperature of heavy species to simulate how air molecules in the balloon would behave out of refrigerator on earth. Then, he decreased gravity from lots of to zero to represent the behavior of air molecules in space. He was accepting that there is no gravity in space but he was unlikely to argue the numerical difference in temperature between on earth and in space. He could not explain this difference throughout this activity but his *elaboration of argument* with *empirical evidence* helped Kelly to be convinced. Then, they wrote their conclusion on the "Our Argument" worksheet as follows (Appendix E):

> Our evidence supports our idea for this are
>
> When looking at the simulation the molecules are at the bottom of the box[5] when the temperature is risen and when the gravity is taken, the molecules expand just as the balloon would if taken out of the freezer and put it in space.

The instance of justifying a claim by means of finding *non-numerical data* and using it as *empirical evidence* was also seen in FG1 discussion. Andy who supported option B as his claim pumped 700 heavy species into the empty chamber at zero gravity instead of lots of gravity to simulate the behavior of air molecules on earth. When he set the temperature at 300 ºK, the pressure of the heavy species increased from zero to 3.40 atm. Then, he cooled these species to 250 ºK and the pressure decreased from 3.40 atm to 2.70 atm. I assumed that he did not read the pressure during these processes and so, he was not aware of the decrease (from 3.40 atm to 2.70 atm) in the pressure from first to second process. He evaluated two processes separate and he believed that the pressure was still high even though the chamber was colder than before.

> Andy: I'm resetting it now. I'm adding the molecules [heavy species] and the pressure is going up. But then when I go like that (he cooled the chamber to simulate the behavior of air molecules in the refrigerator), the pressure is still high and is still going up. Isn't it getting cold? See? Why is the pressure going up? Why don't they [heavy species] wanna start sinking?

---

[5] He was pointing out the chamber of the "Gas Properties" simulation.

Jane nodded her head to show her corroboration with Andy's observation that the pressure was going up at the cold temperature in the "Gas Properties" simulation. However, that such observation violated his expectations did not satisfy Andy and he *challenged his own thinking by asking himself* why the pressure was going up and why heavy species started to sink. Upon these challenging questions, he realized that he was thinking of air molecules on earth but he did not add gravity into the chamber of the simulation. When increasing and then, reducing the gravity in the chamber of the "Gas Properties" simulation, he found *non-numerical data* that while there was no pressure at lots of gravity, the pressures rose at zero gravity. Thus, he began to participate in *elaboration of his group argument* with *empirical evidence* based on this data.

> Andy: Oh, I have to add the gravity. I didn't even think about with the gravity. See there is no pressure (he observed sinking species and decreasing pressure with increasing gravity at 250 ºK.) And the space with no gravity, the pressure rises (at 250 ºK.) So, the balloon will get bigger.

The unexpected observation (heavy species did not start to sink and pressure was going up) induced in Andy generated puzzlement and this puzzlement elicited a *self-question* posed by him to himself, which subsequently encouraged him to search for more accurate *empirical evidence* and construct his group's *Type 2 argument*. Andy saw that all heavy species were first coming down and then, spread out in the chamber of the "Gas Properties" simulation when the pressure increased at 250 ºK with from lots of to zero gravity in his investigation. He described the effect of increasing pressure with an inference that the balloon would get bigger and Jane did not refute this inference with reasoning in her earlier argument that the balloon would get the same size because the space was extremely cold.

Condition III: Elaboration of Argumentation when prompted by a teacher question

Mr. Core and Mrs. Simpson's spontaneously using questioning in the focal groups' discourses scaffold the students' investigations with the "Gas Properties" simulation. The teachers often used signal words such as "why", "how" and "what" in their prompting questions to support students in effectively conducting virtual experiments and constructing more elaborate arguments**.** For instance, to focus this pair's attention on the scenario in the driving question Mr. Core asked a prompting question in excerpt 7-FG1 and to respond this question FG1 students conducted a new experiment with heavy species.

Excerpt 7-FG1

1 Mr. Core: You're on earth, you have a cold air-filled balloon and we're taking it into space. What happens? What are the differences between earth and space?

2 Andy: Space is a lot colder and there is no gravity in space. So, that's the balloon (he pointed out the chamber in the simulation), space is cold. So, it pops in space? What if the balloon pop in space? (He set 900 heavy species at lots of gravity into the chamber of the "Gas Properties" simulation. The temperature was around 900 ºK and the pressure was around .70 atm. Then, he decreased the gravity from lots of to zero. While he reduced the temperature from 900 ºK to 300 ºK, the pressure increased and the lid of the chamber opened.) I think it pops, you see.

3 Jane: When it [balloon] gets bigger.

4 Andy: I looked that's no gravity in space, right? So, it's colder and then, the pressure is going up. And then, it [balloon] is gonna pop.

As can be seen in the excerpt above, when searching for appropriate *empirical evidence* to make a reasonable choice between claims, the FG1 students implicitly evaluated *non-numerical data* in their group *Type 2 argument*. They just observed that the lid of the chamber could not endure the pressure of heavy species and it opened to let these species go out. This helped them to establish a relationship between the heavy species in the chamber of the simulation and the air molecules in balloon and they concluded that the balloon would pop in space. Then, they wrote their conclusion on the "Our Argument" worksheet as follows (Appendix F):

> Our position is that the option B is correct because
> Although it might be colder in space, there is no gravity which allows more movement of the molecules.
>
> Our evidence supports our idea for this are
> With gravity and cold, the molecules stayed toward the bottom of the container[6] needing less space causing the container to shrink.
> Without gravity and cold, the molecules slow down but they are still able to move which would allow the container to increase in size.

<u>Condition IV: Elaboration of Argument when prompted by representation of investigation</u>

In some cases, collecting supportive data to show it as empirical evidence was enough for focal group students to build a consensus on their arguments. For instance, FG4 students, Chris and Justine, who believed that cold air-filled balloon would get bigger in space, elaborated the argument Chris had declared before by searching for *empirical evidence* on the "Gas Properties" simulation. They engaged in the following conversation in excerpt 8-FG4.

Excerpt 8-FG4

1 Chris: It [the number of heavy species] is 500. So, the pressure is pretty high not really and the temperature is very high. So, we wanna a cold balloon. So, we lower temperature, 250 K.

2 Justine: This was in space.

3 Chris: No, this is on earth. This is with gravity.

4 Justine: Oh, right.

---

[6] He was pointing out the chamber of the "Gas Properties" simulation.

5 Chris: So, we have already gone to the space. Zero gravity.

6 Justine: Yeah, that's gonna expand. And it [pressure] pushes out.

7 Chris: Yeah, it [chamber] will expand because the pressure will be up.

8 Justine: When you took gravity off? Yeah.

9 Chris: Did you see? They [heavy species] spread out.

10 Justine: Spread out. Yeah. They pushed against the wall of chamber. So, the balloon expands.

11 Chris: Alright we would convince by showing them our experiment.

As can be seen in the dialogue above, to simulate the behavior of air molecules in a balloon on earth Chris (turn 1) pumped 500 heavy species into the chamber of the "Gas Properties" simulation. He saw that as heavy species moved around, the pressure and the temperature increased. Then, to simulate the behavior of air molecules in a refrigerator on earth he reduced the heat and kept the temperature at 250 ºK in the chamber. Chris (turn 5) set the gravity at zero and he (turn 9) accordingly collected non-numerical data that heavy species spread out. To support his group claim, Justine *elaborated group argument* shifting from this *non-numerical data* to *empirical evidence* "they pushed it [the wall of chamber]." Thus, they wrote their constructed *Type 2 argument* on the "Our Argument" worksheet as follows (Appendix G):

> Our position is that the option B is correct because
> The molecules expand and would push against the wall of the balloon and there is no other atmospheric or any other kind of pressure to force the balloon in. So, it will be expand.
>
> Our evidence supports our idea for this are

> When we added molecules in gravity they had a certain temperature and pressure. When we reduced the gravity to zero, the molecules expand and were hitting against the wall[7].

This case was also observed in FG2 discourse. While Sean shifted from non-numerical data to empirical evidence to justify his group claim at the end of excerpt 5-FG2, he noticed that the chamber was not cold as much as space. This notice prompted FG2 students to *elaborate their Type 2 argument* by searching for new evidence with temperature change in excerpt 9-FG2.

Excerpt 9-FG2

1 Sean: Because the combination of very cold and zero gravity led to a lot of molecules [heavy species] to float freely.

2 Ally: As we added gravity, the pressure was fluctuating up and down, stayed some range of .35 [atm] to .45 [atm]. And the temperature was fluctuating when there are more molecules around. If you look at the molecules they continue moving around.

3 Sean: The pressure goes out.

4 Ally: As the molecules continued to move around and as more heat but at some point they also slowed down, the temperature decreases, that’s why we see the temperature is fluctuating up and down. And then, when they’re moving around, more temperature continues to add more pressure.

5 Sean: What was [option] B? It [balloon] gets bigger?

6 Ally: (She did not respond Sean’s question.) I remember that the smaller the space, more pressure as though, but the bigger the space less pressure the gas molecules were creating.

7 Sean: But it is a balloon. It is not like... It is moving up.

8 Ally: These [heavy species] are the gas molecules in the balloon. I remember that the gas molecules just like this.

9 Sean: I know. Think no gravity?

---

[7] He was pointing out the wall of the chamber in the “Gas Properties” simulation.

10 Ally: Okay. There is no gravity in space. So, they [heavy species] float like freely.

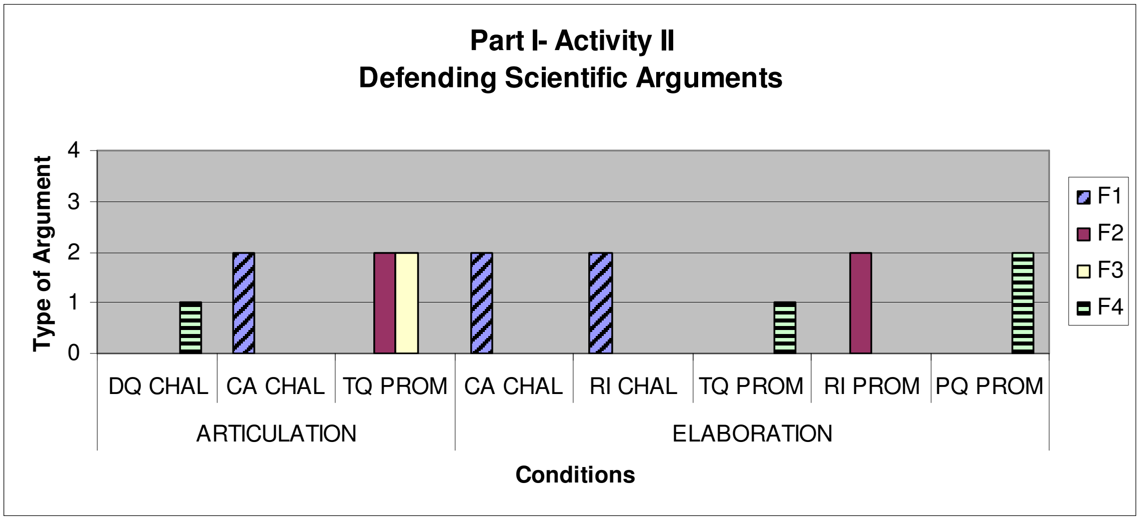
11 Sean: Yeah, and then, umm, there is no change on how it [chamber] is bigger or smaller they get.

In the dialogue above, Sean (turn 1) decreased the temperature at zero gravity in the “Gas Properties” simulation, and observed freely floating heavy species all over its chamber. Yet, he did not tend to numerically indicate the temperature change, which led heavy species to float in the chamber. On the other hand, Ally (turn 2) preferred to tell the story from beginning and mentioned what happened to the pressure of heavy species at lots of gravity. She attempted to collect *numerical data* (i.e. the pressure stayed some range of .35 [atm] to .45 [atm]) as *empirical evidence* to justify group claim but her attempt remained limited with the range of pressure at lots of gravity, that is, the pressure on earth. Then, she (turn 4) sought explanation for why the temperature and pressure were fluctuating up and down. According to her, as heavy species moved around, the temperature and then, the pressure in the chamber of the simulation increased. She implicitly discussed the proportional relationship between temperature and pressure at lots of gravity in her explanation above but it was not directly related to the answer of the driving question what would happen to the cold air-filled balloon in space. Sean’s question (turn 5) arising from his puzzlement with Ally’s explanation set stage for the development of Ally’s idea into more complete one. Ally (turn 6) qualified her reasoning with her existing knowledge that smaller space led to more pressure. Sean (turn 7) was confused with the term of “space” in this reasoning and he highlighted that it was a balloon. However, the statement of “the gas molecules in the balloon” by Ally (turn 8) showed that “space” referred to volume in Ally’s existing knowledge and she could recall the knowledge of the inverse relationship between pressure and volume learnt in Pre- Scientific Argumentation to use in this case. Then, in spite of agreeing with Ally's statement, Sean noticed that there was lots of gravity in the chamber of the "Gas Properties" simulation and he (turn 9) challenged Ally with a proposition "Think no gravity." This proposition led them to think about their *non-numerical data* "they [heavy species] float like freely" and "there is no change on how it [chamber] is bigger or smaller they get" as *empirical evidence* and build a consensus on their group argument. They recorded this argument on the "Our Argument" worksheet as follows (Appendix H):

> Our position is that the option A is correct because
> A- It stays the same because the combination of no gravity and its cool state will allow the molecules to float freely.
>
> Our evidence supports our idea for this are
> In the simulation, added gravity causes the molecules to pull to the bottom.

5.1.2 Activity II - Defending Scientific Arguments using the "Gas Properties" Simulation

In this activity the focal group students from four classrooms defended their arguments initially constructed in Activity I (Figure 5.2).



DQ: Driving question	CA: Counter-argument	TQ: Teacher Question
PQ: Peer question	RI: Representation of Investigation	
CHAL: Challenging	PROM: Prompting	

Figure 5.2: Defending Scientific Arguments in Part I- Activity II

Students *articulated their constructed group arguments* in classroom discussions *when challenged by the driving question or a counter-argument* and *when prompted by a teacher question*. Chris just appealed to his *unsupported reasoning* to defend his group claim in *Type 1 argument*, whereas, Andy, Sean and Simon appealed to *empirical evidence* addressing to *non-numerical data* collected from the "Gas Properties" simulation in their *Type 2 arguments*. However, any of students did not use *numerical data* they had observed in Activity I. Lack of shared evidence with numerical data made it difficult for the focal group students to persuade others of their group claims.

After that, students in each class participated in scientific argumentation in which they weighted evidence and evaluated the potential viability of claims in light of alternatives. During this process, focal group students *elaborated their arguments when prompted by a teacher question, a peer's question or representation of investigation* or *when challenged by a counter-argument or representation of investigation.* These *Type 2 arguments* involved a wide range of *empirical evidence* gathered from the "Gas Properties" simulation to justify their claims about what would happen to a cold air-filled balloon in space. The empirical evidence comprising *non-numerical data* largely came from their "Our Argument" worksheet and caused hard times for the focal group students during scientific argumentation when they tried *to convince* other pairs of the correctness of their claims. When analyzing participants' arguments in this activity, I did not directly evaluate their arguments for accuracy.

<u>Findings:</u> After a period of fairly heated debates within the pairs in all classrooms, Mr. Core and Mrs. Simpson encouraged volunteer pairs of students including focal groups to share their consensus positions in a persuasive classroom discussion in the rest of the course period. Several pairs *articulated their arguments* to support their claims with empirical evidence when challenged with the driving question. Then, they *elaborated these arguments* using the "Gas Properties" simulation during scientific argumentation when challenged with counter-arguments and peers' questions and prompted by the representation of investigation and teachers' questions.

The classroom discussion in each class began with teachers' asking the same driving question from Activity I. For instance, Mrs. Simpson pointed out the driving question on the board and added an account how pairs would argue:

> Mrs. Simpson: You will respond the person who just previously answered, whether you agree, disagree or why?

<u>Condition I: Articulation of argument when challenged by the driving question</u>

When responding this driving question, some of students spontaneously engaged in the scientific discourse of proposing their constructed arguments as their groups' decisions in all classrooms. They articulated for why their classmates[8] should have believed their constructed arguments defended by using evidence and reasoning when challenged with the driving question. For instance, in excerpt 10-FG4 Chris (turn 3) from FG 4 students shared his group's *Type 1 argument* with presenting his unsupported reasoning.

Excerpt 10-FG4

1 Jay: We said A because when we did with simulation, we put the gravity at zero and we put the temperature all the way down, so, that made the temperature drop and pressure drop and species are not moving anywhere. So, we think that heavy species that are a kind of representing air are not moving a lot in space. So, the balloon will stay the same.

2 Nate: We had B because it [air] is really dense on earth. When they [air molecules] are going to the space, there is no gravity, so, the molecules flied forever to make balloon expand.

3 Chris: We picked B as well it [balloon] gets bigger because the molecules will expand in space and would push against the wall of the balloon and there is no other atmospheric or any kind of pressure to force the balloon in. So, it will expand.

4 Carolyn: We said C that it [balloon] will get smaller because we put them [heavy species] on cold and we put the gravity off so that it would be like in space and like a clearly you can see the species stop moving and they go there slowly. So, it just slowly deflates because you can get species slowly.

5 Chris: What did you say?

6 Carolyn: We said we did with the chamber like a balloon in space, there is no gravity and we put it to cold and we watched what happened.

7 Chris: You put in the cold when you're in space or you're on earth?

8 Carolyn: In space. Would you like to see?

---

[8] All the names of classmates in this dissertation are pseudonyms.

As seen in the excerpt above, while Chris just appealed to his *reasoning* to support option B as his group claim that the cold air-filled balloon would get bigger, Carolyn made a link between her group claim (option C) and non-numerical data counted as empirical evidence, engaging in what they did in her group investigation. Chris (turn 7) asked a question related to a process in this investigation and upon this question, Carolyn (turn 8) proposed to represent her group investigation on the "Gas Properties" simulation. Chris's nodding his head to request the representation of this investigation in the videotape showed that Carolyn's and Chris's *articulation of their group arguments* in words were *not enough convincing* for each other.

<u>Condition II: Articulation of argument when challenged by a counter-argument</u>

Different from the dialogue in the case depicted above, some focal group students articulated their arguments when challenged by other pairs' arguments. To persuade others of their claims, they backed up these arguments with *empirical evidence* addressing to *non-numerical data* collected from the "Gas Properties" simulation in Activity I. For example, in excerpt 11-FG1 Sam (turn 1) argued his group decision by providing justification for why non-numerical data they collected from the "Gas Properties" simulation counted as empirical evidence. *Challenged* by Sam's group decision which was option A (the cold air-filled balloon would get the same size in space), Andy (turn 2) *shared his group's Type 2 argument*, which supported option B, by specifying *empirical evidence* from the simulation.

Excerpt 11-FG1

1 Sam: I said, first we tested filling the hypothetical balloons [the chamber of the "Gas Properties" simulation] with heavy and light species separate (he most likely tried both types of species to become sure.) And we froze the species and they had little or no movement in both cases. Also in both cases we added

gravity and so, pressure, it wasn't a matter how much pressure and gravity were, the balloons were not affected (he meant that the chambers like the balloons on earth did not pop.) Because, hmm, we figured out space is cold like a fridge, we took them into space, and one variable changed and what changed was gravity. And here if they were in less gravity, then, nothing happened to be right in the simulation what we did.

2 Andy: He said that it [balloon] would be the same size. We're refuting because when we were doing demo here with the heavy species in the container [chamber of the "Gas Properties" simulation], we thought that like heavy molecules, the lid popped, so we're just pretending that this container was a big balloon filled with air completely. And we added to no gravity and cooled the container like in space, the temperature cool down inside the container. No gravity and the cold temperature made the pressure, the pressure went up and then, the lid [of the chamber] flied off. So, it is like the balloon pop.

As can be seen in the dialogue above, Andy (turn 2) attempted to justify his group claim by shifting from *non-numerical data* to *empirical evidence* "no gravity and the cold temperature made the pressure, the pressure went up and then, the lid [of the chamber] flied off." When talking about this supportive evidence, Andy considered quantitative change in one variable which was the amount of gravity (i.e. no gravity) but he did not quantitatively mention other variables such as how much the temperature cooled down and how much the pressure increased from on earth into space. Thus, articulating argument without specifying quantitative changes in all variables reduced the persuasiveness of his argument.

<u>Condition III: Articulation of Argument when prompted by a teacher question</u>

In FG2 students' classroom discussion I encountered a different case that caused them to articulate their arguments. While most of pairs agreed upon option B as the correct claim with reinforcing each other's arguments in the classroom discourse, Sean (turn 12) disclosed his group argument with supportive *empirical evidence* in response to Mr. Core (turn11)'s question.

Excerpt 12-FG2

1 Carl: We thought that the balloon is cold; there is no external pressure and gravity. So, it loses nothing.

2 Nancy: So, it's still the same?

3 Carl: It's the same.

4 Nancy: We agree with Carl. Our thought was that the balloon would stay the same and reasoning behind that was that if you add cool heavy species into it [chamber] and there is no gravity, umm, in the lab it showed that all the species, they stopped they're still, they stopped moving so, that was reasoning to say it will stay the same.

5 Allis: We don't agree with Nancy and Carl. We're saying that it [chamber] is gonna expand because when you take away gravity, they [heavy species] seem to move quicker. It made the lid pop off in the simulation when you took away the gravity. So, we said that it grew bigger and expanded because when there was gravity, they were all at low level, they were slow moving but when you took gravity away, they moved quicker.

6 David: We agree with Allis. We thought that it would expand because space has less degree of temperature, so, they [gas molecules] were moving like slightly when there was also no pressure upon the balloon itself. So if we would not have any forces pushing it out, so it won't have more to expand. And also there is no gravity so that it would allow the balloon to expand because slightly moving and there is no external pressure on it.

7 Nick: We agree with Allis and David. We're doing simulation with gravity and it was cold and all the heavy species are like in one region and they were still in the chamber like in the balloon. If we took away gravity they were still move around so, it's is gonna expand.

8 Jack: We think that at the balloon if it is in space, it gets smaller because it is colder so the temperature happened affect all the molecules.

9 Lena: We said the same thing with Nick. When you added colder temperature with normal gravity, all of these heavy species set in the bottom of chamber. When you took away the gravity, the species expanded and took more space in the chamber so, we said that the balloon would expand.

10 Kevin: We also agree that the balloon will expand because it wouldn't the balloon goes from refrigerator let it shrunk because of the temperature and the slowing down of the molecules and it would go to out of space with no gravity and so the molecules are more able to move, the size of the balloon is pushed

out because of the increased amount of moving to another molecules. So, it makes the balloon bigger.

11 Mr. Core: Alright, all is gonna pose that with this argument, you need to be able to convince each other. So, add heard arguments different reasons or different positions but now, for those who had different position and then, you need to be able to convince each other. Who has the position that it stays the same? Your position what?

12 Sean: We believed that, umm, the balloon, it stays the same because it was going from the cold refrigerator and molecules would slow down and when it was going to space, they [molecules] would still be moving slowly. That will only be difference that the gravity would go down. We noticed in the simulation when the gravity went down, the pressure didn't change much. So, we figured out that it just stayed the same because the pressure would affect the size of the balloon.

As seen in excerpt 12-FG2, Allis, David, Nick, Lena and Kevin, who put forward their arguments with justifications, seemed to build a consensus on option B by presenting different empirical evidence but they did not attempt to *convince* Carl, Nancy and Jack, who provided *counter-arguments*. Hence, Mr. Core posed a question in turn 11 to remind the students to convince each other with a reasonable critic of acceptability of a claim. *Upon this question*, Sean *articulated his group's Type 2 argument* to support option A with *empirical evidence* comprising *non-numerical data* "we noticed in the simulation when the gravity went down, the pressure didn't change much." Yet, he did not try to show his group investigation using the "Gas Properties" simulation. The absence of both numerical data and visually presented argument on the simulation *reduced the persuasiveness of his group argument* by other students.

Similar case depicted above was also seen in the classroom discussion FG3 students participated. During the discussion, Simon posed some questions "what about it?" and "why?", which reflected his puzzlement regarding the science concept (oxygen) used by Ashley (turn 7), but he did not articulate his group argument until Mrs. Simpson asked him whether or not he thought the same thing with Ashley.

Excerpt 13-FG3

1 Tim: We put it into the simulator. We put heavy species into it like on earth so that heat is up and the pressure is risen already stuff like that as you go to space, as there is no heat and there is no gravity. We change it there is no gravity and then, you cool it down. In our simulator it didn't do anything, so, we figured out that okay it [balloon] stays the same. But then, we figured out that it is actually bigger and it expands and pops because like the rapid cooling makes the rubber expand and release the molecules into outer space.

2 Mrs. Simpson: So, ultimately what was your answer?

3 Tim: I'm not sure.

4 Mrs. Simpson: Anyone says it [balloon] gets bigger?

5 Ashley: That was true.

6 Mrs. Simpson: So, why?

7 Ashley: I think my end but I think mine is different but I still say that it gets bigger. I said because of oxygen.

8 Simon: What about it?

9 Ashley: You blow up a balloon and it is like if you go out of space, it is gonna like expand, it is gonna like pop.

10 Simon: Why?

11 Ashley: Because we compared the fridge to space and simulated that this is cold and the difference is that space has no oxygen and fridge has oxygen. We said that we blow up the balloon and put it into fridge, it will shrink and then oxygen in the balloon cool down but we put it in space since the differences of oxygen then, do the opposite no fridge but it expands.

12 Mrs. Simpson: Do you think the same thing with Ashley?

13 Simon: No. It did not have the same thing we did it in a different way. So, how the process before we're talking about how the difference between the fridge and the space. This is in fridge on earth (he was pointing low temperature in the chamber) and the heavy species are at the bottom of the box (he was referring

the chamber of the simulation.) When the balloon was taken out the fridge, the heavy species move around because it [temperature] is hot. Then, we bring it into space and the gravity was taken, the pressure increase in the box [chamber] causes the box get expand like the balloon get expand.

14 Gabriel: The temperature of space is colder than fridge and then, cold makes rubber smaller.

Instead of considering empirical evidence from the "Gas Properties" simulation, Ashley defended her group claim just using her reasoning. Simon (turn 13) agreed with her that the correct claim was option B, however, different from Ashley, Simon negotiated between his personal experiences and beliefs and, what his group had collected as observations, that is, their *non-numerical data* in the "Gas Properties" Simulation. He articulated his group's *Type 2 argument* by explicitly connecting his group claim and supportive *empirical evidence* "the pressure increase in the box [chamber] causes the box get expand." Nevertheless, his argument was *not convincing* Gabriel (turn 14) because it was just defended upon a thought process that the temperature of space and fridge was the same.

<u>Condition IV: Elaboration of argument when prompted by a teacher question</u>

In another case FG4 students participated, Carolyn made her group argument visible to increase the persuasiveness of her group argument by her classmates. She represented the procedure of her group investigation underlying group argument but Chris (turn 6) from FG4 students criticized this procedure in which the balloon was cooled down in space. He was thinking that the balloon was in a refrigerator on earth before taking it outer space and the chamber of the simulation referring to this balloon should have been cooled down before making the zero gravity. Upon being confronted with a salient contrast between Chris's and Carolyn's thoughts, Mrs. Simpson (turn 7) posed a question to *prompt* Chris's (turn 8) *elaboration of his argument*.

Excerpt 14-FG4

1 Carolyn: We pumped heavy species with lots of gravity and they do what you said, they go all the way up.

2 Chris: No gravity in space.

3 Carolyn: Yeah, we put the gravity down first and the temperature goes down because there is no gravity in space and it drops.

4 Chris: What drops?

5 Carolyn: Pressure.

6 Chris: But what you did was you took the balloon into space and fit it up there. And then, you cooled down the balloon in space but the [central] question asked that the balloon on earth and you're taking it from on earth into space. You have a cold balloon on earth.

7 Mrs. Simpson: So you're arguing is that?

8 Chris: When we cool the balloon on earth, the temperature decreases a little bit, it isn't that much I guess. But when we take it up to space, the molecules expand and they hit against the walls of the balloon and there is no atmospheric pressure that can like put the balloon down and molecules are made out when it [balloon] gets bigger.

In excerpt 14-FG4 Chris's reasoning was further elaborated by Mrs. Simpson's question to back up the claim. His reasoning involved the statement of "When we cool the balloon on earth, the temperature decreases a little bit, it isn't that much I guess" which had not existed in his previous argument. Although he strongly insisted on his argument, Chris pitted against Carolyn's idea via a series of reasoning based *not on concrete data or empirical evidence* but rather on testable predictions. Therefore, Carolyn who was *not totally convinced* by Chris's *Type 1 argument* asked Chris whether he could show the class his evidence as I describe in more detail later.

Condition V: Elaboration of argument when prompted by a peer's question

When engaging critically but constructively with each other's ideas in FG4 classroom discussion, peers posed questions arising from their puzzlements with various aspects of articulated arguments. These questions prompted students to generate more elaborate arguments by adding further details to existing arguments. For instance, in excerpt 15-FG4 Carolyn (turn 1) posed a question when puzzled with the lack of evidence in Chris's argument. In response to Carolyn's question, Chris qualified his argument from Type 1 to *Type 2* by recourse of a clear articulation of the evidence underlying his thinking. He presented *empirical evidence* supporting the claim that the cold air-filled balloon would get bigger in space using the "Gas Properties" simulation.

Excerpt 15-FG4

1 Carolyn: Can you show us your evidence?

2 Chris: Yeah. See it. We set 500 heavy species right. This is under gravity, so you're on earth and we lower the temperature because we wanna a cold balloon. So, we wanna it gets down there.

3 Carolyn: Oh, so the temperature is down?

4 Justine: Just watch.

5 Chris: So, we have constant volume, so, that has been the balloon (he was pointing out the chamber.) And then, when you take off gravity because you're now going to the space (he's showing the heavy species in the chamber at zero gravity.) The heavy species go up and then expand though.

6 Mrs. Simpson: Do you agree with your friend?

7 Carolyn: We quite misunderstand the question. We did it in space, so ours is different thoughts.

In the above excerpt, the question Carolyn (turn 1) posed led Chris to showing his investigation to provide empirical evidence. Visualization of investigation guided him to play an intellectual role that included coordinating claim and evidence. While his empirical evidence consisted of *non-numerical data* "the heavy species go up and then expand though", it invoked an improvement on Carolyn's previous thoughts and increased *persuasiveness of Chris's group argument* for Carolyn.

Condition VI: Elaboration of Argument when challenged by a counter-argument

When pairs were expected to listen to each other's arguments carefully and to evaluate the quality of evidence and reasoning presented in these arguments, they increasingly elaborated and expanded these arguments to support their decisions. To illustrate, consider the previous FG1 excerpt. Sam and Andy declared two competing arguments and other pairs were supposed to criticize these arguments by means of assessing empirical evidence presented by Sam and Andy. Excerpt 12-FG1 showed that Mr. Core (turn 1) intuitively recognized this need and he asked questions in order to encourage other pairs both to evaluate Sam and Andy's arguments and to articulate their arguments. Accordingly, these questions prompted Casey and John to share their evidence and reasoning in turn 2 and turn 3. *Challenged by* John's empirical evidence, Andy (turn 6) from FG1 ultimately *elaborated* his argument using *new empirical evidence* from the "Gas Properties" simulation.

Excerpt 16-FG1

1 Mr. Core: Anyone to support that or refute that? What was right or wrong with Sam's and Andy's arguments?

2 Casey: We agree with Andy. It would be bigger because the amount of pressure insides of space will make the molecules move faster, and such a small space eventually blow up the balloon. We did in the simulation, inside of the program and we proved that it was right. And, if you think about it, all weather balloons go up and come back down because they pop and so, that's why, we get the gear always because of the pressure in the balloon in space, so the pressure will grow in the balloon and the balloon gets bigger.

3 John: We don't agree with Casey. The balloon gets smaller because the pressure goes down.

4 Mr. Core: What did you do test it out?

5 John: We did with light species and we put zero gravity and cold temperature in the simulation and then, the pressure went down. So, we got the balloon smaller.

6 Andy: When it gets cold and there is no gravity, the molecules [heavy species] in the container [chamber of the "Gas Properties" simulation] slow down but they are still able to move around which causes the container to increase, so, the balloon pops.

7 John: But it is frozen, the species don't move like this.

In the dialogue above, Andy (turn 6) *elaborated* his *Type 2 argument* presenting *new empirical evidence* with *non-numerical data* "when it gets cold and there is no gravity, the molecules [heavy species] in the container [chamber of the "Gas Properties" simulation] slow down but they are still able to move around which causes the container to increase." Although his verbally expressed empirical evidence was *not enough convincing* for John, it was from the FG1's "Our Argument" worksheet (Appendix F) where Andy and his pair discussed rebuttal against a counter-argument as follows:

> Someone might argue against our idea by saying that his/her position is the option C because
> The pressure decreases and the molecules freeze causing them to not be able to move so the balloon will shrink. Since it is colder in space, it will cause the molecules to freeze even more and stop movement so the balloon will shrink.
>
> We would convince him/her by
> Saying that although it is colder in space there is no gravity in space unlike earth. So on earth when it gets cold the molecules slow down and get dragged down toward the bottom of the container[9] causing it to shrink. However, in space there is no gravity so even though they get slowed down they are still able to move around which cause the balloon to increase.

---

[9] He was pointing out the chamber of the "Gas Properties" simulation.

Condition VII: Elaboration of argument when challenged by representation of investigation

In the extension of this discourse, to convince John, the FG1 students, Andy and Jane, conducted their group investigation in front of class and *made their argument visible* using the "Gas Properties" simulation as follows:

Excerpt 17-FG1

1 Andy: We'll show you it here. If we're on earth with lots of gravity and put 1000 heavy species there, we have all those species float around. Then, we start to cool it down. So, we cooled it down to. What we said again? 300 ºK?

2 Jane: Yeah.

3 Andy: Yeah, we cooled it down all the way down 300 ºK to simulate cold space. (Classmates observed that the species slowed down and got dragged down toward the bottom of the chamber.)

4 John: Because if coldness causes the heavy species slow down, the balloon must begin to get smaller. They are not moving around.

5 Sam: It [chamber] is still the same.

6 Andy: It hasn't been in space yet because it is still as full gravity.

7 Jane: We talked about how the difference between the fridge and the space before doing our experiment. We did it in steps because we could not do it all the way once. We did it with cold and gravity first.

8 Andy: This is representing fridge. And then, we take away all that gravity. It [chamber] expands and that lid pops off because pressure increases. (The lid did not pop off in their representation.) It didn't work. But we did it last time, it worked.

In the third to eight turns above, Andy considered the amounts of heavy species, temperature and gravity variables when representing his group investigation. Different from what Andy and Jane had done in the group investigation, he put 1000 heavy species instead of 900 heavy species, decreased the temperature to 300ºK at lots of gravity instead of at zero gravity, then, he reduced the gravity from lots of to zero to simulate the behavior of air molecules in space. Because of these differences in the amounts of variables and in the order of the processes between the group investigation and the classroom representation of this investigation, Andy could not reach the same *empirical evidence* “lid pops off because pressure increases”. Therefore, Andy’s *elaborated Type 2 argument* was *not convincing* with the evidence obtained from the representation of investigation to support the claim that the cold air-filled balloon would get bigger in space.

<u>Condition VIII: Elaboration of argument when prompted by representation of investigation</u>

In another case FG2 students participated, Nick and Lynn who were not convinced with Sean’s argument made their group’s argument visible using the “Gas Properties” simulation. They represented their group investigation in front of the class, thus, they attempted to show their evidence and justify option B as their group claim which was different from the focal group’s claim. However, this representation of investigation worked for another claim that FG2 students supported as follows:

Excerpt 18-FG2

1 Lena: We disagree with Sean because we thought the balloon would expand. To test it out we did it with the light species and there is no gravity because it [balloon] is in space. So, we added light species at zero gravity. And then, cold temperature since the space is cold. The pressure rose, kept rising and lid popped off, they would be like the balloon would pop. So, we thought the balloon would pop in space since there is cold.

2 Nick: We have another way to show here. If we’re on earth with lots of gravity and put 1000 heavy species there, we have all those molecules float around. Then, we start to cool it [chamber] down. We cooled it down all the way down 1 K to simulate cold space.

3 Jack: If coldness causes the particles slow down, the balloon must begin to get smaller.

4 Nick: It hasn't been in space yet because it is still as full gravity. This is just in fridge.

5 Lynn: We did it in steps because we could not do it all the way once. We did it with cold first and then gravity.

6 Sean: It's still the same.

7 Nick: We thought it [balloon] is gonna pop for sure because umm, like for instance, you know weather balloons. When they go up, the way to come down isn't by deflation; it is by popping the balloon. So, that balloon was up into the space with cold air we think that it is gonna pop because how much faster the molecules are moving inside. So, it tends to fewer moves around, eventually, it pop.

As seen in the dialogue above, Nick and Lynn tried to defend their argument using the "Gas Properties" simulation. In second to fifth turns, they presented what they investigated in their pair discussion to the class without interrogating their numerical data. They reached *empirical evidence* that the lid of the chamber in the simulation did not pop off and this evidence supported Sean's claim that cold air-filled balloon would stay the same in space. In the rest of the discussion instead of weighing this empirical evidence, Nick's (turn 7) negotiating with his beliefs and intuitions indicated that this evidence justifying Sean's *Type 2 argument* was *not enough convincing* for him.

5.2 Part II - Arguing to compare the behaviors of air and Helium molecules in space

Part II began with the driving question Mr. Core and Mrs. Simpson posed to *challenge* students:

> There are 2 balloons at the same place of the outer space. They are identical in size and material. One balloon is filled with air and the other balloon is filled with Helium. The balloons have the same number of molecules. How does the pressure of the air balloon compare to the pressure of the Helium balloon in space?
>
> a) The pressure in the air balloon is equal to the pressure in the Helium balloon.
> b) The pressure in the air balloon is less than the pressure in the Helium balloon.
> c) The pressure in the air balloon is greater than the pressure in the Helium balloon.

The teachers, Mrs. Simpson and Mr. Core, wrote this question with three alternative claims ranged from option A to option C on the boards of their classrooms and asked students to choose which of three claims best represented the comparison between the pressures of Helium and air balloons. The teachers conducted a straw poll of students to find out how many of them thought option A, option B or option C as their claim. Fifteen students supported option A, seventeen students raised their hands for option B and other twenty-five students voted for option C. Then, to accomplish the goals of constructing scientific arguments and defending these arguments using the "Gas Properties" simulation, all students first worked in pairs in Part II-Activity I and then, all the pairs returned to the classroom for discussion in Part II- Activity II. Thus, these two activities performed by the same pairs from Part I facilitated my examining the following research questions in more detail:

1. How do interactive computer representations support students in developing arguments?

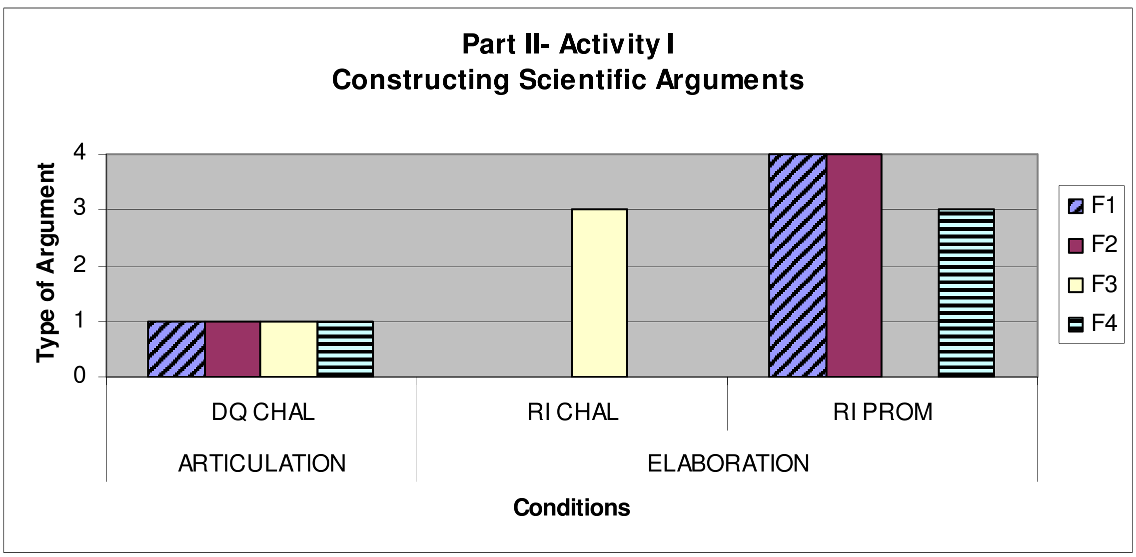
2. What type of arguments do students use?

3. What type of arguments do students find convincing?

4. What conditions help students to improve their arguments?

5.2.1 Activity I - Constructing Scientific Arguments using the "Gas Properties" simulation

In this activity the focal group students from four classrooms attempted to construct their arguments in order to defend them in Activity II (Figure 5.3).



DQ: Driving question
CHAL: Challenging
RI: Representation of Investigation
PROM: Prompting

Figure 5.3: Constructing Scientific Arguments in Part II- Activity II

Students initially identified their claims and *articulated their arguments when challenged by the driving question* Mr. Core and Mrs. Simpson posed. In these initial *Type 1 arguments* Andy, Sean, Simon and Chris only appealed to their *reasoning* to justify their claims. Students did not use empirical evidence from their previous investigations in Pre-Scientific Argumentation and Scientific Argumentation- Part I and lack of shared evidence made it *difficult to convince their pairs of their arguments*.

After that, the focal group students engaged in the practices of designing and conducting their experiments using the "Gas Properties" simulation in order to collect data. During these practices, they gathered and combined a wide range of scientific data from the simulation to discuss how the pressure of the air balloon compared to the pressure of the Helium balloon at the same conditions in space. The data they collected largely took a form of *numerical data* consisting of the pressures of air and Helium balloons which were the *dependent variables* of their experiment. They reasoned numerical data to generate *empirical evidence* and *elaborated their arguments* with this empirical evidence *when challenged or prompted by representation of their investigations.* Different from FG3 (Simon and Kelly) and FG4 (Chris and Justine) students, FG1 (Andy and Jane) and FG2 (Sean and Ally) students elaborated their arguments by engaging in a form of *systematic investigation* in which they considered all *independent and dependent variables* of their experiments (i.e. temperature, volume, number of molecules, gravity and pressure) to learn if their claims were correct. These systematic investigations led FG1's and FG2's *Type 4 arguments* to get more sophisticated than FG3's and FG4's *Type 3 arguments* toward the end of pair discussions and this relatively made easier for them to support their arguments during the classroom discussions when they tried to convince other pairs of correctness of their claims in Activity II. When analyzing participants' constructed arguments, I did not directly evaluate their arguments for accuracy.

Findings: Mr. Core and Mrs. Simpson formed students into the same pairs from Part I in their own classrooms and initiated the group discussions with the same driving question. Pairs evaluated the potential viability of three alternative claims under this question and constructed scientific arguments using the "Gas Properties" simulation in group discussions. To help pairs structure their arguments, Mr. Core and Mrs. Simpson gave pairs the same "Our Argument" worksheet (see Appendix D) containing writing stems that required pairs to state their claim, evidence, reason(s) for their claim and counter-argument in 20 minutes. Pairs worked collaboratively to write their arguments for their view of which the best claim was. The same four pairs from Part I in four classes were selected as my focal group students to engage in their discussions.

Condition I- Articulation of argument when challenged by the driving question

Jane (FG1 student) in Mr. Core's classroom and Simon (FG3 student) in Mrs. Simpson's classroom raised their hands for option A as their claim that the pressure in the air balloon would be equal to the pressure in the Helium balloon. Ally student (FG2 student) in Mr. Core's classroom and Kelly (FG3 student), Justine and Chris (FG4) in Mrs. Simpson's classroom supported option B as their claim that the pressure in the air balloon would be less than the pressure in the Helium balloon. Andy (FG1 student) and Sean (FG2 student) in Mr. Core's classrooms voted for option C as his claim that the pressure in the air balloon would be greater than the pressure in the Helium balloon. Table 5.2 presents this data below.

Table 5.2: Focal Group Participant Claims in Part II

Participant	Focal Group	Claim
Jane	FG1	Option A: The pressure in the air balloon is equal to the pressure in the Helium balloon.
Simon	FG3	
Ally	FG2	Option B: The pressure in the air balloon is less than the pressure in the Helium balloon.
Kelly	FG3	
Justine	FG4	
Chris	FG4	
Andy	FG1	Option C: The pressure in the air balloon is greater than the pressure in the Helium balloon.
Sean	FG2	

Some of these focal group students tended to *articulate their arguments* for why they chose their claims at the beginning of the group discussions when challenged by the driving question. To illustrate, Andy chose a claim which was option B by providing *unsupported reasoning* in excerpt 19-FG1.

Excerpt 19-FG1

1 Andy: Think air and Helium have equal areas (the volumes of Helium and air balloons were the same in the driving question) and [the pressure of] air is less than [the pressure of] Helium or [the pressure of] Helium is less than [the pressure of] air? [The pressure of] Helium is less than [the pressure of] air because air is heavier than Helium.

2 Jane: We need to do experiment.

3 Andy: Alright.

Andy (turn 1) first could not decide on whether or not the pressure of air balloon was less than the pressure of Helium balloon and he hesitated between option B and option C in his argument. Then, when mentioning that the pressure of Helium would be less than the pressure of air, Andy referred to option C as his claim using his *reasoning* "air is heavier than Helium." However, he *articulated his Type 1 argument* without providing any evidence for his claim. From Jane's (turn 2) proposition of "we need to do experiment" it can be inferred that Andy's argument did not satisfy Jane and did not help her to resolve her initial puzzlement in her mind.

Similar case depicted above was also seen at the beginning of the group discussion FG3 students participated. Simon also used only his *reasoning* "because like helium and oxygen they both don't have gravity" when he *articulated his Type 1 argument* for option A as his claim. But his proposition of doing experiment referring to "let's see" showed that his argument only comprising claim and reasoning did not satisfy himself.

> Simon: Connected to question we did if the balloon is gonna be bigger or smaller or stay the same in space, I think both of them wouldn't get bigger because like helium and oxygen they both don't have gravity, so the same thing would happen to the balloons but let's see.

Accordingly, Simon and his pair, Kelly, designed and conducted their experiment using the "Gas Properties" simulation so as to find empirical evidence and justify their claim by recourse to this evidence (discussed in more detail later.)

Another group who responded the driving question just presenting their reasoning was the FG2 students. Upon in response to the driving question rephrased by Ally, Sean *articulated his Type 1 argument* appealing to his *reasoning* in excerpt 20-FG2.

Excerpt 20-FG2

1 Ally: If we have two balloons with the same number of molecules in them, one's just filled with air; one's filled with Helium, they have the same size, everything is the same, which one is more [pressure]? Helium has more pressure?

2 Sean: No, heavy one has more pressure because it [air]'s less moving to be all around.

3 Ally: Okay. What is your evidence to put your claim?

4 Sean: I'll show you it here.

Sean (turn 2) explicitly chose option C as his claim presenting his reasoning "it [air]'s less moving to be all around" but he did not provide any evidence. Upon in response to the request of evidence by Ally, instead of expressing his evidence in words, Sean preferred to show it to his pair on the "Gas Properties" simulation (described in more detail later.)

As the similar cases that I encountered above, Chris from FG4 students justified option B as his claim with reasoning when *articulating his Type 1 argument*. His reasoning which was "one that is floating has Helium molecules going faster" was different from students' in other focal groups.

Excerpt 21-FG4

1 Chris: I think it will be [option] B because one that is floating has Helium molecules going faster.

2 Justine: Why are they going faster?

3 Chris: Because it moves, it is floating so, it is active. If it is not floating, it is not active.

When responding to the question posed by Justine, Chris drew on his existing knowledge to elaborate his reasoning but his response did not weave together claim, evidence and this reasoning. The lack of shared evidence led them to initiate their investigation to construct sophisticated argument.

Following these interactions, all focal group students worked on the task that required them to find evidence to provide the best account of the given phenomenon under study. They designed and conducted their experiments and collected their data using the "Gas Properties" simulation. During these experiments they analyzed and synthesized the data points into some coherent series and shifted from *data* to *empirical evidence* to justify their claims.

<u>Condition II: Elaboration of Argument when challenged by representation of investigation</u>

Focal group students followed up by making use of empirical evidence from their investigations with the “Gas Properties” simulation to construct more elaborate arguments. When designing their investigations, all focal groups first discussed and decided on whether light or heavy species in the “Gas Properties” simulation represented Helium molecules. Then, they attempted to find *empirical evidence* that would support their claims. For instance, in the following excerpt 22-FG3 Kelly and Simon pumped the handle twice to observe the behavior of heavy and light species first at little bit less than lots of gravity and reached empirical evidence supporting option C instead of option A which was their first choice. This unexpected observation puzzled him and led Simon (turn 3) to become more cognizant of the assumptions about the conditions under which the pressures of heavy and light species were observed. He noticed that air and Helium balloons are in space and space has zero gravity. Upon this notice, FG3 students pumped the handle twice at zero gravity to simulate the behavior of air and Helium molecules in space.

Excerpt 22-FG3

1 Simon: Pump the handle twice. Not lots (gravity.) Little bit less than lots. Pump do with heavy and then, with light to see that the pressures come exactly the same. Where does it stop? So, it fluctuates like that?

2 Kelly: There is less pressure for the light one.

3 Simon: I’m confused... Ohh, they are in space, space has zero gravity. Two pumps of heavy species at zero gravity. Does it stop?

4 Kelly: One point thirty four, five, six, seven, eight and forty-two.

5 Simon: How are we supposed to be accurate reading of pressure with fluctuates?

6 Kelly: Let say the number stays within 1.35 [atm] up there. (After pumping the handle twice to put light species) for the blue one the pressure is …

7 Simon: Pressures are different. So, the pressure of the air balloon is greater than the pressure in the Helium balloon. I wanna third pump to see what happen if there are more light species. Would the pressure rise?

8 Kelly: Yeah, it is also the same thing for the other one.

9 Simon: Okay it [chamber] takes more Helium to get the same pressure as air. Let's try with heavy species. Heavy species, three pumps and then, zero gravity, it was getting up too. It should go higher than what was before, right? Is it exactly the same conditions last time we did it? They're colliding. Give some time to collide. So, it wants to go higher. So, within .45 and .50. So, now they [heavy species] took, you did three. So, they [light species] take four to get within .45 and .50. It is always one up.

To justify option A as their claim that Simon argued in excerpt 21-FG3, Simon and Kelly conducted their experiment pumping the handle for heavy and light species respectively on the "Gas properties" simulation. Different from other focal group students, FG3 students decided on the same number of pumps instead of the same number of heavy and light species in each trial. This decision *challenged* them and led them to reach to *empirical evidence* supporting another claim which was option C under the driving question. When they pumped the handle twice to get heavy and light species into the chamber, they observed that the pressure of heavy species was greater than the pressure of light species. Simon (turn 7) asked for third pump to see what would happen if there were more light species and this new trial led him (turn 9) to think that the chamber took more light species to get the same pressure as heavy species. He collected *numerical data* to compare the pressures (*dependent variable*) of these species at zero gravity which was the only selected *independent variable* of the investigation he considered. At the end of the investigation, they *elaborated their Type 3 argument* referring to this collected numerical data in words but they wrote their inference from this data as *empirical evidence* on the "Our Argument" worksheet (Appendix I) as follows:

> Our evidence supports our idea for this are
> When using the simulation it took more molecules or (pumps) of Helium to get an equal or slightly higher pressure of an air filled balloon.

<u>Condition III: Elaboration of argument when prompted by representation of investigation</u>

During the analysis of discourses between the focal group members, I encountered some cases that collecting supportive data to show it as empirical evidence was enough for these students to prompt elaboration of their arguments and build a consensus on their end-product. For instance, Chris and Justine collectively worked on a task they designed to provide *empirical evidence* and justify option B as their claim. Chris pumped 500 heavy species at zero gravity and measured the pressure of these species. Then, he did the same thing for light species and saw that the pressure of heavy species (1.3 atm) was less than the pressure of light species (2.2 atm.)

Excerpt 23-FG4

1 Chris: So, these [heavy species] will be air and these [light species] will be Helium.

2 Justine: Try with constant volume because they have the same size. Okay. If we have the same amount of molecules, so, we do with heavy one first.

3 Chris: How many species?

4 Justine: So, do with 500 heavy [species] at zero gravity. How much pressure?

5 Chris: The pressure is keeping going down. It is like between 1.2 and 2.5.

6 Justine: Okay. So, do you wanna try with light species?

7 Chris: Yeah. I think we did too. Helium has less pressure because it is floating.

8 Justine: It is lighter.

9 Chris: 500 light species. The pressure is higher.

10 Justine: It is a lot higher?

11 Chris: Yeah. What was the average pressure for the heavy species?

12 Justine: It was like 1.3 [atm]. Now it stays around 2.8 [atm] (for the light species.) So, they are the pressures in the space. It is B.

13 Chris: See it drops.

14 Justine: Yeah. And then, they stay where?

15 Chris: So, it is like 2.2 [atm] for the light species.

16 Justine: But it is just gonna keep slowing down toward zero.

17 Chris: I don't think so because molecules are also moving even it is cold.

In the dialogue above, Justine (turn 2 and turn 4)'s pointing out zero gravity and volume showed that the focal group students recognized these selected *independent variables* affecting the *dependent variable* which was pressure in their investigation. They decreased gravity in the "Gas Properties" simulation to compare the pressures of heavy and light species at the same volume but they did not tend to control temperature which was another independent variable. Then, Justine (turn 12) who was *convinced* with this investigation *elaborated Type 3 argument* shifting from *numerical data* to *empirical evidence* "it was like 1.3 [atm]. Now it stays around 2.8 [atm] (for the light species.) So, they are the pressures in the space" without referring to this *missing independent variable*. As will be seen in Activity II, this caused hard times for the focal group students during the classroom discussion when they tried to convince other pairs of the correctness of their argument written in the “Our Argument” worksheet (Appendix J) as follows:

> Our position is that the option B is correct because
> Helium is moving faster than air.
>
> Our evidence supports our idea for this are
> We simulated that when we have 500 molecules and take off gravity to simulate Helium and the pressure came to 2.2 Atm. Then, when we threw gravity to the equation the pressure fell lower than Helium’s pressure (1.3.) So, the air-filled balloon is less than the Helium.

The case of students’ *elaborating group argument* presenting numerical data as empirical evidence was also seen in FG1 discussion. To collect data with the Gas Properties” simulation Andy and Jane designed their investigation. They represented Helium molecules with light species and air molecules with heavy species and kept them separate in the simulation. They put100 heavy species and then, 100 light species and cooled these species at zero gravity to visualize the substantive features of phenomenon portrayed by the driving question. When Andy compared the pressures of light and heavy species at 32 ºK and zero gravity, the following dialogue revolved around this investigation in excerpt 24-FG1 led Andy to show *empirical evidence* and to change his mind to support option A as his group claim.

Excerpt 24-FG1

1 Jane: How many heavy molecules [heavy species]?

2 Andy: 100.

3 Jane: .51 [atm]. Here it [pressure] looks like .55 [atm]

4 Andy: Okay. Hold on. So, I feel like Helium would have more pressure because Helium molecules are lighter to move around more and create more pressure.

5 Jane: Alright. Let's record this one.

6 Andy: So, [option] B. [The pressure of] air equals .54 [atm]. Okay now we let little those and do light, 100 light molecules [light species.]

7 Jane: So, it [pressure] is like the same.

8 Andy: Yeah .54 [atm]. So, let's switching. So, our position is option A and our evidence for this area [space on the worksheet] is that the pressure for 100 heavy or light molecules is .54 [atm] at the same conditions.

The observation of the pressure of heavy species led Andy (turn 4) intuitively to think about option B as his group claim that the pressure in the air balloon would be less than the pressure in the Helium balloon. He used his reasoning "because Helium molecules are lighter to move around more and create more pressure" to explain why he preferred that claim to support but he did not provide any evidence. Upon this interaction between Andy and Jane, FG1 students engaged in a form of systematic investigation by controlling all *dependent* (pressure) and *independent variables* (number of molecules, volume, temperature and gravity) to learn if option B was correct. Andy reset the "Gas Properties" simulation and pumped 100 light species in its empty chamber. When he reduced the temperature from 300 ºK to 32 ºK at zero gravity and at the same volume in order to compare the pressures of heavy and light species at the same conditions, the FG1 students noticed that the pen of the barometer in the simulation was moving around .54 atm. This *systematic investigation* led these students to change their minds and became *convinced* with option A as their claim in *Type 4 argument*. While Jane (turn 7) concluded that heavy and light species would have the same pressure at the same conditions, Andy went further in his explanation and shifted from *numerical data* to *empirical evidence* "the pressure for 100 heavy or light molecules is .54 [atm] at the same conditions". That contributed FG1 students to displaying a relatively higher quality of reasoning in the "Our Argument" worksheet (Appendix K) in spite of not taking note of the amount of temperature for heavy and light species on the worksheet.

> Our position is that the option A is correct because
> If the volumes of containers are the same and they are in space, so there is no gravity then the pressure is based solo on the moment of the molecules which is about the same.
>
> Our evidence supports our idea for this are
> The pressure for 100 heavy (air) molecules is .54
> The pressure for 100 light (Helium) molecules is .54

The similar instance was also noticed in FG2 students' discussion. When designing their experiment using the "Gas Properties" simulation, they considered Helium molecules as "light species" and air molecules as "heavy species" in the simulation. They decided on making observations with pumping 400 light species first and then, 400 heavy species into the chamber of the simulation at zero gravity that represented the gravity in space. They saw that the pen of the barometer in the "Gas Properties" simulation did not show a fixed number and it was changing between 1.8 atm and 2.2 atm for light species. While conducting their experiment with 400 heavy species, they observed the moving pen back and forth around 1.8 atm for these species. With regard to these observations, Ally (turn 1) supported option B as the group claim that the pressure in the air balloon would be less than the pressure in the Helium balloon in excerpt 25-FG2. She argued for her decision by providing justification for why *numerical* and *non-numerical data* they collected from the "Gas Properties" simulation counted as *empirical evidence*. However, Sean was *not convinced with* this decision and he (turn 2) refuted Ally's decision by identifying a flaw in their experiment "we should add cold into it because the space is cold," which pointed out the progress in Sean's higher order reasoning skills (Osborne et al., 2012.) Then, in the rest of excerpt 25-FG2 they redesigned their experiment and collected their data using the "Gas Properties" simulation all over again.

Excerpt 25-FG2

1 Ally: It [the pressure of the light species] is still higher by like 0.2 [atm] I guess. I think that's [the pressure of heavy species] is gonna keep going down since the [heavy gas] molecules are going down. So, we got an answer.

2 Sean: No, we should add cold into it because the space is cold.

3 Ally: Why does it [temperature] make a difference?

4 Sean: Actually it makes a difference.

5 Ally: It doesn't matter as long as you keep it the same. Now put 400 heavy [species] in. The temperature will stay at 150 ºK. It wouldn't change. That would be a constant variable.

6 Sean: It is between .98 [atm] and 1.05 [atm]. Now put 400 light [species]. You know the temperature will still be 150 ºK. We will get the same.

8 Ally: The pressure is between 0.95 [atm] and 1.0 [atm] at zero gravity.

9 Sean: These are almost the same.

10 Ally: That's weird. So, now the pressures are all the same. I did first time only little bit higher. I think it [the pressure of light species] is the same [as the pressure of heavy species] now because that [the pen of the barometer] is not moving up anymore.

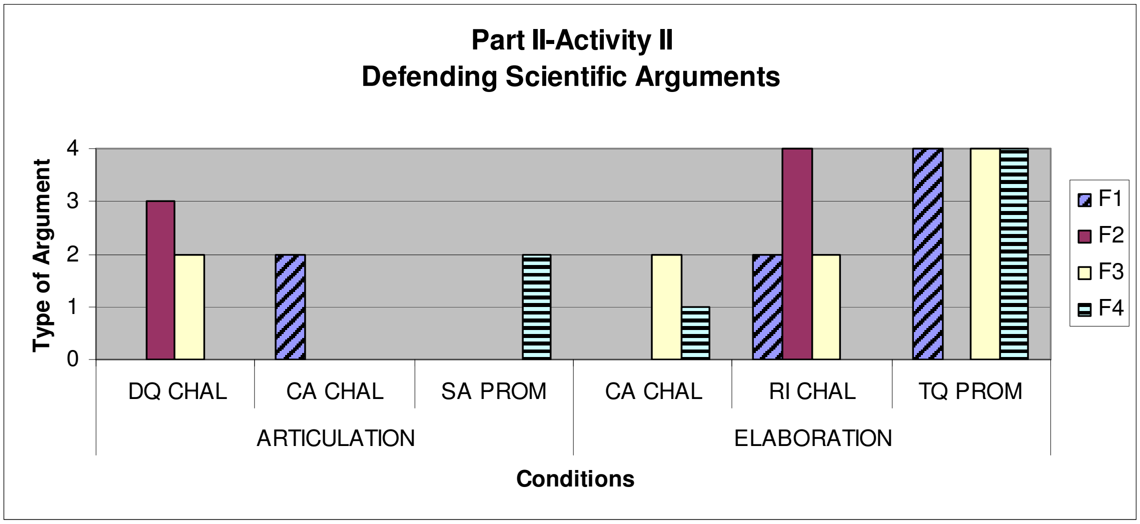
11 Sean: I think they will be the same though. I didn't change my mind.

Sean and Ally controlled all *independent variables* of their experiment (i.e. temperature, zero gravity, volume and number of molecules) when they were examining the changes in the *dependent variable* (the pressures of heavy and light species) in their *systematic investigation*. In turn 5 Ally sophisticatedly criticized that temperature would not make a difference as long as they kept the same temperature for heavy and light species because temperature was "constant variable" in their investigation. Accordingly, she proposed to keep the temperature at 150 ºK for the same number of heavy and light species and Ally and Sean collected *numerical data* to compare the pressures of heavy and light species. They showed this numerical data as *empirical evidence* to support option A as their claim that the pressure in the air balloon would be equal to the pressure in the Helium balloon and their group argument grew progressively *more elaborate*. However, instead of putting forward this *Type 4 argument* with justification for why this *numerical data* counted as *empirical evidence* on the "Our Argument" worksheet (Appendix L), they recorded non-numerical data as empirical evidence.

> Our position is that the option A is correct because
> Because the temperature of space will make the Helium and air similar.
>
> Our evidence supports our idea for this are
> We put 400 heavy species and 400 light species (at different times) and kept them at the same temperature and the pressure was relatively close.

5.2.2 Activity II - Defending Scientific Arguments using the "Gas Properties" Simulation

In this activity the focal group students from four classrooms defended their arguments initially constructed in Activity I (Figure 5.4).



DQ: Driving question   CA: Counter-argument   SA: Similar Argument
TQ: Teacher question   RI: Representation of Investigation
CHAL: Challenging   PROM: Prompting

Figure 5.4: Defending Scientific Arguments in Part II- Activity II

Students *articulated their constructed group arguments* in classroom discussions *when challenged by the driving question or a counter-argument or* and *when prompted by a similar argument*. In his initial *Type 3 argument* Sean was only student who appealed to *empirical evidence* with *numerical data* to defend his group claim; in their initial *Type 2 arguments* Simon, Andy and Chris appealed to *empirical evidence* addressing to *non-numerical data* collected from the "Gas Properties" simulation. Although Sean numerically recognized the *dependent variable* of his group investigation which was pressure but he did not numerically indicate all *independent variables* such as the amount of temperature and the number of molecules to support his group claim. Hence, the lack of articulated numerical independent experiment variables in the course of providing empirical evidence made it difficult for these FG2 students to persuade others of their group claim.

After that, students in each class participated in scientific argumentation in which they weighted evidence and evaluated the potential viability of claims in light of alternatives. During this process, focal group students *elaborated their arguments when prompted by a teacher question* and *when challenged by a counter-argument or representation of investigation.* These arguments involved a wide range of *empirical evidence* gathered from the “Gas Properties” simulation to justify their claims that compared the pressures of Helium and air balloons in space. When focal group students shifted from numerical data to empirical evidence, they addressed to numerical changes in all dependent and independent variables of their investigations, which led to their arguments being the highest quality and *Type 4*. Through the end of the activity, other pairs became convinced with the correctness of these arguments or they convinced the focal group students of their Type 4 arguments by means of assessing the credibility of empirical evidence in focal groups’ arguments. When analyzing participants’ elaboration of their arguments, I did not directly evaluate their arguments for accuracy.

<u>Findings</u>: After argument construction work in pairs, the discourse move was intended to shift the discussion from information seeking to sharing thoughts and findings in a persuasive classroom discussion in the rest of the course periods. Some volunteer pairs of students *articulated* and *elaborated their group arguments* constructed in Activity I when *challenged by a counter-argument, representation of investigation or prompted by a teacher question.* The discourse in each class was initiated with teachers’ asking the same driving question from Activity I. For example, Mr. Core rephrased this question written on the board without indicating the options under the question as follows:

Mr. Core: So, the question is if we have two balloons in space they are made of the same material, and the same size and the same number of molecules in them. One is just filled with air and the other is filled with Helium, and you're comparing the pressure of the air balloon versus the pressure of the Helium balloon. Make your claim, have evidence. Someone start it.

Condition I: Articulation of Argument when challenged by the driving question

After the teachers asked this driving question, they began the discussions by having volunteer pairs vocalizing their initial arguments and supporting these arguments by using the "Gas Properties" simulation. While they put forward multiple perspectives from their "Our Argument" worksheets, they were encouraged to use *empirical evidence* to back up their gas behavior related decision-making. For instance, like other pairs, FG3 students, Kelly and Simon, attempted to justify their claim (option C) using *empirical evidence* from the "Gas Properties" simulation in excerpt 26-FG3. Simon (turn 3) *articulated his group argument* and tried to convince other pairs of this *Type 2 argument (non-numerical data* as *empirical evidence.)*

Excerpt 26-FG3

1 Ashley: I will start, umm, we think it is A the air and Helium are the same because we did some calculations and then, umm, we decided that the species, heavy or light, then, we put them in 200 species and then, take it both trials, and then the pressure ranked both the same. They were around the same thing and if they're in space, it doesn't matter because there is no gravity or no pressure.

2 Dennis: Me and my partner Colin, we decided to simulate, umm, trying to figure out which ones we said that both of them were the same because, in the beginning we thought that they were that air has more because they're air molecules, we did it to look at to it. But then, I had decided to put the equal amount of molecules, I' ll take that they're in the species, I want it for both of them the equal same amount and then, I had seen which pressure went up and then, they were around the same so I presumed they were equal.

3 Simon: Kelly and me picked the C the pressure of the air balloon is greater than the pressure of the Helium balloon. It is hard to explain without showing it. I'll

try to explain first, umm, we did, we changed the conditions, or set measurement tools, this makes molecules [species] collide because it was like what actually happens. We took other gravity off because in space there is no gravity. We did like four five trials and we noticed that it takes three pumps of heavy molecules so it is like air filled balloon to a ratio of four pumps of light molecules to get an equal pressure. So, that a sort of disproves A where they say both equal because it takes more molecules of Helium to get an equal pressure to the air filled balloon.

As can be seen in the excerpt above, in turn 3, Simon shifted from *non-numerical data* to *empirical evidence* “it takes three pumps of heavy molecules so it is like air filled balloon to a ratio of four pumps of light molecules to get an equal pressure” in his group’s *Type 2 argument*. Yet, this empirical evidence challenged other students’ thinking instead of convincing them of Simon’s claim and it shaped the rest of the classroom discussion that followed.

Similar case was also seen in another classroom discussion which FG2 students took part in. To support group decisions in excerpt 27-FG2, students *articulated group arguments* related to what they did in their investigations and what they found in these investigations. Until Sean (turn 5), the students drew on Type 2 argument (non-numerical data as empirical evidence) to convince each other.

Excerpt 27-FG2

1 Jack: Me and Helen had first saw the option’s gone be B because on earth the pressure sort of keeps Helium balloon float but then, after like we consulted the group next of us, here James and Loran said, we think that it’s is gonna be [option] C just because when we were playing around with the simulation, the heavier species did have more pressure than the light species when we fluctuated temperature and the gravity so, from making in space to not in space.

2 Kevin: We said that our position was [option] C because our evidence was that when we’re using the program, having the temperature at the same level and heavy and light species, heavy species have slightly higher pressure, we tested them both times.

3 Nick: So like we kept the temperature constant as the temperature of the space we had there and so, after keeping the same number of species like the question said and the same temperature which is temperature of the space, we saw that there is a very slight difference in the pressure reading and that larger species the blue ones, they were slightly higher by one tenth of the reading compared to the smaller species and we saw that that will show that [option] C that the air molecules have that slightly higher pressure than the Helium molecules.

4 Mary: We said that, umm, since it did slightly higher pressure and seems that it is in space there is no pressure or other forces it made outside, they may cause to expand there, making the air balloon, umm, have a greater volume than the Helium balloon.

5 Sean: We found that we did the same thing, we kept the temperature constant and then, we had the same number of molecules but we found that both traveled the pressure like fluctuating like between .9 [atm] and 1.05 [atm] and so, we just tend to say that we know [option] B that, ohh no, [option] A that will be equal because they both fluctuated around the same range. It didn't stay at constant number.

6 Lena: We had the same result as you guys. We picked [option] A that the pressure of air balloon will equal to the pressure of the Helium balloon, umm, because we put like 82 species of each one and then, we made the temperature zero and then, we tried again with 32 degrees and each time it will be the same pressure.

As can be seen in the excerpt above, Sean (turn 5) shifted from *numerical data* to *empirical evidence* "we kept the temperature constant and then, we had the same number of molecules but we found that both traveled the pressure like fluctuating like between .9 [atm] and 1.05 [atm]" in his group's *Type 3 argument*. He numerically pointed out the *dependent variable* of his group investigation, which was pressure, but he did not numerically identify selected *independent variables* such as the amount of temperature and the number of molecules to support his group claim. Lena (turn 6) agreed with Sean and articulated selected dependent and independent variables numerically but her empirical evidence comprising non-numerical data "each time it will be the same pressure" was not sufficient to foster Sean's argument. As described in more detail later, Nick's and Mary's making their group argument visible in the extension of the classroom discussion showed that *neither Sean's nor Lena's articulated group argument was convincing* for other pairs.

Condition II: Articulation of argument when challenged by a counter-argument

Different from the dialogues in the cases depicted above, some focal group students articulated their arguments and backed up these arguments with *empirical evidence* when they were challenged by a counter-argument. For instance, in excerpt 28-FG1 Sara argued her group position and then, Andy (turn 2) from FG1 rebutted this position *articulating his group argument* sustained by group investigation.

Excerpt 28-FG1

1 Sara: Alright, I think that Helium balloon is lighter than the air balloon because there is less gravity in space. Therefore, there is less gravity, basically the gravity and pressure are the same things, and so because there is less pressure in space, less gravity means that the pressure around the balloons will be less. So, the Helium balloon is lighter than the air balloon.

2 Andy: I disagree. We and my partner, we picked [option] A because we did the boxing (he pointed out their experiment, using "Gas Properties" simulation) and we did heavy molecules [heavy species] which represent like air and we added cold and put the gravity to zero. The pressure went down and we did with light ones which represent Helium and we put cold and put gravity zero and both of the pressures went down. So, they were equal. So, we said the same.

3 Casey: I disagree with Andy because I picked [option] C. By adding the heavy molecules and removing all heat and, umm, the lid opened and the pressure increased. And when adding the light molecules and removing the heat, the lid stayed on and the pressure decreased.

As can be seen in excerpt 28-FG1, instead of using empirical evidence that what found in her group design experiment using the "Gas Properties" simulation, Sara (turn 1) would rather to support her group Type 1 argument only with her reasoning. She basically argued that the gravity was less in space than on earth, less gravity would lead to less pressure around the Helium and air balloons and Helium balloon would be lighter than the air balloon in space as on earth. Her argument was not directly related to one of the options under driving question. On the other hand, Andy who disagreed with this argument counter-argued by mentioning empirical evidence his group found using the simulation that cold temperature and zero gravity brought about the same amount of pressure for both heavy and light species. However, he neither included numerical data as empirical evidence nor presented his group experiment on the "Gas Properties" simulation at the beginning of the discussion. Indeed, his *Type 2 argument* (*empirical evidence* with *non-numerical data*) made *difficult to convince* other pairs (like Casey and Katy) of option A as his group claim that the pressure in the air balloon is equal to the pressure in the Helium balloon.

Condition III- Articulation of Argument when prompted by a similar argument

In a classroom discussion FG 4 participated, Jeff, Carolyn and Eric who were from volunteer pairs to share their groups' consensus positions supported different claims with empirical evidence and reasoning. Jeff (turn 1) argued his group position by providing justification for why non-numerical data they collected from the "Gas Properties" simulation counted as empirical evidence. Challenged by Jeff's position which was option C, Carolyn (turn 4) defended option A as her group claim only using her reasoning without considering empirical evidence from the simulation. Then, Eric (turn 5) who was not satisfied with Jeff's and Carolyn's arguments disclosed his group argument just appealing to his reasoning. However, this argument was not rich enough for Amy to convince other pairs of option B and to pave the way toward resolving their puzzlements. Hence, she (turn 6) put forward her group argument with empirical evidence involving numerical data collected from their investigation with the simulation to compare the pressures (dependent variables) of the same number (independent variables) of heavy and light species. Amy's justification of option B as her group's claim using empirical evidence set the stage for what was to come and encouraged Chris's *articulation of his group Type 2 argument* for the same claim.

Excerpt 29-FG4

1 Jeff: Our claim is option C that the pressure in the balloon where there are just air would be greater than the pressure in the Helium balloon because we tested it out on the simulation, we put 900 light species in and we measured how much pressure there was and then, we put 900 heavy species in and there was more pressure in one if they had the same amount of species.

2 Carolyn: Are you saying the heavier species have more pressure?

3 Jeff: Yeah. So, I'm saying that the pressure in the balloon filled with normal air was greater.

4 Carolyn: I disagree with Jeff. We pick A, umm, I think that regular oxygen would be greater than Helium on earth because I said Helium is lighter than air which is one makes possible for the balloon to float. Umm, in space but in space the same thing would happen to both of them regardless of what is inside of them.

5 Eric: I want to share my group's position. When we're doing this, we agree that our position will be B that Helium is lighter than oxygen because if you notice Helium when you put in the computer when you're putting light species, you notice that the molecules always run to move around. So, when they are moving around, the balloon will definitively float but more than that when we're talking with Mrs. Simpson, we also talked a conclusion that Helium and oxygen have two different amount of density. The oxygen has more density than Helium. So, Helium balloon floats because there is less density in it.

6 Amy: I agree with Eric. We also chose B because what we did when we're doing the simulation. We did a little bit different. We thought the box with 1000 red species which was light species. They moved all the way over to open the box and the lowest pressure amount on the little scale was 1.3 [atm]. And then, we did the same thing with heavy species. We reset the simulation and then, we put 1000 heavy species what was like oxygen and the highest amount of pressure was .9 [atm] and the lowest was .8 [atm] which was obviously a lot lower than 1.3 [atm]. So, you had the more pressure in Helium balloon.

7 Chris: I agree with Amy and we said that Helium has more pressure than air like because we did a test. We just constantly pumped heavy molecules [heavy species] into the box [chamber of the "Gas Properties" simulation] until the lid first opened up; the pressure went up a lot quicker than when we tested it with heavy molecules because Helium floats faster.

In turn 7 Chris engaged in what his group had done in their investigation to provide *empirical evidence* "Helium floats faster" shifted from *non-numerical data*. However, he did not attempt to represent this investigation on the "Gas Properties" simulation. The absence of both numerical data and presented argument on the simulation reduced the persuasiveness of his group argument by other students and the argumentation continued.

<u>Condition IV: Elaboration of Argument when challenged by a counter-argument</u>

When students presented their arguments and counter-arguments to each other, some focal group students elaborated their arguments to a greater degree, increasing persuasiveness of their group argument for other pairs. For instance, in the following dialogue, while other students declared that option A was correct in their arguments, Simon from FG3 still believed that option C would be more appropriate. Therefore, Simon (turn 2) mentioned all trials his group had done in their investigation and provided progressively more sophisticated argument in excerpts 30-FG3.

Excerpt 30-FG3

1 Daniel: We and Jay we chose A that the air and Helium will be equal in space and we came that conclusion because when we set the gravity to zero and we released the same amount of species into the same exact size and shape like container [chamber], they moved around at the same speed which made that the pressure stayed at the same. So, when they were colliding, it wasn't like smaller one [species] moving faster than heavier one [species].

2 Simon: Kelly and me didn't just do three pumps to four we checked it to the ratio thing, right. So, we did like if it takes three pumps to get the pressure to be

equal to four, like it takes three to four. We did it with four to five and then, we did six to seven. We kept doing to see the pressure always stays equal to which it did. So, we assumed that [option] C was correct going of to that.

3 Mrs. Simpson: Agree or disagree?

4 Daniel: Disagree.

5 Mrs. Simpson: Right now, we kept the people say A. Some people were saying C. You need to be able to convince each other of what the answer is.

6 Daniel: If they are in space, it doesn't matter. They both have the same thing.

7 Simon: No, we changed the condition.

8 Ashley: Wait wait. Go ahead what you say.

9 Simon: We did a condition in space and we changed a lot of advance tools [he pointed out "advance options" tool in the simulation] we supposed to make the molecules [species] collide. So, it is like click that and to do the conditions in space because the simulation catches it if the molecules just went down when they don't collide to each other, when in a real situation they really do collide. So, that could be a reason why they are like.

10 Ashley: Show yours.

In this excerpt, Simon (turn 2) elaborated his group argument by revealing more than one trial that led them to reach the same evidence and shifting from *non-numerical data* to *empirical evidence* "it takes three pumps to get the pressure to be equal to four, like it takes three to four. We did it with four to five and then, we did six to seven. We kept doing to see the pressure always stays equal to which it did." In this *Type 2 argument* he attempted to compare the pressures of heavy and light species referring the number of pumps but his attempt was limited only with providing an account that specified what happened and why it occurred. Upon Ashley (turn 8)'s request for more explanation, Simon (turn 9) focused his talk on externalizing how his group arranged some experiment conditions on the simulation under which the pressure of heavy species would be greater than the pressure of light species but he did not explicitly state what were these particular conditions. Ashley (turn 10) was further puzzled by lack of the shared articulation of the experiment conditions and posed a further demand to be convinced: "Show yours." This demand set the stage for what was to come and shaped the discussion that followed.

Similar instance was also seen in a dialogue FG4 students participated. In excerpt 31-FG4 Jay (turn 1)'s argument involved one of the conditions affecting air and Helium balloons in space which was zero gravity. When challenged by Dana's argument, Chris (turn 5) *elaborated his argument* using the experiment conditions his group had set in their investigation. He believed that Helium and air balloons would float at zero gravity but Helium balloon would float faster than other.

Excerpt 31-FG4

1 Jay: If the balloons are gonna be bigger or smaller or stay the same in space, I think both of them would be the same because like Helium and oxygen they both don't have gravity. So, the same thing would happen to the balloons.

2 Nelson: It is also like that heavy species are actually bigger compared to light species and if we have 1000 light species compared to 1000 heavy species, you have a lot more room available for light species. Heavy species actually bounce up more because they have less available room in the balloon compared to light species so I thought they might lead to more pressure.

3 Jeff: I agree with Nelson because light species are smaller than heavy species. It will take a lot of light species to build up the same pressure in the container. We know that heavier species filled up the space quickly to adapt the pressure in container. And then, the same thing was applied for light species but light species took a lot more to put the same pressure based on their size.

4 Dana: Since there is no gravity and they are the same amount, I don't think there will be any difference in pressure between balloons in space, so I'm pretty sure that both will float.

5 Chris: I disagree with Dana. I think that gravity is a constant variable. If you take it out completely, you can just say that obviously both will float but one

> floats faster because it has more, umm, pressure. And I think Helium floats faster even in space.

By this time, Chris's argument grew progressively more elaborate and was slightly more detailed than the one he had given earlier when he realized that Helium and air balloons were at the same place in space so that they were exposed to the same amount of gravity, that is, zero gravity. However, in turn 5 his *Type 1 argument* without supportive evidence was not enough qualified to convince other pairs of his group claim.

Condition V: Elaboration of argument when challenged by representation of investigation

Another observed condition in the classroom discussions was focal group students' elaboration of their arguments when they were challenged by the representation of their own or peers' investigations. Students' investigations provided different perspectives about the answer of the driving question. The representation of these investigations engaged students in and encouraged them to reflect on their own ideas about and their justifications for those ideas that paved the way toward resolving their disagreements.

In the classroom discussions FG1 and FG2 students participated, other pairs represented their investigations, whereas, in the discussion FG3 and FG4 students took place, the focal groups' students depicted their investigations using the "Gas Properties" simulation. The discussions continued with evaluating these visualizations of the investigations in the classrooms. For example, in excerpt 32-FG1 Sam who was not satisfied with all these arguments so far used the "Gas Properties" simulation for the first time in the classroom discussion to justify his group argument. He did not verbally articulate his claim, reasoning and evidence in turn 1; instead, he first attempted to represent his investigation and then, articulated his argument. There was strong resistance by Andy against Sam's argument revolving around his representation of investigation. Andy began to evaluate Sam's findings critically and he played the role of "critic" in generating and sustaining further talk.

Excerpt 32-FG1

1 Sam: I disagree with Andy as you can see here this is the air [heavy species] (he was repeating their group experiment to show it to his peers.)

2 Andy: Which one do you pick? A, B or C? (Andy wanted Sam first to state their claim)

3 Sam: [Option] B. This is in the space (he's simulating the air molecules in space pumping 50 heavy species into the chamber of "Gas Properties" simulation), there is cold and as you can tell, the pressure is staying at, like low. If you change it with 50 Helium [light species]…

4 Katy: Andy, Andy, just said that.

5 Sam: Oh yeah, one of the ways we disagree with him. There is more movement that is happening, they [light species] are moving faster and then, slowing down but we add cool air [heavy species] but they take more time to go down because there is more room to move in the balloon and they move faster. Look at how faster to move.

6 Andy: What is your argument?

7 Sam: I'm saying smaller Helium molecules are moving faster than our slow moving air molecules. So Helium is smaller, so they have more room to move because like I just did with heavy species which is 50, you can see that it is a kind of like not as fast but we do with light species because there is more room to move, so they are moving much faster phase which makes [option] B.

8 Andy: But at the end of the experiment this pressure [of light species] still goes down, so it is still equal [to the pressure of heavy species].

While Sam was focusing on the relative movements of the heavy and light species in the representation of his group investigation, Andy specifically pointed out their pressures on the barometer in the "Gas Properties" simulation. According to Andy, the pressure of light species would decrease to get the same pressure as heavy species. Thus, this representation prompted Andy (turn 8) to *elaborate his Type 2 argument* by making visible his *empirical evidence* "at the end of the experiment this pressure [of light species] still goes down, so it is still equal [to the pressure of heavy species]". However, the absence of numerical data *reduced the persuasiveness of his argument* for Sam and did not help Sam change his mind yet.

Similar case was also seen in another classroom discussion which FG2 students took place. Nick and Mary were volunteer pair to *make their group argument visible* on the "Gas Properties" simulation in front of the class. Indeed, they put forward similar designed experiment with FG2 students, Sean and Ally, but they chose option C since they supposed that the pressures of heavy and light species would be a constant number instead of fluctuating in a range.

Excerpt 33-FG2

1 Nick: This was the heavier species we did. We did the same amount of [heavy] species each one, 700 species and the same area in space. The pressure we did fluctuated over time at zero gravity but the average pressure was .03 [atm] we posed on. And then, we did the exact same, umm.

2 Mary: We did the same exact scenarios we had 700 of Helium, we had 700 light species, it was kept that the same temperature and the same constant volume of two, and then, the pressure have fluctuated and first it stayed steady at .02 [atm] and that was still less than what we saw with heavy species in the other example. It was .03 [atm].

3 Sean: The same temperature, the same number of molecules and what pressure did you find?

4 Nick: The pressure of the heavy species being air was slightly higher than the lighter species being Helium.

5 Sean: It is in a range I think. The pressure is in a range.

6 Nick: Yeah, it was slightly higher average for heavy ones. But it was almost in the same range.

As seen above, Mary and Nick represented their investigation and empirical evidence in front of the class. Surprisingly, they properly identified all *independent* (temperature, number of molecules, gravity and volume) and *dependent* (pressure) *variables* and they collected *numerical data* to show it as *empirical evidence* in their *Type 4 argument*. Sean did not criticize the investigation of Mary and Nick but he criticized their empirical evidence. The reason of this critic was that Sean together with Ally conducted a similar investigation but they reached different empirical evidence which justified their claim. As can be recalled from Activity I of Part II, Sean and Ally observed that the pen of the barometer in the simulation did not stop on a constant number, instead, it moved around the same range for heavy and light species in their group investigation. Upon Sean (turn 5)'s articulation of this observation Nick (turn 6) changed his mind and *became convinced* that the pressure in the air balloon would be equal to the pressure in the Helium balloon.

Different from the classroom discussions FG1 and FG2 students participated, FG3 students, Simon and Kelly, were willing to represent their investigation when defending their argument. Excerpt 34-FG3 presents the dialogue among the students on the FG3 students' representation.

Excerpt 34-FG3

1 Dennis: No, Me and Andrew had it set to collide and we still thought A.

2 Kelly: Did you guys change the temperature or did you guys keep the temperature the same?

3 Dennis: We kept the same. No change the temperature, no constance, we have the species collide on.

4 Daniel: Someone is wrong.

5 Dennis: Let’s see. Who’s wrong? Because I know I’m not.

6 Daniel: Simon, did you have the same number of species each?

7 Simon: Yeah, ohh no, we tried to get three pumps of Helium [light species] and three pumps of air [heavy species].

8 Daniel: You have to pump the same number of molecules.

9 Simon: We noticed that whenever we used Helium like light molecules and air like heavy molecules, whenever we tried to do with three pumps, the pressure of light molecules was lower than the pressure of heavy molecules.

10 Dennis: But in the question you had to have the same number of molecules and same size for each one.

11 Simon: We tried to do with same number of molecules but it doesn’t come up with people.

12 Dennis: No, you can. You had gas in the chamber and type in how many of each one you put the same exact number.

In turn 7 instead of keeping the same number of molecules in each trial, Simon kept the same number of pumps to observe and then, to compare the pressures of Helium and air molecules in his *Type 2 argument.* Simon (turn 9) *elaborated his argument* by making his empirical evidence visible; however, using *non-numerical data* as *empirical evidence* “whenever we tried to do with three pumps, the pressure of light molecules was lower than the pressure of heavy molecules” *reduced the persuasiveness of his argument* for other pairs. Specifically, Dennis (turn 12) who was obviously unconvinced encouraged Simon to consider another investigation with the same number of heavy and light species in the simulation. Simon’s modified investigation with the same number of species shaped the rest of the discourse that followed.

Condition VI: Elaboration of Argument when prompted by a teacher question

An analysis of the discourse transcripts showed that questions posed by teachers also played an important role in generating and sustaining further talk. These questions explicitly created a context to support scientific argumentation in which students debated their investigations, different claims and their justifications for those claims with their peers. For example, in excerpt 35-FG3 Mrs. Simpson's question (turn 1) focaled on eliciting FG3 students' investigation about comparing pressures of heavy and light species that represented air and Helium molecules in the driving question.

Excerpt 35-FG3

1 Mrs. Simpson: What are you doing right now?

2 Simon: We kept the both molecules [species] separate. See with the highest one like the highest pressure they will get for heavy molecules 3.3 [atm]. The conditions we're taking about the same. So, we reset it, we did it with the same number of light molecules so, the highest pressure is 2.7 [atm]. The pressure of heavy molecules was higher than the pressure of light molecules (he demonstrated the correctness of option C that his group supported as their claim.)

3 Daniel: But we're talking about range like the pressure stays the same like it keeps constant at the same place, not the highest because if this one only gives 2.7 [atm] the highest one and heavy molecules get 3.3 [atm] the highest one, it doesn't mean that heavy molecules didn't drop down and then, they stay at the same range as light molecules did.

4 Dennis: Also it is not talking about comparing at high in the pressure. It is taking about comparing at where they stand like for longest period of time.

5 Daniel: The only problem why you guys see when everybody else say [option] A is that you said number instead of range. You put 100 heavy molecules and then, 100 light molecules. They [pressures] don't stay at specific number. That's why; we tried to say that they were equal because they stayed at the same range.

6 Simon: Yeah, they were almost in the same range.

As can be seen from the dialogue, in attempting to answer teacher's question (turn 1), Simon (turn 2) elaborated his argument by making his modified investigation visible on the "Gas Properties" simulation. He first pumped heavy species into the chamber. Then, he reset the system on the simulation and pumped the same number of light species into the chamber at the same conditions. Keeping heavy and light species separate at the same conditions led him to control all *independent variables* affecting the *dependent variable* which was pressure in this investigation. When comparing the pressures of heavy and light species at the same conditions, he collected *numerical data* to show it as *empirical evidence* in his *Type 4 argument*. Daniel (turn 3) and Dennis (turn 4) criticized the credibility of Simon's *empirical evidence* because they thought that the pen of the barometer in the "Gas Properties" simulation did not show a specific number for heavy and light species. Daniel (turn 5) identified more relevant empirical evidence from this investigation for his argument that the pressures of heavy and light species were equal because they stayed at the same range on the "Gas Properties" simulation. The existence of such evidence made easier to convince Simon of correctness of Daniel's claim in Activity II.

Another instance for elaboration of argument when prompted by teacher question came from FG1 students' classroom discussion. While Sam attempted to qualify his argument by making it visible throughout the activity, FG1 students who supported different claim did not specify their group investigation until Mr. Core requested them to show what they had done on the "Gas Properties" simulation.

Excerpt 36-FG1

1 Sam: So, this is space at zero gravity (he pumped 50 heavy species up into the chamber and he represented the chamber as air balloon) but there is difference in their [heavy and light species] pressures obviously.

2 John: Are you making cold because you're simulating space?

3 Sam: Yeah, space. This is the space with the air balloon. The pressure is really bouncing to 10.11 [atm] and now for light species I'll set it [system] again. I'll set it with 50 light species, it is cold, and its pressure is going up 14 [atm]. It is freezing when its pressure is 14.50 [atm]. The other one was that 10.11 [atm]. So, there is more pressure inside this one [the chamber for light species] because they are moving faster than heavy species.

4 Katy: Alright, so basically, umm, we're getting Sam's argument but I think that when we did with the heavy species and removed the heat to decrease temperature on the simulation, the pressure increases which makes the chamber pop off, and the lid opens. When we did with light species and remove the heat, pressure decreases and the lid stays on.

5 Sam: So, there is more pressure inside Helium balloon in which the molecules are moving faster, because there is much more room for the movement of Helium molecules than other heavy molecules which are air because air molecules are basically heavy species, so they're bigger and not moving faster. But when light species are Helium, there is more room to move which those generate more pressure.

6 Katy: But that means the Helium balloon will pop and the air balloon will stay the same?

7 Sam: Yeah, Helium [balloon] will pop off because there is more pressure in that, and then the air [balloon] will take longer to pop off because it has less pressure. Like I said, the movement is a big key on what is going on.

8 Mr. Core: What affect the movement inside the balloon?

9 Sam: The temperature. How cold the space is. So, I know what you mean that it is obviously very cold for each one. But the amount of movement is also a big key which creates pressure. Okay I think the cold has a lot of doing with pressure, so Helium balloon will pop off because the movement and speed are building up the amount of pressure, and heavy one takes longer to pop off because there is less movement and less pressure to build up over time with the cold.

10 Andy: The temperature is the same since they [molecules] remain at the same place in the space. What we did give the same outcome when we added basically cold into the chamber.

11 Jane: We said that the pressure will be the same for both [air and Helium balloons] because we tested it on here (he pointed out the “Gas Properties” simulation.) We put heavy species and then, we set the volume the same, temperature of them were the same; we read the same pressures at the moment.

12 Mr. Core: Okay, can you show us?

13 Andy: Yeah, the temperature is 32 ºK and it says the pressure around .54 [atm]. Then, we did it with light molecules.

14 Mr. Core: What is the temperature now?

15 Andy: 32 ºK. And the pressure [light species] is around .54 [atm] or .55 [atm] which is the same with heavy molecules.

16 Mr. Core: Why did you keep the same temperature?

17 Andy: Because in space if they are the same places, their temperature will be the same there too.

In turn 1 Sam was intuitively arguing that there was difference in the pressure between Helium and air balloons. When he (turn 3) was conducting his group investigation on the “Gas Properties” simulation which would give him a concrete way of convincing other students, he elaborated his argument with shifting from numerical data to empirical evidence in his Type 3 argument. Because he did not tend to observe the pressures of heavy and light species at the same low temperature, his designed investigation revealed that he had difficulties in controlling independent variables to reach plausible conclusion. Indeed, Sam was still thinking that the difference in pressure between air and Helium balloons was only because Helium molecules like light species moved faster and hit each other more often than air molecules even at different low temperature. He considered this non-numerical data more than numerical data in his argument when presenting empirical evidence to justify his claim. Mr. Core (turn 8) attempted to prompt Sam's thinking with a question but he was insisted on using his non-numerical data to build empirical evidence of his argument. Upon the response of Sam to this question, Andy and Jane focused on the temperature and argued that if Helium and air molecules had the same temperature in the space, Helium and air balloons had the same pressure as well. Specifically, Jane (turn 11) mentioned her group investigation without fostering it with numerical data that reduced the persuasiveness of her group argument. To prompt the FG1 students to *elaborate their argument* with considering numerical data, Mr. Core (turn 12) posed another question and requested them to show what they had done on the "Gas Properties" simulation in their group investigation. Andy and Jane set gravity at zero and the temperature at 32 ºK, and they pumped 100 heavy species into the same volume of chamber. Then, Andy (turn 15) pointed out the amount of pressures (*dependent variable*) of heavy and light species as *numerical data* properly controlling all *independent variables* in his investigation. Using this numerical data as *empirical evidence* "the pressure [light species] is around .54 [atm] or .55 [atm] which is the same with heavy molecules" in Andy's *Type 4 argument* relieved Sam's concerns about how the different gas molecules behave the same way in space. Sam's ideas changed as result of evaluation against this available empirical evidence which consisted of numerical data collected from the "Gas Properties" simulation with controlled all dependent and independent variables.

Similar case was also seen in the classroom discussion FG4 students participated. In turn 1 Mrs. Simpson posed a question to help students think about the temperature which should have been one of the selected independent variable in their investigation. Dana (turn 2) and Jay (turn 3) replied that they considered the same low temperature for both heavy and light species in their investigations since air and Helium balloons were in the same place in space. However, only taking about how the same low temperature in space would cause the same outcome, that is, the same pressure inside two balloons was not enough to convince Chris. He still insisted on supporting his claim (option B) without using any evidence from his group investigation that he mentioned in turn 4. Then, Mrs. Simpson (turn 5) asked him for showing what his group had done to justify their claim. His argument became *more elaborate* when explaining his group investigation in the rest of the dialogue that followed in excerpt 37-FG4.

Excerpt 37-FG4

1 Mrs. Simpson: In our question, the balloons have the same size, the same number of molecules inside and also they are in the same place in space. So, what can you say about their temperature?

2 Dana: The temperature is the same since they [air and Helium molecules] remain the same place in space. What we did give the same outcome when we added basically cold into the chamber.

3 Jay: We can get the same outcomes of both balloons since it is basically freezing cold space.

4 Chris: Like I said before, the main thing that is affecting these balloons is the movement inside the balloons. We did the same experiment for all heavy and light molecules [species], we did it with a constant temperature and volume at zero gravity and then we figured out that the balloon will expand in space so, umm, since the Helium balloon has like small molecules that are moving faster, and then, it has more pressure.

5 Mrs. Simpson: Show what you did to get your answer.

6 Chris: We put 500 light molecules into the simulator and we take off gravity and now we get 2.2 atm for the pressure. And then we reset it and do with 500 heavy molecules at the same temperature. We are not putting any gravity on it. The

pressure is 1.3 atm for air. So, we said B that the air balloon is less than Helium balloon because it is much faster.

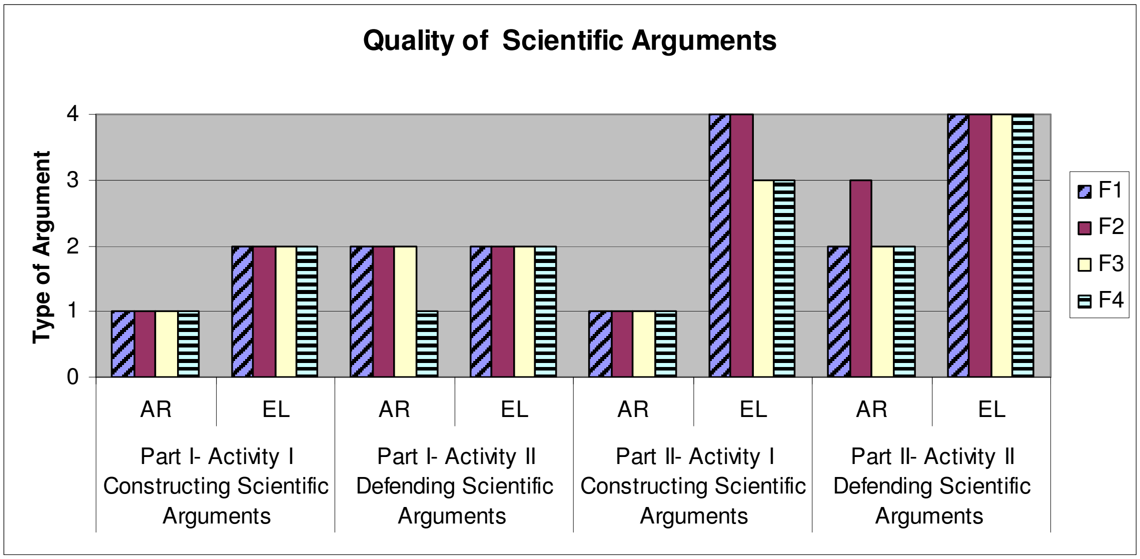
7 Jay: We did the same thing but we just said they are the same because they were so close for the pressure. We put the same number of molecules in the simulation. 250 for each at 175ºK. If you look at the pressure, it is fluctuating up and down. Now what the heavy species for the pressure we get is between .39 [atm] and .46 [atm]. Then, we reset it and put 250 light species. The pressure [of light species] is varying like between .40 [atm] and .44 [atm]. So they [pressures] are working close and their pressures are pretty much the same.

8 Chris: Okay. It is in a range I think. The pressure is in a range. It was slightly higher on the range of this one but they both fluctuated around the same range

Chris (turn 6) demonstrated his group experiment on the "Gas Properties" simulation and pointed out *numerical data* collected from his group investigation. The numerical data that he showed as *empirical evidence* was the amount of the pressures of the same number of heavy and light species at zero gravity (i.e. 2.2 atm for light species and 1.3 for heavy species.) He compared the pressures (*dependent variable*) of heavy and light species in his *Type 4 argument* by means of controlling the number of species, gravity and temperature which were the *independent variables* of his investigation he put into words. Chris's investigation stimulated more extended cognitive engagement of Jay who refuted Chris's claim. Although Chris and Jay (turn 7) did similar investigations to find empirical evidence and justify their claims, they evaluated their findings different. While Chris searched for certain amount of pressure for heavy and light species, Jay focused on the pressure fluctuating in a range. Jay's empirical evidence "now what the heavy species for the pressure we get is between .39 [atm] and .46 [atm]" and "the pressure [of light species] is varying like between .40 [atm] and .44 [atm]. So they [pressures] are working close" was strong enough to *convince* Chris (turn 8) of Jay's claim which was option A.

5.3 Conclusion

In this research I observed the improvement in the quality of students' arguments in scientific argumentation as in Figure 5.5.



AR: Articulation EL: Elaboration

Figure 5.5: Quality of Scientific Arguments in Argumentative Discourses

The Figure shows that the focal group students could not present the highest quality of scientific arguments in Part I. They articulated Type 1 argument with unsupported reasoning when challenged by the driving question in the Activity I. Then, they elaborated their arguments and constructed Type 2 argument with empirical evidence consisting of non-numerical data when challenged by a peer's question or a self-question or when prompted by a teacher question and representation of investigation. They built evidential reasoning-based consensus on their Type 2 argument which seemed enough convincing for the focal group students to defend their claims in Activity II.

In Activity II the focal group students articulated their constructed group arguments in classroom discussions when challenged by the driving question or a counter-argument and when prompted by a teacher question. Only one group appealed to Type 1 argument to defend his group claim, whereas, other groups appealed to their constructed Type 2 arguments. Because the groups did not use numerical data in their arguments, they could not persuade others of their group claims. When prompted by a teacher question, a peer's question or representation of investigation or when challenged by a counter-argument or representation of investigation, they elaborated their Type 2 arguments with a wide range of empirical evidence gathered from the "Gas Properties" simulation to justify their claims. The empirical evidence comprising non-numerical data made it difficult for the focal group students to convince other pairs of the correctness of their claims.

Similar to Part I, the focal group students initially identified their claims and articulated their Type 1 arguments when challenged by the driving question in the Activity I of Part II. The groups did not use empirical evidence from their previous experiences with the "Gas Properties" simulation. Then, they elaborated their arguments when challenged or prompted by representation of their investigations with the "Gas Properties" simulation. Different from the Part I, four focal groups constructed scientific arguments with numerical data. When doing so, two of the groups engaged in a form of systematic investigation in which they considered all independent and dependent variables of their investigations and they constructed Type 4 arguments which got more sophisticated than the other groups' Type 3 arguments. The reason of this situation can be shown that this second opportunity given with Activity I in Part II enabled the participants to understand the importance of presenting data in a similar form to that of the raw data (e.g. numbers) in arguments to persuade their peers of their claims. However, only two groups achieved at Type 4 arguments because they tried to agree on scientific arguments based on evidence drawn from these investigations with the waxing and waning amount of building consensus over time rather than to persuading each other to change a particular viewpoint.

On the other hand, in the Activity II the focal groups articulated their constructed group arguments in classroom discussions when challenged by the driving question or a counter-argument or and when prompted by a similar argument. To defend their group claim, only one group, who constructed Type 4 argument in Activity I, appealed to Type 3 argument with empirical evidence consisting of numerical data. Other focal groups preferred presenting Type 2 arguments which did not allow their audiences to construct a relatively clear picture of the relationships between dependent and independent variables of the focal groups' investigations. Because the groups did not numerically mention all of the investigation variables in their arguments, they could not persuade others of their group claims. When prompted by a teacher question or challenged by a counter-argument or representation of investigation, they elaborated their arguments and used a wide range of empirical evidence. All focal groups shifted from numerical data to empirical evidence and addressed to numerical changes in all dependent and independent variables of their investigations in their Type 4 arguments. As a result, defending their claims with the highest quality of arguments relatively made much easier for the focal group students to persuade other pairs of correctness of their claims.

CHAPTER 6

DISCUSSION AND CONCLUSION

6.1 Introduction

In this chapter I discuss the research findings to address the four overarching research questions that guide this proposed study. To gain an understanding of how interactive computer representations support students in developing arguments I will begin the discussion with comparison of scientific arguments across Part I and Part II. Then, I will provide classroom-based conditions that supported argumentation in this research. At the end, I will finish the chapter with conclusions obtained from this research and several limitations that would affect the results of this research.

6.2 Discussion

Argumentation activities set in science learning contexts can be a vehicle for developing students' reasoning with appropriate scaffolding by teachers. In spite of its centrality to learning of science argumentation is rarely used by teachers in classrooms (Driver, Newton & Osborne, 2000; Erduran & Jimenez- Aleixandre, 2008). The reason underlying this situation is the fact that most teachers lack time to fully design their own argumentation activities or have low pedagogical design capacity for argumentation associated with lack of experience. They need pedagogical content knowledge that includes strategies and knowledge about how to incorporate argumentation into the science classrooms. Therefore, the broad feature of this work has been to design learning contexts that could be used as a reference for preservice and inservice teachers, who need help learning about how to integrate scientific argumentation into their teaching.

Argumentation activities have the potential to help students learn to reason well. Successful reasoning requires students to justify their claims by accounting for all of the available evidence and then, coordinating with the best fitting evidence. That is to say that considering evidence and its implications is generally considered being an essential part of argumentation. Examining the relevance, coherence, and sufficiency of existing evidence enhances the quality in students' arguments while analyzing and evaluating different positions. Hence, the specific feature of this work has been to design argumentation activities in school science contexts that could be a means for supporting students in constructing higher quality of arguments defended with appropriate evidence.

As can be inferred from the above statements, argumentation always occurs in a context where learners exchange their views (Kolstø & Ratcliffe, 2008). The research reported in this paper involved science learning contexts in which high school students used a computer representation as a resource to investigate a topic and attend to one another's ideas about the topic as they made sense of science concepts and theories in a visible environment. The "Gas Properties" computer simulation made the natures of two similar Kinetic Molecular Theory-related phenomena accessible for these students. As in Suthers and Hundhausen's (2003) research, salient components and relationships received more elaboration, promoted effective communication among students, and enhanced student discourse about science concepts and processes in this research. Thus, the results of this study revealed how the use of a computer simulation supported students in developing arguments in scientific argumentation by examining what types of arguments students used, what types of arguments they found convincing, and what conditions helped them improve their arguments.

As emphasized by Driver, Newton and Osborne (2000), there is a need to shift the impression of science away from just the unproblematic collation of facts about the world toward science inquiry where building arguments are concerning the appropriateness of an experimental design, weighting evidence and assessing alternative theories. Different from other studies (e.g. Chin & Osborne, 2010; Simon et al., 2012), competing evidence were not reported to students at the beginning of classes in this research. Instead, students collected empirical evidence by means of designing and carrying out experiments based on the idea they defended as a focal group. When pondering two driving questions in Part I and Part II focal groups generated a set of experiments expanded and revised into the "Gas Properties" simulation. The set of extensions of experiments was impressive both in its scope and its depth. Among the many extensions focal groups tried were: heating and cooling heavy and light gases, modeling the speeds of two gases, introducing gravity into the chamber of the simulation, increasing and decreasing pressure in the chamber, and observing kinetic energy of heavy and light gas molecules. Thus, focal groups conducted investigations with the "Gas Properties" simulation to search for empirical evidence to back up their claims and to construct arguments.

6.2.1 Comparison of Scientific Arguments across Part I and Part II

Students produced different types of arguments as discussing many aspects of two driving questions in Part I and Part II. My comparison of these arguments held the potential to investigate whether or not there was the improvement in the quality of arguments across the Parts. In essence, the quality of students' arguments increased from Part I to Part II since their developing skills to formulate cogent arguments towards the end of Part II. As Berland and Hammer (2012) noted, students have argumentation skills at least in nascent form to evaluate competing claims by using empirical evidence, however, as Simon et al. (2012) stated, they need many opportunities to develop these skills to argue effectively. In this respect, participating in two interventions in this research significantly contributed to the development of the focal students' skills in employment of argumentation. Students consistently formulated chains of reasoning, considered evidence, provided justifications, examined the reasonableness of their assertions, considered alternative perspectives, and questioned the validity and reliability of data. Over time, they constructed progressively more sophisticated, more elaborate and slightly more detailed arguments moving from Type 1 to Type 2 in Part I and then, from Type 1 to Type 4 in Part II.

In Part I focal students were unable to present the highest level of arguments due to developing argumentation skills. Before engaging in their experiments in pairs, students started looking for possible responses to the driving question. Claims were initially identified and reasoning was indicated for why they chose their claims to support but evidence was not provided from their previous experiences with the "Gas Properties" simulation in support of these claims. Their reasoning stemmed from their personal beliefs, intuitions or existing knowledge rather than using evidence to make sense of phenomena, which led pairs to articulate the lowest quality of initial arguments (Type 1 arguments) at the beginning of their pair discussions. Evaluating the strengths and weaknesses of these available arguments allowed focal students to anticipate and appreciate the need of evidence in order to increase the persuasiveness of their group arguments. Pairs proposed the different scenarios depending on the possible conditions in the phenomenon mentioned in the driving question, simulated them on the “Gas Properties” simulation, and collected data as empirical evidence to persuade peers of their understanding.

According to Sampson and Clark (2006), students have difficulty to revolve around the patterns in data but rather tend to give priority to single pieces of evidence that support their theories. In the first activity of Part I, when searching for appropriate empirical evidence to make a reasonable choice between claims, focal students focused on data that they collected without considering a detailed explanation of all patterns observed in their investigations. They also failed to quantitatively control experiment variables and to argue the quantitative relationships between the variables throughout this activity. Thereby, their “Our Argument” worksheets provided little information about how they had arrived at empirical evidence consisting of non-numerical data. Two focal group students attempted to collect numerical data as empirical evidence to justify group claim, nevertheless their attempts remained limited. All focal groups prefer to evaluate numerical data as non-numerical data (for instance, calling the amount of pressure as “a lot” or ‘high’ instead of presenting data with numbers in a similar form to that of the raw data) in their investigations and to interpret non-numerical data as their empirical evidence. The groups eventually ended the construction of their arguments with presenting empirical evidence, which would be qualified in terms of audiences’ perceptions or opinions during classroom discussions.

In other words, the audiences must have trusted these groups' inferences from their investigations.

To achieve the goals of persuading peers of their arguments, all focal groups shared their consensus positions in classroom discussions. The groups were eager to justify their claims and, they articulated and elaborated their arguments with empirical evidence involving non-numerical data. Although this evidence was found upon thought processes with numerical data in the group discussions, they were not sufficient for students to engage in a classroom discourse in which they evaluated each other's inferences in light of alternatives in *a persuasion type of argumentation*. In addition, focal groups failed to communicate their arguments in a persuasive way since they did not put emphasis on the patterns of investigations, which led them to gather empirical evidence. Without being familiar with the groups' experiment designs, it was difficult for peers to rely on plausibility and logic underlying evidence. All of these situations caused hard times for the focal group students to convince their peers of the correctness of their claims during scientific argumentation.

Different from Part I, in the first activity of Part II focal groups, who familiarized with scientific argumentation, had an ability to make judgments about the validity and strength of their group arguments. They elaborated their arguments shifting from numerical data to empirical evidence and examining patterns of their investigations within group discussions. As in Part I, the groups initially declared reasoning for why they chose their claims at the beginning of their group discussions but they did not present any evidence from their previous experiences with the "Gas Properties" simulation. They were willing to put forward their arguments with strong justifications by obtaining empirical evidence from the “Gas Properties” simulation. For this purpose, focal groups carried out experiments to find empirical evidence and to provide the best account of the given phenomenon under study. This time, they often generated a detailed explanation of all patterns observed in their systematic experiments and specified quantitative changes in selected dependent and independent variables. Some statements (e.g. we need to do experiment, let’s see) showed that they became more adept at collecting and summarizing data and, discussing the meaning of data gathered and combined from their experiments with the simulation. The focal group students changed and used empirical data as well as patterns in their investigations as evidence for their claims. They provided reasoning to support their claims based on these data that largely took a form of numbers. Thus, focal group students built a consensus on their claims by presenting more relevant empirical evidence and provided more sophisticated arguments illustrative of Type 3 and Type 4 in the first activity of Part II. This made it relatively easier for them to justify their arguments during the classroom discussions; when they tried to convince other pairs of correctness of their claims in the second activity.

In the extension of group discussions, focal groups followed up by participating in the persuasive classroom discourses to present their group arguments. They defended why their peers should have believed these group arguments by making links between their claims and numerical data in the second activity of Part II. They consistently drew upon the patterns of their investigations and considered quantitative changes in all independent and dependent variables of their investigations to interpret their numerical data. Providing numerical data as empirical evidence with systematic investigations increased persuasiveness of pairs' arguments for their peers who criticized their empirical evidence and what they did in their group investigations.

Developing skill and ability to argue effectively is a long-term process requiring many opportunities to engage in scientific argumentation throughout the curriculum (Simon et al., 2012). In Part II focal students still had lacked experience in the enactment of argumentation in their science classes but they were able to take part in argumentation successfully. I observed improvements in the qualities of focal students' arguments on several fronts. Focal students learned to create convincing arguments illustrative of Type 4, that is, construct and defend their arguments with designing their experiments, generating a detailed explanation of all patterns observed in their experiments, controlling quantitative changes in experiment variables, presenting numerical data as empirical evidence and coordinating empirical evidence with claims. Beyond these improvements they evaluated their peers' alternative data collection processes. They occasionally criticized their peers' arguments by evidencing weak and strong points included in data collection processes.

6.2.2 Classroom-based Conditions that Support Argumentation

These improvements in students' arguments did not spontaneously happen at some junctures where pairs of students had difficulty to examine the design of investigations or the methods used to acquire evidence. In addition to providing similar opportunities in Part I and Part II, a range of classroom-based conditions helped students to reason about evidence and to generate more complete and convincing scientific arguments. Presence of driving questions, peers' questions, self-questions, teacher questions, counter-arguments as well as similar arguments and representations of investigations on the “Gas Properties” simulation helped pairs to articulate and elaborate their arguments in the activities.

When constructing and defending their arguments in Part I and Part II, focal students were challenged by driving questions to articulate their arguments in pairs and in the whole classroom. These arguments consistently involved claims with simple reasoning or claim with reasoning and evidence, which were indication of why their peers should have believed their arguments. First, reasoning without any evidence did not seem sufficiently convincing for students to defend their claims, which stimulated them to put forward their arguments with strong justifications in pairs. They engaged in designing and conducting experiments to find empirical evidence and articulated more explicit arguments consisting of empirical evidence from the “Gas Properties” simulation. Secondly, even though arguments comprised claim, reasoning and evidence in classroom discussions, they never became adequately sophisticated, which made it difficult to persuade other pairs of their claims. Therefore, asking driving questions by teachers and letting focal students present their arguments were not enough to expect that they would construct and defend sophisticated and also convincing arguments.

On the other hand, focal students needed some challenging or prompting conditions such as existence of counter-arguments and similar arguments to participate in the persuasive scientific discourse of proposing their arguments in classrooms. In this research I encountered several cases, especially during classroom discussions. Focal students disclosed their arguments to reinforce each other’s arguments with more empirical evidence when agreeing upon the same claim, or focal students generated their arguments to rebut each other’s arguments with their own empirical evidence when challenged by counter-arguments. First, when focal students were expected to listen to other pairs' arguments carefully, focal students who were agreeing upon peers' conclusions were willing to add more evidence from their arguments to reinforce similar arguments. Following the articulation of similar arguments, focal students might have felt that these arguments from their proponents were not rich enough for them to convince opponents of their claims and to pave the way toward resolving opponents' puzzlements. This condition prompted them to elaborate existing arguments for the same claim with more supportive empirical evidence. Second, while focal students disagreed with peers' conclusions and confused with empirical evidence in counter-arguments, they initially rebutted the conclusions by evaluating the quality of evidence and reasoning presented in these arguments. Some pairs also went further and identified flaws in opponents' investigations, which pointed out the development in their higher order reasoning skills (Osborne et al., 2012b). Afterwards, these students argued their group decisions by providing strong justifications with their own empirical evidence from the "Gas Properties" simulation. To increase persuasiveness of their arguments for the opponents they attempted to mention the patterns of investigations, which had led them to find this empirical evidence, and implicitly discussed the changes in independent and dependent variables in these investigations. Thus, counter-arguments that were brought forward by their peers challenged focal pairs to provide progressively more sophisticated arguments by articulating, elaborating and expanding their arguments to support their group decisions.

Examining the cases in this study in more detail, I encountered some conditions where engaging in representations of investigations helped focal students improve their arguments (Figure 6.1). Externalization of ideas and thoughts with computer representations can raise students' awareness of their own ideas and of alternative explanations in argumentation (Gijlers & de Jong, 2009). Focal students in this research appealed to representations of investigations to build a consensus on a group argument in pairs and increased persuasiveness of their group argument for other pairs in classroom discussions. Focal groups used the "Gas Properties" simulation to gather supportive data, showed it as empirical evidence and elaborated their arguments with this evidence. When empirical evidence was coherent and consistent with their available non-numerical data or numerical data with selected experiment variables, it sufficed focal students to build a consensus on their constructed arguments in pairs but this was not sufficient to convince their peers during classroom discussions. The reason of this case is possible that focal group students provided little guidance about their group investigations to support their audiences in determining how they found the empirical evidence and in evaluating whether the available evidence supported their claims. This case supported the assumption of Berland and Reiser (2008): "…students may find the argumentative goal of defending an explanation against critique more challenging than the explanatory goal of communicating a causal account of an event" (p. 28). In this research focal students found it difficult to defend their arguments with the detailed explanation of all patterns observed in their experiments. They could not persuade others of their claims in scientific argumentation. Hence, two situations appeared to foster a need for elaboration of arguments during class discussions: focal group students *proposed* to represent their group investigations in front of the class to make their arguments visible to peers or their peers who were puzzled by lack of shared articulation of experimental conditions *posed a further demand* such as "show yours" for the representations of their investigations. These proposition or demand led focal students to play intellectual roles such as identifying relevant empirical evidence and coordinating claim and empirical evidence in arguments.

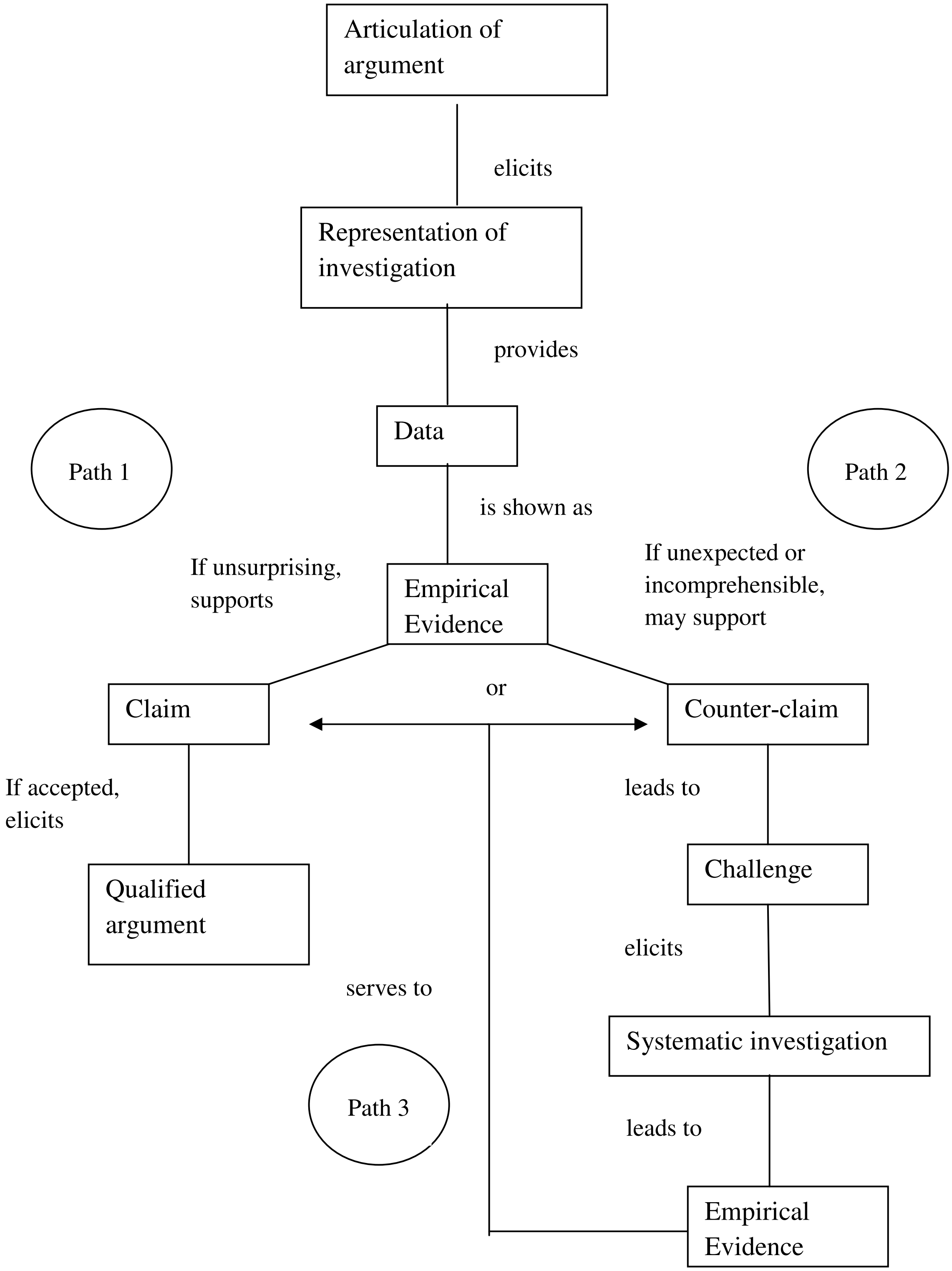


Figure 6.1: A model showing the role of representation of investigations in supporting focal students' elaboration of scientific arguments

This proposition or demand set the stage for what was to come and shaped the discussion that followed (Path 1). They gave a concrete way of convincing peers with showing how focal students arranged experimental conditions on the simulation and how they reached at their empirical evidence to justify their claims. During these representations of investigations if this visual empirical evidence offered no conflict to existing empirical evidence focal group students had already acquired within their group investigations, this visual evidence supported their existing claim and fostered focal group students' arguments to convince their peers. Thus, the representations of investigations helped focal group students participate in qualifying their arguments with visualization of empirical evidence and facilitated focal students to communicate their ideas in a persuasive way.

On the other hand, in some conditions focal students' representations of their investigations worked for counter-claims that other peers supported. While representing their investigations, focal students tried to reach the same findings that they had already acquired in pairs but they could not achieve it, which generated and sustained further talk (Path 2). Since they had difficulty to accurately transfer the patterns of their investigations that they had followed in pairs, they faced unexpected observations violating their expectations and found different empirical evidence in classroom representations. Finding empirical evidence unintentionally justifying counter-claims engendered a sense of challenge in these pairs and led them to become more cognizant of the assumptions about many aspects of the phenomenon in the driving questions. These focal students began to evaluate their findings critically about possible flaws in their investigations, modified some patterns in their investigations, and conducted more systematic investigations in classrooms. That is, their systematic investigations revolved around collecting numerical data with controlling the quantitative changes in independent and dependent variables of their experiments, and showing this data as empirical evidence. Thus, providing a wide range of empirical evidence supporting the same claim helped focal group students to persuade others of their claim or to be convinced with the counter-claim (Path 3).

In addition, as Simon et al. (2012) noted, the groups had different interpretations of the findings in scientific argumentation because group members had different standings for knowledge and problem-solving ability. This research also revealed that even though some focal students conducted similar systematic investigations, they evaluated the findings differently or interpreted the findings of their investigations in a different way (e.g. stating with a constant number instead of a range). This generated a strong resistance between pairs against each other's arguments during classroom discussions and posed a demand for representation of investigations. Focal students who identified the similarities in their investigations did not criticize data collection processes; instead, they critically evaluated the data itself, namely, empirical evidence. Representation of investigations helped them realize that this evidence was yet another way of interpretation of solution, which supported a counter-claim. Thus, elaboration of arguments with representation of investigations eventually led some students to change their minds, to display a relatively higher quality of reasoning, and also, to become convinced with the counter-claim.

All in all, I can summarize the benefits of visualization of investigations concluded from this research as follows:

a) It guides focal students to play intellectual roles that include identifying relevant empirical evidence and coordinating claim and empirical evidence in arguments.
b) It engenders a sense of challenge on focal students' thoughts about the validity and relevance of empirical evidence, and invokes a commitment to the use of systematic investigations for reliable empirical evidence.
c) It stimulates more extended cognitive engagement against each other' ideas via a series of competing empirical evidence comprising the results of systematic investigations.

Thus, the conditions in which focal group students represent their investigations helped these students to improve their arguments by providing a concrete way of thinking.

Counter-arguments, similar arguments, driving questions and representation of investigations do not always stimulate focal students' articulation and elaboration of their arguments in an effective way. Focal students also need to be supported by scaffolds such as peers' questions, self-questions (see Chin & Osborne, 2010, for an extensive review) and teacher questions (see McNeill & Pimentel, 2009, for an extensive review). In this research peer questions usually arose from puzzlement with various aspects of articulated arguments and explanations. If these arguments did not involve plausible empirical evidence, focal group students engaged critically but constructively with each other's arguments and challenged their peers' thinking by asking questions related to findings and processes in their investigations. To respond to these questions, focal students revised their investigations and more carefully observed the system in the "Gas Properties" simulation in order to find more relevant empirical evidence. During this progress, focal students sometimes encountered puzzlement about various aspects of the system, which created a dilemma in students' thinking and elicited new questions, self-questions. In addition to peers' questions, self-questions subsequently encouraged focal students to seek more detailed and comprehensive explanations for these aspects of the system, to search for more accurate empirical evidence, and to participate in elaboration of their arguments by recourse of a clear articulation of this evidence underlying their thinking. The examples of questions spontaneously used by focal students include the following:

- What about it?
- Why do you think that they're going to expand?
- What heat?
- Why is the pressure going up?
- Why don't they [heavy species] wanna start sinking?
- Can you show us your evidence?

Thus, higher-order thinking self-questions as well as peers' questions set stages for developing focal students' ideas into more complete ones and generating more elaborate arguments by adding further details to existing arguments or for changing their minds to support a counter-claim and proposing counter-arguments to their previous arguments. Chin and Osborne (2010) call the second stage as a kind of self-rebuttal to existing arguments, which is an exceptional but significant event in scientific argumentation.

The discussion regarding the results of this research so far uncovered that in optimal cases focal students made publicly different arguments, supported their arguments by making their thinking visible on the simulation, created responses to alternative or similar viewpoints, and asked questions what they were wondering about. Despite the appearance of all these cases, the teachers in this research sometimes encountered the problem that some focal students tended to shy away from articulating and elaborating their arguments in pairs and during classroom discussions. In her research Veerman (2003, pp. 118-119) summarized the causes of this problem that can inhibit students to engage in critical argumentation as follows:

> Students tend to believe in one overall correct solution or show difficulties with generating, identifying and comparing counter-arguments and with using strong, relevant and impersonalised justifications (Kuhn, 1991). In addition, students' exposure of a critical attitude can be inhibited because of socially biased behaviour. For example, students may fear to loose face (e.g. in front of the classmates), to go against dominant persons in status or behaviour (e.g. a tutor), or for what other people think (e.g. that you are not a nice person). Students may choose to avoid social positions by adopting non-implying positions or simply by ignoring the argumentative quality of utterances.

Focal students, therefore, need argumentation-based activities, which include teachers' appropriate scaffolding to prompt critical discussions in school science settings as described in the literature (e.g., McNeill & Pimentel, 2009). In this sense, questions posed by teachers played an important role in encouraging less talkative focal students to articulate their arguments and to evaluate each other's arguments.

Furthermore, teacher questions in this research had different function from initiating discussion which is seen in traditional IRE (Initiate-Response-Evaluate) discourse of science classrooms (McNeill & Pimentel, 2009). Volunteer pairs initiated discussion with vocalizing their arguments and supported these arguments by using the "Gas Properties" simulation in classrooms; but their responses were sometimes disconnected from their peers' ideas or were simple answers to the driving questions or peers' questions. Upon being confronted with a salient contrast between students' thoughts, teachers intuitively recognized the need of students to criticize each other's arguments and asked questions to prompt students' evaluation of arguments by means of assessing existing empirical evidence. In essence, the function of these teachers' questions was to explicitly create a context to support scientific argumentation in which focal students played a role of "critic" in debating investigations and justifications for different claims with their peers. The use of signal words such as "why" and "what" in these prompting questions helped focal students to conduct more systematic investigations, present more elaborate arguments, and criticize each other's argument in an effective way. The examples of questions spontaneously posed by the teachers in this research include the following:

- What is your position?
- So, you're arguing is that?
- What are you doing right now?
- Okay, can you show us?
- What happens?
- What are the differences between earth and space?
- What did you do to get your answer?
- What did you do test it out?
- So, why is it true?
- Do you think the same thing with Ashley?
- Anyone to support that or refute that? What was right or wrong with Sam's and Andy's arguments?

These open-ended but well-structured questions encouraged focal students to disclose their arguments with supportive empirical evidence, to think about the accuracy of their own sources of empirical evidence, to focus their attention on the provided evidence by peers, and to convince each other with a reasonable critic of acceptability of the claim. With teacher questions focal students engaged productively in the same topic for several turns through greater involvement rather than heading for new directions. If they needed, they made their investigations visible on the simulation, modified their investigations and elaborated their arguments with new findings. As a result, these constructed teacher questions improved focal students' higher-order thinking; the questions prompted focal students to weave new findings with their existing findings and to achieve a logical consistency in their ideas.

6.3 Conclusion

This research primarily examined the arguments of four focal group students who used a computer representation in scientific argumentation. The study pursued four research questions, focusing on what type of arguments focal group students used, what types of arguments focal group students found convincing, how interactive computer representations supported focal group students in developing arguments, and what conditions helped focal group students to improve their arguments. To find responses to these research questions I designed a research environment in which four focal group students first participated in pair discussions and then, in classroom discussions to answer two driving questions in Part I (Arguing to explain the behavior of air molecules in space) and Part II (Arguing to compare the behaviors of air and Helium molecules in space). The findings from this research put forward *an inquiry type of argumentation* within focal group discussions. Rather than being a debate between opposing parties, argumentation in focal groups was a way of participants' collectively supporting a scientific claim based on empirical evidence from investigations with the computer simulation and agreeing on conclusions drawn from this evidence. That is, collecting supportive data to show it as empirical evidence was enough for the groups to build a consensus on their arguments. Therefore, none of focal groups tended to construct Type 4 argument in Part I and only two focal groups generated Type 4 argument with the waxing and waning amount of consensus over time in Part II.

On the other hand, the findings from this research revealed *a persuasion type of argumentation* in classroom discussions where the groups tried to win their opponents over to their points of view and, to weaken opposing views with evidence and reasoned arguments using the computer representation. During these processes, confronting with the discrepancy between their point of views and the alternative, led all focal groups to recognize the importance of presenting strong arguments with plausible empirical evidence to convince peers in Part I and, to address all dependent and independent variables of their investigations to produce more sophisticated and convincing arguments, illustrative of Type 4, in Part II.

Furthermore, the findings from this research drew attention to the need of some argument improving conditions during constructing and defending scientific arguments. I found that driving questions, counter-arguments, self-questions, peer questions and representation of investigations were challenging conditions for focal students to articulate and elaborate their arguments. On the other hand, teacher question, similar arguments, peer questions and representation of investigations were prompting conditions for focal students to articulate and elaborate their arguments.

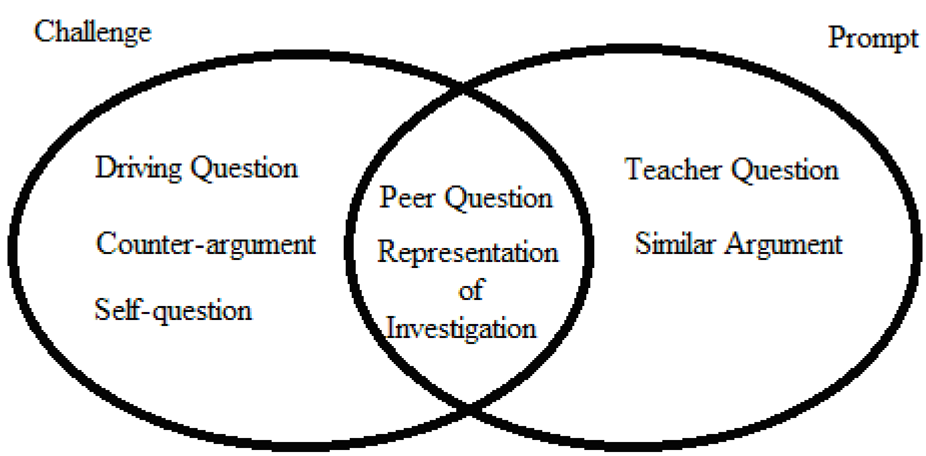


Figure 6.2: Scientific argument-improving conditions

These results highlighted the importance of creating conditions that especially combine the use of peer questions and representation of investigations in a structured way in future researches to meet the need for improving students' scientific arguments.

6.4 Limitations

I considered several limitations that would affect the results of this research:

- I analyzed types of participants' arguments and the persuasiveness of these arguments. I did not directly evaluate student arguments for accuracy.
- I expected that before participating in this research, all participants successfully use the concepts of ratio, rate and proportional relationship, which are the basic concepts for my research. The failure in the use of these concepts would affect the results of this research. This potential limitation was tried to overcome with providing similar opportunities in Part I and Part II.
- Because of the insufficient number of video recorders in this research, I only videotaped the discourse of one pair in each class. Due to likelihood of missing important data, which include other students' construction of scientific arguments in pairs, care should be taken in generalizing these results to other pairs of students.
- I myself recorded, coded and analyzed students' arguments in this research. I believe that with my prolonged engagement in the research setting and intensive immersion in the data, I became the expert judge in coding and analysis. However, to make reliable and valid interpretation

of the data, I utilized from analytic audiences whose roles were to question judgments at all junctures in application of coding schemes.

APPENDIX A

HUMAN SUBJECTS REVIEW QUESTIONNAIRE

Please answer the following questions.

1. How will human participants be used?

Students will participate in learning activities led by a teacher in their usual classroom setting. Activities will require students to argue different viewpoints on physical phenomena.

All activities will be videotaped and later transcribed for close analysis.

2. How have you ensured that the rights and welfare of the human participants will be adequately protected?

By ensuring equitable subject selection, assuring adequate informed consent, assessing and minimizing risks, and maintaining privacy and confidentiality.

3. How ill you provide information about your research methodology to the participants involved?

Before the research, I will inform students about my research methodology. At the beginning of the research I will convince students. I will thoroughly explain the learning activities in which they will participate and the goals of my research. I will describe my videotaping procedure and explain to students I will be available to answer their questions throughout the study.

4. How will you obtain the informed voluntary consent of the human participants or their legal guardians? **Please attach a copy of your consent form.**

Before the first class meeting, students will be explained about the research and given consent forms to be read and approved by their legal guardians.

5. How will you protect the identity and/or confidentiality of your participants?

In transcripts and any other writings, participants will only be identified through pseudonyms. Tapes will be kept in a locked drawer in my apartment. Only one master copy of each classroom meeting will be produced.

APPENDIX B

PARENT/GUARDIAN PERMISSION FORM

Dear Parent/Guardian,

We would like to do a study in our computer laboratory context in order to find out how students reason about science and how teachers can help them reason by integrating technology into their science teaching. Within the scope of this research your son/daughter might work with other students and computers, share his/her ideas with other students, and learn what you can do with science outside schools. Our methods are described in the accompanying permission letter.

We would very much appreciate your permission for your son/daughter to be included in the study.

Sincerely,

Team:

Name of Researcher Name of Advisor Name of Chemistry Teacher

Assent Document for Student Participation in a Research Study

Project Title: Teaching for Reasoning and Understanding Project

Investigator: Tugba Keser (Principal Researcher)

We are conducting a study to examine the best ways to teach for reasoning and understanding in science. We would like to work with your child's teacher to collect some information on science learning. The likely benefits of the study include suggestions for improvement of science teaching and better levels of reasoning and understanding for students. We are asking for your consent to collect this data below.

Parental Permission for Voluntary Participation

My son/daughter volunteers to participate in this study and we understand that:

- He or she may be interviewed briefly after a lesson so that we can determine how the lesson is working.
- Some lessons and interviews may be video or audio tape recorded to facilitate analysis of data. Segments may be shared with researchers or used in teacher training but will not be shared with others.
- Students' names will not be used, nor will they be identified personally in any way at any time in the results from this study. Pseudonyms will be used for each student throughout the presentation of the results.
- The results from this study may be included in Tugba Keser's doctoral dissertation and may also be included in manuscripts submitted to professional journals for publication.
- We may review data collected or withdraw from part or all of this study at any time.
- The curriculum will be part of the regular course of study for the class. However, with regard to the data collection aspects for the study described above, we are free to participate or decline participation without prejudice and without affecting the course grade.

If you have questions or comments regarding this study, please feel free to contact me, Primary Researcher via phone number or via email. You may also contact Reasercher' advisor, Name, at phone number or email.

Parent/Guardian's Signature	Student's signature	Date

If you would like to speak with someone not directly involved in the study, you may contact Linda Griffin at School of Education' Institutional Review Board via email at lgriffin@educ.umass.edu; or telephone (413) 545 685.

APPENDIX C

GROUP WORKSHEET (GAS PROPERTIES)

Group Members:

Write your group's question. Predict its answer. Play with the computer simulation. Write what you did and what your observations and your explanations are.

1. Our question

2. Our prediction

3. What we did on the computer simulation.

4. Our observations

5. Our explanation is that

APPENDIX D

"OUR ARGUMENT" WORKSHEET

Group:

Our position is that the option A/ B/ C (circle one) is correct because …..

Our evidence supports our idea for this are …..

Someone might argue against our idea by saying that his/ her position is the option A/ B/ C (circle one) because ….

We would convince him/ her by …..

APPENDIX E

PART I: FOCAL GROUP 3 "OUR ARGUMENT" WORKSHEET

OUR ARGUMENT

Group: [redacted]

Our position is that the option A/ B/ C (circle one) is correct because .....

Our evidence supports our idea for this are .....

When looking at the simulation ~~when~~ the molecules are at the bottom of the box when the temperature is risen and when the gravity is taken, the molecules expand just as the ~~[illegible]~~ balloon would if taken out the freezer and put in space

Someone might argue against our idea by saying that his/ her position is the option A/ B/ C (circle one) because ....

They would think the molecules would escape due to the temperature change and or difference in temperatures.

We would convince him/ her by .....

~~showing~~ Talking about molecular reaction to temperature with effects ~~of~~ on molecules w/ or w/o gravity

APPENDIX F

PART I: FOCAL GROUP 1 "OUR ARGUMENT" WORKSHEET

OUR ARGUMENT

Group: [redacted]

Our position is that the option A/(B)/ C (circle one) is correct because ..... although it might be colder in space there is no gravity which allows more movement of the molecules

Our evidence supports our idea for this are .....

- w/ gravity and cold the molecules stayed toward the bottom of the container [illegible] less space causing the container to shrink.
- w/o gravity & cold the molecules slow down but they are still able to m[illegible] which would allow the container to increase in size

Someone might argue against our idea by saying that his/ her position is the option A/ B/(C) (circle one) because .... the pressure decreases and the molecules freeze causing them to not be able to move so the ballon will shrink, since it is colder in space it will cause the molecules to freeze even more and stop movement so the ballon will shrink.

We would convince him/ her by ..... saying that although it is colder in space there is no gravity in space unlike earth. So on earth when it gets cold the molecules slow down and get dragged down toward the bottom of the container causing to shrink. However in space there is no gravity so even though they get slow down they are still able to move around which would cause the ballon t[illegible] increase.

APPENDIX G

PART I: FOCAL GROUP 4 "OUR ARGUMENT" WORKSHEET

OUR ARGUMENT

Group: [redacted]

Our position is that the option A/ (B)/ C (circle one) is correct because ... gets Bigger

The molecules expand and would push against wall of the balloon and there is no other atmospheric or any other kind of pressure to force the balloon in. So it will be expand.

Our evidence supports our idea for this are .....

When we added molecules in gravity they had a certain temperature and pressure. When we reduced the gravity to zero the molecules expand and were hitting against the wall.

Someone might argue against our idea by saying that his/ her position is the option (A)/ B/ C (circle one) because ....

The temperature didn't change it all so it will remain the same.

We would convince him/ her by .....

Showing our experiment and looking for what ~~did~~ they did wrong. In this case it was that they blew the balloon in space. or they cooled the balloon down in space or something like that.

APPENDIX H

PART I: FOCAL GROUP 2 "OUR ARGUMENT" WORKSHEET

OUR ARGUMENT

Group: [redacted]

Our position is that the option A/ B/ C (circle one) is correct because .....

A - it stays the same because the combination of no gravity and its cool state will allow the molecules to float freely

Our evidence supports our idea for this are .....

in the simulation, added gravity causes the molecules to pull to the bottom.

Someone might argue against our idea by saying that his/ her position is the option A/ B/ C (circle one) because .... the slow moving molecules will make the balloon lose volume

We would convince him/ her by ..... showing them in the simulation that the molecules move freely in 0 gravity

APPENDIX I

PART II: FOCAL GROUP 3 "OUR ARGUMENT" WORKSHEET

OUR ARGUMENT

Group: [redacted]

Our position is that the option A/ B/ C (circle one) is correct because .....

Our evidence supports our idea for this are .....

When useing the simulation it took more molecules or (pumps) of Helium to get an equal or slightly higher ~~than~~ pressure of an air filled balloon

Someone might argue against our idea by saying that his/ her position is the option A/ B/ C (circle one) because ....

A) Argues both balloons pressures are =

disproves this with the simulation

8 pumps of Heavy species — 4 pumps of light species to get = or higher then pressure

We would convince him/ her by .....

The conditions of both balloons are = amount of molecules or pumps. disproving A and B.

APPENDIX J

PART II: FOCAL GROUP 4 "OUR ARGUMENT" WORKSHEET

OUR ARGUMENT

Group: [redacted]

Our position is that the option A/ B/ C (circle one) is correct because .....

Helium is moving faster than air.

Our evidence supports our idea for this are .....

We simulated that when we have 500 molecules and take off gravity to simulate Helium and the pressure came to 2.2 Atm. Then, when we threw gravity to the equation, the pressure fell lower than Helium's pressure (1.2) so, the air-filled balloon is less than the Helium

Someone might argue against our idea by saying that his/ her position is the option A/ B/ C (circle one) because ....

They might believe that when the balloon is heavier so there is more pressure toward the bottom, which is greater than heliums pressure on the whole balloon.

We would convince him/ her by .....

the molecules in the balloon would be all over the balloon but most of the molecules will be on the bottom, but not all of them will be.

APPENDIX K

PART II: FOCAL GROUP 1 "OUR ARGUMENT" WORKSHEET

OUR ARGUMENT

5-16-13

Group: [redacted]

Our position is that the option A/ B/ C (circle one) is correct because .....

If the volume of the containers are the same and they are in space so there is no gravity then the pressure is based solo on the movement of the molecules which is about the same

Air = .54
Helium = .5

Our evidence supports our idea for this are .....

- the pressure for 100 heavy (air) molecules is .54
- the pressure for 100 light (helium) molecules is .54

Someone might argue against our idea by saying that his/ her position is the option A/ B/ C (circle one) because .... air molecules are heavier and bigger which would create more pressure

We would convince him/ her by .....

* although the air molecules are bigger and could create more pressure, helium molecules are lighter, which allows them to move around more and create the same amount of pressure as the heavy air molecules

APPENDIX L

PART II: FOCAL GROUP 2 "OUR ARGUMENT" WORKSHEET

OUR ARGUMENT

Group: [redacted]

Our position is that the option A/ B/ C (circle one) is correct because .....

Because the temperature of space will make the helium and air Similar

Our evidence supports our idea for this are .....

we put 400 heavy species and 400 light (at different times) and kept them at the same temperature and the pressure was relatively close.

Someone might argue against our idea by saying that his/ her position is the option A/ B/ C (circle one) because ....

That heavy Molecules add More Pressure while light Molecules adds less pressure.

We would convince him/ her by .....

They're at normal temperature but if you Make it colder (because space is cold) it will cause the Pressure of the two to be Similar.

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