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ANALOGICAL-MAPPING-BASED COMPARISON
TASKS AS A SCAFFOLD FOR ARGUMENTATION

A Dissertation in
Curriculum and Instruction

by
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ABSTRACT

Given the centrality of the argumentation process to science and consequent importance to science education, inviting science students to engage in argumentation and scaffolding that argumentation in order that it lead to learning and not frustration is important. The present research invites small groups of science content learners (54 preservice elementary teachers at a large research university) to use analogical-mapping-based comparison tasks in service of argumentation to determine which of two possible analogues, in this case simple machines, is most closely related to a third. These activities and associated instruction scaffolded student small-groups' argumentation in four ways: 1. supporting new analogical correspondences on the heels of prior correspondences; 2. discerning definitions and descriptions for simple machine elements; 3. identifying and dealing with ambiguity in potential correspondences; and 4. making reflections on prior analogical correspondences in service of their final arguments. Analogical-mapping-based comparison activities scaffolded student small groups both in their argumentation and in content learning about simple machines. Implications, limitations, and directions for future related research are also discussed.
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Chapter 1

Introduction
Introduction

In order to understand science and the process of science that gives rise to new scientific understandings, science learners must understand argumentation (Driver, Newton, & Osborne, 2000; National Research Council (US), 1996). Argumentation can be defined as the process that gives rise to an argument. Differing from the word “argument” in everyday use, a scientific “argument” is a proposed explanation for a scientific phenomenon. A given argument is generated not only to explain but also to persuade other scientists of the appropriateness of the argument (Duschl & Osborne, 2002).

The National Science Education Standards (1996) state that students must be able to:

- Recognize and analyze alternative explanations and models
- Formulate and revise scientific explanations and models using logic and evidence
- Communicate and defend a scientific argument (pp. 175-176)

These show the importance placed on the argumentation practice and necessary related skills such as “[r]ecogniz[ing] and analyz[ing] alternative explanations and models” (and “[f]ormulat[ing] and revising scientific explanations and models…” (p. 175). However, promoting argumentation that leads to learning continues to be far from straightforward in science classrooms (Berland & Reiser, 2011; Sampson & Clark, 2008; Sampson, Grooms, & Walker, 2011; von Aufschnaiter, Erduran, Osborne, & Simon, 2008; Walker & Zeidler, 2007).

Promoting scientific argumentation that leads to learning in classrooms can be challenging, since students have difficulty talking and arguing about what they do not understand (i.e., new science concepts). Von Aufschnaiter et al (2008) sum up this issue: “[l]t is inappropriate to ask students to engage in argumentation around scientific concepts and theories when they lack any background knowledge” (von Aufschnaiter et al., 2008, p. 117). Something of a paradox emerges in which argumentation can lead to learning, but in order to
argue about a science concept, it must first be understood somewhat. Clearly, supporting students in argumentation is necessary, especially in instances where they do not have a clear understanding of the science content. The present research provides such support to students’ argumentation by incorporating and building on past research in the areas of scaffolding and analogy.

Much research has focused on the notion of scaffolding as a way to provide necessary support for argumentation in science classrooms, (Cho & Jonassen, 2002; Clark, Stegmann, Weinberger, Menekse, & Erkens, 2008; Emig & McDonald, 2010; Quintana et al., 2004; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2003). Scaffolding can be a helpful metaphor for understanding how to assist and support students’ argumentation. It is informed by the idea of Vygotsky’s Zone of Proximal Development, which refers to the conceptual space between what a person can do without assistance compared to what he or she can do assisted (Vygotsky, 1978). This assistance, coming from an abler peer, is referred to as scaffolding (Vygotsky, 1978; Wood, Bruner, & Ross, 1976).

Scaffolding students has evolved beyond providing direct assistance from a more able peer to include expertise that is embedded in the task itself (Reiser, 2004; Wood et al., 1976). Scaffolding for the purposes of this research will mean “problematizing” and “structuring” science content and argumentation (Reiser, 2004) with an eye toward “channeling” and “focusing” student attention (Pea, 2004). Reiser (2004) suggests that “problematizing” content means to turn content into a problem to be understood and solved. “Structuring” means to impart order to this process to make it doable for students. He suggests that “problematizing” and “structuring” are in tension, since to “problematize” too much can be to “structure” too little and vice-versa (Reiser, 2004).

The present research puts forth and evaluates a scaffold in the form of “analogical-mapping-based comparison activities” with an eye toward scaffolding student small groups. Specifically, this scaffold was designed to use analogies to problematize and structure simple
machine content and the argumentation process in order to channel and focus student attention in a way that makes learning more likely and frustration less likely.

Why analogy? Analogy is found to be an effective communication and thinking device that is spontaneously used by both experts and everyday people (Clement, 1981; Dunbar, 2001). Dunbar (2001) found that when everyday people understand a concept, they can easily convey a great deal of information about it communicating an analogy without much problem. Other research has found that everyday people can increase their understanding of a new concept when invited explicitly to compare using analogy (Gick & Holyoak, 1980).

Why comparison? Comparison has the power to make important features salient. Bransford et al (1989) provide an example in which a single house is viewed (see figure 1.1). When viewing the single house much will likely go unnoticed. For example, the fact that the house has two windows, one door, a chimney, etc. are commonly noticed features. But, the facts that the chimney is of a certain size or that the windows are of a certain size, however, are not likely to be noticed when viewing the single house. But, when multiple houses (figure 1.1b), which Bransford calls a “contrast set,” are viewed together, those features become salient. The Northern House, for example, has a larger chimney, whereas the Cheerful Living Room house has a larger living room window. These features become salient only when compared with other houses.
Bransford suggests that gaining expertise in one’s field depends upon gathering mental models of various scenarios, models, concepts, circumstances, or situations over time. Only when one has accumulated a large body of such things can one finely discern, apply relevant terms, and correctly anticipate future developments based on past analogues. The ability to discern between cases also depends on a high degree of alignment between them (Markman & McMullen, 2003; Mussweiler & Epstude, 2009). Comparing a picture of a high rise building, for example, would not likely have made chimney size or window size salient on the single house in figure 1.1. The contrast set would have little alignment.

Analogy implies alignment. One important existing body of work in science education that relies on content with a high degree of alignment is that of analogy and analogical models. Analogical Mapping is defined by Gentner (1983) “is a comparison in which relational predicates, but few or no object attributes, can be mapped” (p. 156). This means that relationships between elements may be the same but the elements themselves are different. Mapping analogies is the process of identifying elements of one concept or scenario and making a correspondence between that element and an element on another scenario. Consider the example in figure 1.2. When relationships are considered, the person on top best corresponds to the tree on bottom, since both are restraining the dog. The functions of each become salient, reducing the possibility that superficial features such as appearance are considered. Thus, undertaking the
process of analogical mapping makes it less likely that someone would say the person on top best corresponds to the person on bottom; they have different functions.

The present research makes use of analogical mapping and comparison tasks by offering students the invitation and opportunity to use analogical mapping to compare two possible analogues (see figure 1.3) to determine the best one, or the one with the most alignment. This type of activity is offered and evaluated seven times over seven weeks in the present research as a method of “problematizing” and “structuring” student content learning through argumentation.

The guiding questions for the present research examine the process of analogical mapping to scaffold scientific argumentation, specifically:

- What does it look like to scaffold student small-group argumentation in science classes by inviting them to argue in favor of one potential explanatory analogy over another?
- How does this type of comparative intervention affect students’ interactions with one another?

These questions were developed with an eye toward generating a rich qualitative description of students’ science discourse that can inform instruction and curriculum development.

The bulk of the data used to answer these questions comes from transcripts of small-group (about 4 students) argumentation and discourse analysis thereof. In these, fifty-four preservice elementary teachers in a science content course engaged in analogical-mapping-based comparison activities during a unit that deals with simple machines.

This dissertation’s following chapters will be on each of the following: a review of relevant literature; methods and design rationale; results and analysis including examples from
transcript excerpts and related analysis; and a conclusion chapter describing the implications, contribution, limitations of this work and directions for future related research.
Works Cited


Chapter 2

Literature Review:

A Case for the Present Research

Drawing from:

Argumentation, Scaffolding, and Analogy Research
Introduction to Literature Review

As the present research seeks to use analogical-mapping-based comparison tasks as a scaffold for student argumentation it will need to draw on three principal bodies of scholarship: argumentation, scaffolding, and analogy. Using existing literature, the case will be made that analogical-mapping-based comparison tasks have potential to improve students’ science learning argumentation. First, the need for and importance of communication and argumentation in science education will be discussed. Next, scaffolding argumentation will be discussed. Finally, analogy research will be discussed with an eye toward highlighting its potential contribution to scaffolding argumentation.

The Need for Argumentation in Science Education

Like scientists actually doing science in the field, students learn best when they are encouraged to talk with one another while attempting to understand by communicating around content (Driver, Newton, & Osborne, 2000; Mortimer & Scott, 2003; National_Research_Council, 2007; Schuble, Glaser, Duschl, Schulze, & John, 1995). Unfortunately, not enough communication occurs in the science classroom, as science instruction has tended to take the form of telling (J. S. Brown, Collins, & DuGuid, 1989; Bruner, 1968). Science education should move away from teaching as telling and toward a model emphasizing learning and communication that places science concepts in a larger relevant context (J. S. Brown et al., 1989; Driver et al., 2000). Argumentation can move science education in this direction.

In science education, argumentation can be thought of as persuasion of one’s peers with intent to explain and understand (Driver et al., 2000; Kuhn, 1993). The product of argumentation is an argument that explains something (Duschl & Osborne, 2002, p. 41; Simon, Erduran, & Osborne, 2006, p. 237). So, argumentation is a process, and an argument is a product of that process.
Unfortunately, like dialogic communication generally, argumentation is rare in science classrooms. In science classes, “abstract decontextualized pure science” is favored by teachers as it provides for better message control and perceived efficiency in conveying content (Aikenhead, 2006; P. L. Brown, Abell, Demir, & Schmidt, 2006). Controversy and argument in science generally are deemphasized. To that end, use of the passive voice is encouraged even as early as high school lab reports. Lemke (1990) states, “Experiments are conducted, elements are represented; you don’t have to say that somebody conducted them or represented them.” (p. 130) The facts seem to speak for themselves. It is little wonder that argument and controversy are swept aside in science classroom as students become accustomed to being presented with the one right answer. Science is presented as the way the world is rather than a hard fought set of understandings produced by social processes that have explanatory power and often limitations at the same time. Usually, however, time is not set aside for argumentation, interpretation, or just plain discussion to occur (Driver et al., 2000, p. 307; Scott, Mortimer, & Aguiar, 2006, p. 606). Curricula for teachers is often so structured and predetermined that teachers are not easily able to work in activities that can take time away from content or activities for which teachers are accountable (Simon et al., 2006, p. 238). Even when argumentation is the explicit focus of activity in a science class, students have difficulty questioning and negotiating concepts (Carlsen, 2007, p. 64).

Providing students the opportunity and the support to do argumentation in science class not only can enhance their science content knowledge, but also their understanding of the scientific process of knowledge generation (Lawson, 2003; Sampson & Clark, 2008). That is to say, students can gain a better appreciation that scientific theories do not simply establish themselves as accepted truths without controversy. By doing argumentation in the classroom, students can come to realize that science progresses through competing explanatory theories being presented and defended, sometimes in heated debates that can last for years or decades. In both the classroom and science generally, argumentation is a process that allows for the
comparing and ferreting out of theories or models that explain a given concept better than other, less adequate, theories.

Evolving Criteria for the Elements of Argumentation

An important early work dealing with how to talk about and understand argumentation was Toulmin’s (1958) *The Uses of Argument*. In it, Toulmin identifies the key elements of an argument. According to him, these are: claims, data, warrants, qualifier, rebuttal, and backing (pp. 91-96). He defines a *claim* as the “conclusion whose merits we are seeking to establish” (p. 91). *Data* are the “facts we appeal to as a foundation for the claim” (p. 91). *Warrants* mean statements that “can act like bridges, and authorize the sort of step” (p. 91). An “explicit reference to the degree of force which our data confer” is a *qualifier* (p. 93). A *rebuttal* refers to “conditions of exception” (pp. 93-94). And finally, *backing* provides authority to warrants (p. 96).

Although Toulmin’s work still informs practice today, some researchers have experienced problems with the framework (Duschl, 2008; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; McNeill & Krajcik, 2007; Sampson & Clark, 2008, 2009; Walker & Zeidler, 2007). For instance, it is not always easy to distinguish between some of Toulmin’s categories, such as a warrant and backing. And, often warrants and backing are missing completely from student argumentation. Students speaking together in a shared context assume that other students are already aware of many of the same things they themselves are (M. Pilar Jimenez-Aleixandre et al., 2000; Kelly & Brown, 2003; Kelly, Drucker, & Chen, 1998). Kelly et al (1998) state, “If a student feels her laboratory partner understands a given concept, strategy, or rule for use of a term, then she may not feel compelled to provide an explicit warrant” (p. 867). Anderson et al (1997) offer, “to say less than necessary is to risk leaving the listener confused and to permit the inference that you are being deceptive. To say more than necessary wastes time and may be considered boring or patronizing” (p. 138). What is saying too much and what is saying too little remains a difficult question for students and observers alike. Regardless, it is clear that much
goes unsaid and this can be a problem for researchers attempting to promote or categorize and describe student argumentation. We cannot be quickly and easily aware of what other students do share or do not share as a context. To that end, communication before multiple audiences, as Kelly and Brown (2003) suggest, might be of benefit in argumentation. What was once considered by students to be shared knowledge must be clearly articulated to an uninitiated audience. This of course helps to make thinking visible and promotes better articulation of ideas by students. Yet, the categorization dilemma remains. When exactly does a backing become a warrant, for example?

Along with the ambiguity in distinguishing some of Toulmin’s categories from one another, there are other things Toulmin’s categories leave out altogether. For example, appeals students make to authority or analogy are not well accounted for (Duschl, 2008). Also, to what extent students should be taught to participate in argumentation as an end in itself vs. use it to explore and learn specific content is under debate.

Much work has been done on proposing what exactly is important to consider in argumentation and, perhaps more importantly, on encouraging and supporting argumentation among students (Cho & Jonassen, 2002; Duschl & Osborne, 2002; Sampson & Clark, 2008, 2009; Walker & Zeidler, 2007; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2003). In a work entitled Designing Argumentation Learning Environments by Jimenez-Aleixandre (2008) we can see Toulmin’s influence. Jimenez-Aleixandre (2008) suggests that in argumentation in science classes, students should:

1. generate products or answers
2. choose among competing explanations
3. back claims with evidence
4. use criteria to distinguish good from poor arguments
5. talk and write science
6. attempt to persuade others or to reach an agreement with their peers (p. 97)

And, Sampson and Clark (2006), from an analysis of recent research, synthesized the following list of criteria that had been used in examining the quality of scientific arguments by various researchers:

1. Examine the nature and quality of the knowledge claim
2. Examine how (or if) the claim is justified
3. Examine if a claim accounts for all available evidence
4. Examine how (or if) the argument attempts to discount alternatives
5. Examine how epistemological references are used to coordinate claims and evidence (pp. 658-660)

Both of these lists speak to the notion of quality in student argumentation in science. Jimenez-Aleixandre’s work was intended to support the design of argumentation environment, whereas, Sampson and Clark’s list was synthesized from different researchers’ approaches to evaluating arguments. Both, however, can provide guidance in addressing both analysis and in providing criteria for creating a classroom environment conducive to argumentation that produces both content learning and argumentation process learning.

In both lists we see Toulmin’s influence. For example, in both lists we see that supporting claims is important and that interaction and engagement between students and content are emphasized. Note, however, that a troubled spot for Toulmin-based argumentation research, Toulmin’s warrants and backing, are not present. In Sampson and Clark’s criteria 2, “examine how (or if) the claim is justified,” and in Jimenez-Aleixandre’s criteria 3, “back claims with evidence,” we see the importance of linking claims and arguments to evidence and available information. There is also emphasis on getting students to evaluate how well evidence does or does not support a given claim. (c.f., Sampson and Clark’s criteria 2 and 3, and Jimenez-Aleixandre’s criteria 4) We see that comparing claims and respective evidence to other claims and evidence is important (c.f., Sampson and Clark’s criteria 3 and 4, and Jimenez-
Aleixandre’s criteria 2). We see that working toward genuine consensus in a student group is also important (c.f., Jimenez-Aleixandre’s criteria 6). Implied by some criteria (c.f., Sampson and Clark’s criteria 4 and Jimenez-Aleixandre’s criteria 2 and 4) is the importance of rebuttals in argumentation. Other researchers have suggested that the quality of argumentation increases when rebuttals are present. For example, Erduran et al (2004) state, “conversations with rebuttals are, however, of better quality that those without given that individuals who engage in talk without rebuttals remain epistemically unchallenged” (p. 926). The criteria presented above, when taken together, speak to the importance of a dynamic environment with communication and shared meanings in which alternative competing explanations are explicitly compared and evaluated and from them a best explanation is put forth by students.

Jimenez-Aleixandre’s (2008) criteria were used to inform the design of this work, as they are comprehensive, clear, concise, and easily distinguished from one another. Jimenez-Aleixandre’s criteria allow for student utterances and actions to be more easily categorized than with Toulmin’s criteria. Also, Jimenez-Aleixandre’s criteria identify features of argumentation that suggest the importance comparative thinking.

Both criterion 2, “choose among competing explanations,” criterion 4, “use criteria to distinguish good from poor arguments,” and criterion 6, “attempt to persuade others or to reach an agreement with their peers,” speak to the centrality of comparison in argumentation.

Getting students to do the elements of argumentation listed above is not without problem, however. Consider the need for scaffolding argumentation.

Scaffolding Argumentation

Supporting science learners in argumentation is important. Von Aufschnaiter et al (2008) state, “It is inappropriate to ask students to engage in argumentation around scientific concepts and theories when they lack any background knowledge” (von Aufschnaiter, Erduran, Osborne, & Simon, 2008, p. 117). Students do not discuss well what they do not yet
understand. Although, students are expected to learn through argumentation, since they do not argue about what they do not understand, argumentation can result in frustration. Something of a paradox emerges. “So the paradox is that in order to find out if our understanding is ‘true’ we would have to know what we were trying to understand before understanding it” (Wallace & Louden, 2003, p. 558). This can lead to student frustration. In argumentation, student claims can go unrebutted and meanings can go unshared between students; communication may not proceed toward explanation and learning. Under these circumstances, argumentation will not produce the desired learning. Clearly, students must be helped, or more specifically, scaffolded, if argumentation is to lead to learning.

Scaffolds are considered to act within Vygotsky’s zone of proximal development (ZPD) (Vygotsky, 1975). Vygotsky’s ZPD is a performance by a student that is just beyond their current ability to do unaided. With the aid of peers or a teacher, however, a student can achieve a given behavior or performance. A scaffold fits into Vygotsky’s ZPD because it is a temporary support that can be offered to a learner to allow for a performance objective to be met, and in the process allow for better learning and understanding (Mascolo, 2005; Pea, 2004; Rosenshine, Meister, & Chapman, 1996; Wood, Bruner, & Ross, 1976). Wood et al. (1976) are credited with defining the term scaffold as a “temporary support.” They further state, “a scaffolding process that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts” (Wood et al., 1976, p. 90).

In the argumentation context, scaffolds can be applied to improve learning and argumentation performance. Cho & Jonassen (2002) offer the following modification of Wood et al’s definition: “Scaffolds are temporary frameworks to support students’ performance beyond their capacities, in this case, constructing arguments” (p. 6).
Types of Scaffolds

Scaffolds can take various forms. Mascolo (2005) asserts that there are three general types – social, ecological, and self. Social scaffolding, Mascolo asserts, “refers to the processes by which co-regulated exchanges with other persons direct development in novel directions” (p. 189). These can be: prompting and encouragement; modeling; and/or performing joint activities with another person. Ecological scaffolding, according to Mascolo, “refers to the ways in which one’s relation to or position within the broader physical and social ecology moves action toward novel forms” (p. 190). Ecological scaffolding can be accomplished through positioning – standing on a ladder while picking an apple, for example – or through the task being organized or structured either naturally or by someone else. Self scaffolding is the things that we might do for ourselves to make a task more manageable, such as arranging scrabble letters variously in the hopes that a word might more easily be found. Self scaffolding could also be the application of prior knowledge to newer situations. A professor, for example, might use a former syllabus to write a new one (p. 194).

All of Mascolo’s scaffolding types are important in learning science. And, as educators we must bear all types in mind when designing learning environments. We can, of course, make students aware of various processes that might help them to self scaffold. Also, we can put them in contact with other students who might socially scaffold them. However, in designing an educational context, emphasis is best placed on ecological scaffolding, or a scaffold embedded in the task itself, and how it can support argumentation.

Problematizing and Structuring

“Problematizing” and “structuring” a task can provide an ecological, or embedded, scaffold to students (Reiser, 2004). To problematize, in this case, means to turn content into a problem, as opposed to simply presenting it in a lecture. Problematizing a task can “provoke learners to devote resources to issues they might not otherwise address” (Reiser, 2004, p. 282).
Using a task in which there is no one correct answer can problematize content. For example, in one such intervention, students were shown contradictory documents that stated that an orca (killer) whale is dolphin, while also viewing other documents and texts that stated that it is a whale (R. A. Engle & Conant, 2002). Is an orca a whale or a dolphin? An ambiguous task such as this one problematizes content and scaffolds students by getting them to examine and talk about features like dorsal fins, teeth, etc. in making claims and evaluating evidence. These features might normally be acknowledged by students (or not) and forgotten in a moment, rather than talked about and analyzed over time as when the material is not problematized in such a way.

Structuring a task, on the other hand, means to embed certain features that make it manageable, such as asking questions in a certain order to make patterns salient, automating certain aspects with computers (e.g., graphing software), or providing tools or representations to use. Reiser points out that structuring and problematizing are in tension with one another; to problematize too much can be to structure too little and vice-versa (Reiser, 2004, p. 273). Specifically, the structuring of a task for students to allow it to be more easily done could lead to less problematization and thus less to talk about for students. But, other times scaffolding students by giving them tools such as graphing programs can reduce time spent on extraneous tasks and help increase the proportion of time spent on activities leading to new learning.

According to Pea (2004), the goal of scaffolding students is to channel and focus student attention. It is advantageous to channel and focus student attention with the task for reasons of efficiency. Modeling effective argumentation to individuals or groups, for example, each and every time could be very time consuming. And without channeling and focusing, students can attend to superficial features or parts of a task to the detriment of the intended learning goal (Holyoak & Thagard, 1995). They may become bogged down in calculations or other secondary tasks that are not germane to the new learning.
How to Scaffold Argumentation?

Given the importance of scaffolding and the necessity of embedding the scaffold in the educational task itself, our question now becomes how best to focus and channel student attention toward maximum learning. Pea (2004) offers that scaffolds are best informed by “the nature of learning as it is spontaneously structured outside formal education” (p. 446). Since often argumentation does not lead to desired learning, and since channeling and focusing student attention by problematizing and structuring the argumentation task are important components of productive argumentation, then it seems that, as educators, our job is to be informed by learning as it occurs outside the classroom.

Learning as it naturally occurs has a rich, detailed, relevant, and immediate context filled with things to point to and compare, people at our sides sharing a similar (perhaps) point of view attempting to work towards similar understanding goals, and the possibility for meaningful interaction with our immediate environment (J. S. Brown et al., 1989; Lave & Wenger, 1991). Thus, it seems our job as educators attempting to scaffold argumentation is to provide these things for our students, particularly a shared rich and detailed context in which argumentation leads to meaningful and productive interaction leading to learning.

On the one hand, a given argumentation task in science class will come and go. But what about the scaffold? Should a scaffold be something that uniquely helps students to the task and then is discarded? In the case of scaffolding by teacher encouragement and modeling, the answer would seem to be an obvious yes. We do not expect our teachers to be there by our sides years from now offering the same insights. And, since a scaffold is often embedded in the task directly, it would seem that in this case too, the scaffold is not transferrable.

Pea (2004) distinguishes between two types of phenomena that people are really talking about when they refer to scaffolds. The first he calls scaffolding with fading. This would be something like teacher coaching and encouraging. The scaffold is offered, helps the student, and then is eventually faded, or removed (Pea, 2004, p. 431). Ideally, the student was enabled
by the scaffold to perform and learn the task due to the scaffold. It is then removed and the student, having learned the necessary technique, is able to continue the performance unaided. In this scenario, the scaffold goes but the learning stays.

Pea asserts that it is worth distinguishing between scaffolding with fading and something he calls “distributed intelligence.” Distributed intelligence, Pea argues, is often called a type of scaffold. But, Pea says, it is not. Rather, Pea says, it is a “much more pervasive form” of support (Pea, 2004, p. 431). He asserts that teachers and researchers alike use

“scaffolds-for-performance in a way that will require them to continue to be used by the learners to be able to have them deliver the performances that are desired. Thus, there is distributed intelligence, not scaffold-with-fading.” (Pea, 2004, p. 438)

Pea goes on,

“Learning to scale heights without stairs, compose a sitting position without a chair, and unaided fast motion in the air [as in an airplane] are not goals of these scaffolds, and no one expects fading to be an integral part of the use of stairs, chairs, and planes as scaffolds.” (Pea, 2004, p. 439)

So an airplane will never be “faded” allowing for unaided flight, for example. And, students will likely never be without a calculator or a computer for real-life tasks in the future. Pea states,

“Such fading, I argue, is an intrinsic component of the scaffolding framework: Without such a dismantling mechanism, the kinds of behaviors and supports that have been more recently described” are distributed intelligence (Pea, 2004, p. 431).

What does this mean for argumentation scaffolding? Should an argumentation scaffold necessarily be faded? According to Pea, if we are to call it a scaffold, then the answer is yes. Pea’s goal, after all, was to emphasize the need to differentiate between “scaffolding with
fading” and “distributed intelligence.” The latter contains the *embedded knowledge of countless people* and is not meant to disappear allowing unaided performances ever after. Clearly, whether one considers a calculator or Microsoft Excel®, for example to be a scaffold or not, they are worth students’ time to learn about and use. Pea’s distinction is useful in that it begs the question, how long should a scaffold last? And, can “distributed intelligence” be evaluated as a type of scaffold?

Yes, distributed intelligence is embedded in our understandings in countless ways. No one alive today can claim to have invented the meter or the inch, yet all use these standards. Most of us did not create software that scaffolds our performance in many of our daily activities, yet if it is removed the performance it allows for will not be accomplished. Instead we go through job update training to stay up to date with current versions of software. We form groups or communities around the use of software. These software programs become agreed upon standards for understanding, talking about, or rendering the world.

The use of distributed intelligence as a scaffold is certainly well within Vygotskian socio-cultural theory tradition, which emphasizes the socially situated nature of knowledge. (Vygotsky, 1975) Scaffolds in the form of software, for example, after all, are brought to us by others in order to help us with our work. In this way they enable us to perform within our ZPD. They are created by groups of people and worked with by groups of people to make our jobs and lives easier. Not only is embedding distributed intelligence in student argumentation tasks in keeping with the Vygotskian tradition, it is essential.

Software as a Scaffold

Software-based scaffolding has some parallels to the scaffolding in the present research, since it shares many of the same goals and techniques. Specifically, students have been scaffolded by computer programs that facilitate comparison, channel and guide student attention through questioning, and problematize and structure tasks for students (Cho &
Jonassen, 2002; Clark, Stegmann, Weinberger, Menekse, & Erkens, 2008; Kelly & Crawford, 1996; Quintana et al., 2004; Zembal-Saul et al., 2003). Sometimes the programs are sometimes very specific to the immediate task at hand (e.g., Galapagos Finches Software). Other times however, these programs have much in common with programs that can organize, graph, and collate data more generally, such as Microsoft Excel ® and Microsoft Access ®. These programs will not likely be abandoned by students anytime soon. Consider some research on computer based scaffolds.

Zembal-Saul et al (2003) posed the following research question, among others: “In what ways do the scaffolds embedded in the Galapagos Finches software influence the development of pre-service teachers’ arguments?” (p. 438). The software allowed students “to explore the data, it automatically generates graphs so that learners can focus on analyzing the data rather than constructing graphs. This scaffolding strategy is called automating portions of the task.” (Zembal-Saul et al., 2003, p. 442) Their larger goal was to help answer the question of,

“how to support learners as they participate in complex, data-rich investigations of scientific phenomena that require giving priority to evidence and constructing and evaluating scientific arguments.” (p. 438)

To do this they provided students access to Galapagos Finches software and asked them to create arguments on natural selection and evolution using it. The researchers analyzed electronic artifacts that students generated, videos of student pairs generating and refining their arguments, and student presentations of their arguments to the class. Findings state that when students were evaluated on use of evidence, the students compared favorably to their peers in other literature (Zembal-Saul et al., 2003, p. 447). This was in part attributed to the software. The authors caution, however,
“regardless of the scaffolding strategies embedded in the software, the instructor plays a crucial role in supporting students in engaging in argumentation. Conversations that explicitly attend to ways to explore data, the nature and quality of evidence, and alternative explanations for phenomena must become part of the social discourse of classrooms.” (p. 455)

In spite of signs of argumentation being improved by scaffolds, more work remains to be done on scaffolding that gets students to attend to other things such as considering quality of evidence with computer based scaffolds.

To that end, Clark et al. (2008) reviewed various literature in a work entitled: “Technology-Enhanced Learning Environments to Support Students' Argumentation.” The authors discuss many technology-enhanced learning computer based environments. All “involve structured knowledge bases, unstructured knowledge bases, media-rich representations, visualizations, and other formats” (p. 221). “Students in these environments,” the authors continue, “therefore create, modify, and share permanent external representations of their ideas and arguments with one another” (p. 222). Thus, the computer can act as a sort of organizer and checklist for student ideas. One such approach, a program called Belvedere, attempts to structure student argument along the lines of Toulmin's elements of argument. The software provides a graphical template of the structure components of an argument including claims, evidence, etc., as mentioned previously. Cho & Jonassen (2002), found that students using the Belvedere program as an argumentation scaffold “produced significantly more argument components during group discussions” (p. 13). Again, this result does not necessarily equal quality argumentation per se, nor does it indicate learning, but, since students are engaging more with evidence and claims, it is a step in the right direction.

Kelly & Crawford (1996) also analyzed student interactions with computers in small groups. They asked twelve groups of four students to do a computer based laboratory activity
in which they linked oscillatory motion to different types of representations. Analysis of student discussions “reveals the role the computer plays in the group context and the ways that this context is shaped by the computer” (p. 693). Kelly & Crawford emphasize two ways to the computer can enter into student discourse. Either it offers a representation to students that first must be interpreted before entering into the conversation, or the students can employ an already interpreted representation to support their argument (p. 701). A list of how the computer can play its part in student discourse follows:

1. The computer enters as an ally for one or more students in their effort to make a case.
2. The computer acts to help construct meaning in the group; there is an explicit appeal to the computer. Students demonstrate an event or events to others by drawing attention to a specific piece of data.
3. The computer exhibits vital information. Data crucial to the point being made in the conversation are exhibited on the computer screen.
4. The computer elicits students’ responses.
5. The computer presents students with anomalies to their expectations.

(p. 701, emphasis added)

Again, the computer scaffolds student argumentation. In the work we see that the computer is always mediated into the conversation by students, who ultimately are charged with interpreting computer representations. Nonetheless, the computer does have the power to initiate ideas, refute or confound, and support student positions. In concluding Kelly & Crawford state, “The computer is thus best interpreted as a member in the group and conversation” (p. 706).

Since students are clearly being affected by the computer, it is appropriate to say that scaffolding is occurring in the computer supported argumentation environments discussed
above. Pea’s (2004) “distributed intelligence,” emphasizes another aspect of the computer’s participation in such events, that of embedded knowledge, which has been shown as a type of scaffolding. There was human knowledge and interpretation engineered into the software before the students ever even interacted with it. What features of collective human “distributed intelligence” ought to be emphasized in software based scaffolding if learning is to be best supported?

Design Principles for Software-Based Scaffolds

Quintana et al. (2004) have some answers to this question. They also inform the present research. They provide a “scaffolding design framework for software to support science inquiry” based on prior empirical and theoretical work. Their goal was to create a common theoretical framework that provides “rationales and approaches to guide the design of scaffolded tools” in classroom science (p. 337). They break down the functions of scaffolding goals into: sense making, process management, and articulation and reflection. Sense making, suggests multiple ways students can interpret, organize and use representations. The criteria are the following:

Sense Making

1. Use representations and language that bridge learners’ understanding
2. Organize tools and artifacts around the semantics of the discipline
3. Use representations that learners can inspect in different ways to reveal important properties of underlying data (p. 345)

Sense making, as it is accounted for above, is a structuring process (as opposed to problematizing), since it can help students to break down larger parts of a problem and talk about how they fit into a larger whole. Through the use of bridging representations (c.f., criteria 1), students’ attention can be channeled and focused. For example, representing sound waves
graphically on paper with a sine wave channels and focuses student attention to things like amplitude and wavelength and perhaps away from the particles in air themselves (Podolefsky & Finkelstein, 2007). Embedded representations can greatly affect the very nature of a task. For example, work on sound waves, for example, gains great efficiency from being able to be represented with a sine wave as opposed to particles being compressed. Mascolo (2005) would call these ecological scaffolds, since to the students, at least, they are embedded in the task itself.

Process management is another way Quintana et al. suggest scaffolds should support students. The list of criteria that process management scaffolding should accomplish is below:

Process Management

4. Provide structure for complex tasks and functionality

5. Embed expert guidance about scientific practices

6. Automatically handle non-salient, routine task

(p. 345)

Automatic graphing, or ordering student performance or attention with questions in order to make certain features more salient, would be examples of process management. Yet another way to structure, process management can make complex tasks more doable and likely to produce learning for students. Criterion 5 speaks directly to Pea’s “distributed intelligence.” Embedding expert guidance might take many forms including offering analogies, showing data gathered over many years, showing models of things too large or too small to be directly studied, etc.

Facilitating articulation and reflection is another important feature of scaffolding student argumentation. Without this important step students might prematurely reach a consensus that does not account for all evidence or features of an argument. Quintana et al. state simply:
Articulation and Reflection

6. Facilitate ongoing articulation and reflection during the investigation.

Articulation and reflection can also be facilitated in many ways. For example, it could be accomplished by inviting students to present their findings or argument to a group of their peers, as Kelly & Brown (2003) have suggested. This can encourage students to articulate or reflect upon those features of a concept or argument that may be assumed to be implied, but in fact may be poorly understood by some members of the group. Articulation and reflection can also be embedded in the task itself. Rather than just offering analogies or models, for example, students can be invited to interpret them and discuss how a given model or analogy accounts for available observations and data.

Although the authors caution that these criteria are only to be used to inform the development of software scaffolds, the criteria are sufficiently general as to be able to support development of other type scaffolds. These criteria are shared in the present research because they represent the closest body of scholarship to the present scaffolding using analogical-mapping-based comparison tasks. Consider the literature on analogy and how it gives rise to an analogical-mapping-based comparison task as a scaffold for argumentation.

How Can Analogy Inform a Scaffold for Argumentation?

Comparison makes things easier to talk about and understand and better situates new content. In both argumentation and scaffolding, comparative thinking is important. Argumentation is, in effect, choosing between possible explanations. Thus it is fundamentally a comparative process. Scaffolding argumentation can be done by facilitating comparison, as has been shown in the research discussed previously. Putting questions in a particular order so that consideration of one thing after another can lead naturally to comparison (c.f., mole activity p. 43, this work) is one means of embedding expert reasoning in an given argumentation task.
Also, even the automatic rendering of a simple graph for students, for example, can aide their ability to compare. They can compare the y variable over time, the trend displayed on that graph to the trend vs another, a variable over time span A vs time span B, etc. If argumentation is comparison, then an important way to make argumentation more effective at promoting learning is to facilitate comparison by learners.

The first step in promoting argumentation is structuring and problematizing a task that invites students to propose and compare explanatory arguments. Scaffolding approaches that leave some ambiguity and provide time for discourse among students and teacher and do not lead to one correct answer can be effective in promoting argumentation and learning (Varelas et al., 2007). Comparative tasks can provide for this desired ambiguity. In ambiguous tasks students often consider more possibilities and question basic assumptions in order to gain direction. Researchers have found that students solving more ambiguous ill-structured problems create richer, more coherent arguments that those solving well-structured problems (Cho & Jonassen, 2002). One potential way to scaffold argumentation and learning could be to offer students analogies and support their interpretation of these analogies systematically while having them generate an argument.

Analogies are a powerful way to compare. Analogies can serve a communicative and evaluative function, since they can be negotiated and made sense of with others (Kelly & Duschl, 2002; Kelly & Green, 1998; Wilbers & Duit, 2006). Researchers have found that people generate and use analogies as natural scaffolds to think and develop their own arguments all the time (Clement, 1981, 1988, 2008b; Dunbar, 2001). Glynn (1991) states the importance of analogy in human thinking and communication:

"Let me give you an analogy. . ." "It's just like..." "It's the same as. . ." "It's no different than. . ." "The process of relating concepts by means of analogy is a basic part of human thinking, and authors, teachers, and students are certain to use it. (p. 222)"
An analogy, as defined by Gentner (1983), is “a comparison in which relational predicates, but few or no object attributes, can be mapped” from one scenario or situation to another (Dedre Gentner, 1983, p. 161; D. Gentner & Kurtz, 2006, p. 636). Relationships correspond between situations, whereas the features of the objects involved do not. Gentner refers to this correspondence between relationships in analogous situations as “mapping.” In the classic English class analogy - a hat is to a head as a glove is to a hand - a hat does not look like a glove and would never be mistaken for one. Rather, the way a hat relates to a head is much like the way a glove relates to a hand; both cover their respective body parts in order to insulate them. The relationships are key. The superficial characteristics of the glove, etc. are not.

Let us look also at what an analogy is not. An analogy is not a literal similarity (D. Gentner & Kurtz, 2006, p. 613). Such a similarity would involve a featural match, for example, a hat with finger spaces. Two cars are not analogous to one another, for our purposes; they are literally similar. An example of something is also not an analogy. Glynn (1991) states, “Lightning is not like a big spark, it is a big spark! So, lightning is an example of electric spark” and not analogous to it (p. 225). Things in the same category are not analogous to one another – two eggs, for example. So for our purposes, analogies are not examples, members of the same category, or things that are literally similar or the same.

What about metaphors? Metaphors are different from analogies. Usually, a metaphor borrows and applies language directly from one scenario to another. To state, “She is a gazelle on the track field,” is a metaphor. In fact, she is not really a gazelle, and the statement is literally untrue. But, the concepts are blended deliberately to yield new understanding of her track prowess. Humans understand metaphors effortlessly (Lakoff & Johnson, 1980). Whereas, to state, “She runs like a gazelle,” accomplishes much the same thing as the metaphorical version, but it could be literally true. It is thus an analogy, not a metaphor. In science, however, the division between metaphor and analogy can become blurry. A teacher
might state, for instance, that an “atom is like a solar system” (an analogy) and then later speak of a “solar system atom” (a metaphor) (Harrison & Treagust, 2000, p. 356). Regardless, of whether via metaphor or analogy, mapping correspondences is a very common and effective way of achieving new understanding in human thought (Fauconnier, 2001, p. 255; D. Gentner & Kurtz, 2006, p. 636).

An analogy can be also regarded as a type of argument, called abduction (other types include deductive and inductive arguments), in which one situation is offered as being like another situation, and the similarity allows us to better understand a new situation. Hypotheses can be borrowed from one situation and applied to another. Peirce called reasoning by analogies to make hypotheses, abduction. Kwon et al state, “Abduction is the mental process of generating hypotheses in which an explanation that is successful in one situation is borrowed and applied as a tentative explanation in a new situation” (Kwon, Jeong, & Park, 2006, p. 245). Abductive reasoning is a process of reasoning by analogies that leads to a hypothesis or assumptions about something unknown. Abduction supposes that since something is true of one situation, it may be true of another.

Analogies have been used by countless scientists for centuries to help them make creative-leap-type arguments about various scientific concepts (Glynn, 1991). For example, Darwin did this when he hypothesized that natural selection operated much like controlled breeding of animals and plants (Venville & Treagust, 1997, p. 283). The astronomer, Johannes Kepler paid homage to analogies, stating, “I cherish more than anything else the Analogies, my most trustworthy masters. They know all the secrets of Nature” (as quoted in Glynn, 1991, p. 219). Joseph Priestley used analogies in proposing the law of electrical force (Glynn, 1991, p. 219). Robert Oppenheimer, famed physicist, also stated in a 1955 speech,

“Analogy is indeed an indispensable and inevitable tool for scientific progress. . . .
Whether or not we talk of discovery or of invention, analogy is inevitable in human thought, because we come to new things in science with what equipment
we have, which is how we have learned to think, and above all how we have
learned to think about the relatedness of things.” (as quoted in Glynn, 1991, p.
220)

Their arguments were made possible by analogies. In this way, the analogy is not only a type of
argument but also acts as a scaffold as well. Our thinking about the structure of one situation
or concept is borrowed from another, better understood concept, “thereby creating additional
structure in the target” (Fauconnier, 2001, p. 255). A target refers to the newer more poorly
understood situation, whereas the base is the better understood situation offered as analogous
to the target. The scientist’s argument and thinking is channeled along the analogical
 correspondence. In the case of evolution, for example, Darwin reasoned that traits such as
longer beaks or larger stature are selected for by nature, since the members of a species having
these traits were more likely to survive and pass on these traits to offspring. This, Darwin
reasoned, was similar to human directed breeding in which traits desired by humans were
selected for by allowing animals possessing them to breed with one another. Understanding
from breeding was applied to the natural world by analogy, and Darwin described natural
selection for the first time. Of course, an argument by analogy is only possible in so far as the
relationships hold between the two situations supposed to be analogous.

Sometimes abduction, or comparative analogy, between two situations seems a step too
far. Again, a type of scaffold, called a bridging analogy, can help. In research by Clement
students, were asked to analyze the following problem and
then solve it by thinking aloud (Clement, 1988, p. 565).

Spring Coils Problem

“A weight is hung on a spring. The original
spring is replaced with a spring made of the
same kind of wire, with the same number of coils, but with the coils that are twice as wide in diameter. Will the spring stretch from its natural length, more, less, or the same amount under the same weight? (Assume the mass of the spring is negligible compared to the mass of the weight.) Why do you think so?” (Clement, 1981)

The participants were not provided any hint to search their own background. However, Clement, a member of the physics faculty himself, expected people to appeal to analogy with past experience to solve this. And, they did. For example, one study participant produced the following drawings and explanations during his attempt at a solution. In figure 2 we see identical weights placed on two rods. One is longer than the other. This was the first analogy to the spring problem produced by that participant in attempting to solve the spring problem. Roughly, the longer bar on top of figure 2 corresponded to the larger diameter spring. But, this participant deemed the difference between the two scenarios too large to be reconciled and so the author suggests the drawing in figure 3 above represents a “bridging analogy,” or one which “links conceptual frameworks for the rod situation and the original spring situation” (Clement, 1981, p. 4). This “bridging analogy” encompasses aspects of both situations for a common solution. Clement concludes that reasoning with analogies is not necessarily an “instant solution” but has the potential to be a “more extended process of conjecture and testing” (p.1). Clement further states that there is “reason to believe that some of these processes [of reasoning and conjecturing with analogies] are learnable, rather than being exclusively a product of genius” (p. 9).

We see that the problem solver’s argument for a solution was analogical (abductive) in nature. But, we also see that the solver was scaffolded, or supported by the process of abductive reasoning, or reasoning by analogy. Clement states, “Analogous cases can either
play a temporary heuristic role in helping to generate conjectures during the solution, or they can play the more permanent role of a model in the final solution, or both” (Clement, 1981, p. 9).

Clement lists the “major processes involved in using an analogy” by experts as in the above case (Clement, 1988, p. 571).

1. Generating the analogy
2. Establishing confidence in the analogy relation
3. Understanding the analogous case[s]
4. Applying findings

(p. 571)

Unfortunately, this list does not apply well to the use of analogies in science education, since in practice analogies are usually offered to students rather than generated by students in science classes. An important step is usually lacking in the student experience – active interpretation and meaning making which leads to learning and understanding. In later work, Clement (1993) suggests, that “much more effort than is usually allocated should be focused on helping students to make sense of an analogy” (p. 1241). Guidance from teachers in how to interpret the ready-made analogies we deliver to students is especially important (Duit, 1991, p. 656). To assume that learners will “abstract principles from single examples or that they will spontaneously draw comparisons across examples [will lead to learning that is] likely to fall well short of potential gains” (Dedre Gentner, Loewenstein, & Thompson, 2003, p. 404).

Analogies in science can be difficult, often situations are compared which have many objects and relationships between them. These are referred to as elaborate conceptual analogies. Elaborate conceptual analogies are often offered to students in science classes to help them understand and explore complex concepts that are not easily observed or visualized, such as the cell and electric current, among many others. The cell, for example, might be compared to a house and all its components in order to make features and functions that are not directly studied more salient, understood, and memorable to students. And electricity, which
also cannot be directly witnessed with the five human senses, can be analogically compared to water, with water pressure being compared, or mapped, to voltage and electric current through a circuit being compared to water flow through a pipe. Through analogical comparison, concepts relating to electricity such as voltage and current can be more easily visualized, talked about, and understood.

Research on elaborate conceptual analogies has taken a larger focus than just the mapping of one or two relationships, suggesting instead that analogy is the comparison of underlying networks of relationship structures between situations. Individual object features are deemphasized, but the focus is on a network of structures and how they correspond, as opposed to just one relationship (see next page) (Duit, 1991). Analogy, rather than being something captured on paper and shared, is better thought of as a process (Glynn, 1991, p. 223; Kelly & Duschl, 2002, p. 14). Glynn (1991) says that analogy is “a process of identifying similarities between different concepts” (p. 223). These systems-comparison-based-process approaches can make sense if we consider elaborate conceptual analogies, which have more elements than the simple ones we might encounter in an English class, such as the one about hats and gloves.
What is Analogical Mapping?

Analogical mapping is the process of identifying elements or objects from one scenario or concept and find corresponding elements or objects on an analogous scenario or concept. This can improve understanding as in the following example.

Holyoak (2004) found that when people are asked to which object in the bottom picture the man in the top, whom he calls “target object,” best corresponds, people choose the boy. However, when asked to match all the objects between the bottom and top picture – analogical mapping – they choose the tree, since both are restraining the dog. Holyoak states, “They are led to build an integrated representation of the relations among the objects and of higher-order relations between relations” (Holyoak, 2004, p. 128). To the left, an analogical mapping table, listing correspondences between pictures is shown. By drawing attention to the system of relationships between objects in both pictures, our interpretation or understanding is affected. Interpretation of one object constrains and guides that of another. For example, if the man (top picture) best corresponds to the tree (bottom picture) than he cannot also best correspond to the boy (bottom picture). In this way, an argument in favor the man-tree correspondence is made stronger by triangulation. Understanding of either or both pictures (scenarios) moves away from superficial features and toward deeper structural features.

Table 2.1: Analogical Mapping Table

<table>
<thead>
<tr>
<th>Top</th>
<th>Bottom</th>
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<tbody>
<tr>
<td>Person</td>
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<td>Dog</td>
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<tr>
<td>Cat</td>
<td>Person</td>
</tr>
<tr>
<td>Tree</td>
<td>Cat</td>
</tr>
</tbody>
</table>
Use of Analogies in Science Education

This section will discuss the use of analogies in science education with an eye toward building on current practice with the present research. Analogies, like discourse in science classrooms generally, are not used as well as they might be. Often, analogies are simply presented in a lecture or a text and there is little room for interpretation or discussion (D. E. Brown & Clement, 1989; Else, Clement, & Rea-Ramirez, 2008; Theile & Tregust, 1991). The teacher’s role should become one of aiding and guiding students and away from merely presenting analogies to yield some immediate insight (Theile & Tregust, 1991). When Else et al. (2003), had students work with analogies they found that “[a] considerable portion of the understanding students gained came from exploring through reasoning and dialogue” between students and teachers about the analogy (Else, Clement, & Ramirez, 2003, p. 10). Presenting elaborate analogies without offering students guidance in how to interpret them can lead to misunderstandings and confusion (Tregust, 2007, p. 380).

Two examples of elaborate conceptual scientific analogies from actual science textbooks are now presented. The first one is from Moog & Farrell’s Chemistry: A Guided Inquiry (2008). It offers an analogy for understanding the mole concept in chemistry. The second, from Paul Hewitt’s Conceptual Physics (1999), analogically compares electricity to a system involving water.

The book from which the activity comes is a workbook to be paired with a text book by the same authors. The authors describe the workbook as using “guided inquiry.” As to what they mean by this term, the authors, who are chemistry professors, state:

If ever a book was written for students-this is it. This is not a textbook. This is not a study guide. This book is “a guided inquiry,” in which you will examine data, written descriptions, and figures to develop chemical concepts…” “You and your group study the Models and Information and systematically work through the Critical Thinking Questions.
In doing so, you will discover important chemical principles and relationships. If you understand the answer to a question, but other members of your group do not, it is your responsibility to explain the answer. Explaining concepts to other members of your group not only helps in their understanding, it broadens your understanding (Moog & Farrell, 2008, p. 1).

In the box at the top of the activity (next page), we see two analogies offered, although the word analogy is not used:

*One elephant has one trunk and four legs.
*One methane molecule, CH₄, contains one carbon atom and four hydrogen atoms.

We can see that an elephant is analogous to a methane molecule, since the elephant has four legs and the methane molecule has four hydrogen atoms. Also, an elephant has one trunk and a methane molecule has one carbon atom. Also:

*1 dozen = 12 items
*1 mole = 6.022 x 10²³ items

In the activity, a dozen and a mole are analogically compared since they are both words.

Figure 2.4: The Mole Analogy (Moog, Farrell, 2008)

ChemActivity  28

The Mole Concept

Model: The Elephant and the Methane Molecule

One elephant has one trunk and four legs.
One methane molecule, CH₄, contains one carbon atom and four hydrogen atoms.

1 amu = 1.6605 x 10⁻²⁴ g
1 dozen = 12 items
1 mole = 6.022 x 10²³ items = Avogadro's Number

Critical Thinking Questions

1. How many trunks are found in one dozen elephants? Give your answer in terms of a number (such as 17 or 3.25 x 10¹⁵ trunks).

2. How many legs are found in one dozen elephants? Give your answer in terms of a number (such as 17 or 3.25 x 10¹⁵ legs).

3. How many carbon atoms are found in one dozen methane, CH₄, molecules? Give your answer in terms of a number (such as 17 or 3.25 x 10¹⁵ C atoms).

4. How many hydrogen atoms are found in one dozen methane molecules? Give your answer in terms of a number (such as 17 or 3.25 x 10¹⁵ H atoms).

5. How many trunks are found in one mole of elephants?

6. How many legs are found in one mole of elephants?
representing numbers. The analogical mappings are listed in a table below.

From Moog and Spencer’s introductory statement, we can see that students are meant to “work through the critical thinking questions” together with their groups, and, “If you understand the answer to a question, but other members of your group do not, it is your responsibility to explain the answer” (p. 1). Clearly, students are meant to engage in argumentation around the analogy the authors have created.

<table>
<thead>
<tr>
<th>Base (well understood concept)</th>
<th>Target (new concept)</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elephant</td>
<td>Methane Molecule</td>
<td>Both have four of something and one of something else</td>
</tr>
<tr>
<td>Legs</td>
<td>Hydrogen Atoms</td>
<td>Both are possessed in amounts of four.</td>
</tr>
<tr>
<td>Trunk</td>
<td>Carbon Atom</td>
<td>Both are possessed in amounts of one by their respective “owners”</td>
</tr>
<tr>
<td>Dozen</td>
<td>Mole</td>
<td>Both are words that represent a number</td>
</tr>
</tbody>
</table>

The authors created this analogy specifically in order to make the mole concept easier to talk about and learn for students. The use of everyday objects such as an elephant and a dozen, with which students are already familiar, helped the authors to minimize some of the typical errors students make when working with analogies. These errors include: overmapping of features, mismapping, and retention of a base feature (Else et al., 2003, p. 8). Overmapping would occur, for example, if a student asserted that a methane molecule must have a tail. This feature simply does not map. Mismapping would be to state that the elephant’s trunk maps to the methane’s hydrogen atoms – again not true; better would be to map the trunk to the carbon atom, since both are possessed singularly. And, retention of a base feature would be if a
student were to say that a methane molecule had four legs instead of four hydrogen atoms, for example.

An elaborate and more typical conceptual analogy is offered to help students understand electricity. Below are some excerpts from Paul Hewitt’s (1999) *Conceptual Physics* textbook. Hewitt’s book series, *Conceptual Physics*, has been praised for its detailed descriptions, breakdowns, and illustrations analogies (Glynn, 1991). Glynn states,

In the analogy Hewitt has drawn between currents of water and currents of electricity, the effectively has performed all of the operations specified in the **TWA model**. In the electric current excerpt, he introduces the target concepts of voltage, current, and resistance. Next, in the flow of charge excerpt, he cues the reader to retrieve from memory information about currents of water. (Glynn, 1991, p. 232)

On the next page are some of Hewitt’s illustrations and explanations (Hewitt, 1999, pp. 532-535) that serve to break down various aspects of the electricity-water analogy. Figure 2.6 is an illustration that shows water flowing from higher to lower levels. This, Hewitt says, is analogous to the force that moves...
electricity through wires and electrical devices – electromotive force (EMF), measured in Volts. Difficult to visualize and imagine for students, electromotive force is now easier to talk about, understand, and remember.

Those electrical devices and the wires themselves resist the flow of electricity. This is called resistance. At right, Hewitt shows an illustration of another aspect of the analogy – electrical resistance. The thickness of the water pipes is different in the illustration, with more water coming out of the larger pipe. Similarly, Hewitt states, in the text above, “Thick wires have less resistance than thin wires,” a fact now easily visualized and understood in light of the analogical illustration (Hewitt, 1999).

To provide a meaningful and more expansive analogy on electricity, Hewitt provides the following an elaborate conceptual analogy drawing in the drawing below (Else et al., 2003; Glynn & Takahashi, 1998). It combines the analogies for resistance and electromotive force, discussed above. Note that the electrical resistance in figure 2.7 is in the same relative position as the small curvy pipe (left) Hewitt calls the “line.” The valve is analogous to the switch - both turn the flow on and off. The valve and switch are also in the same respective positions, helping students to see the correspondence. So too are the “pump” and “dry cell” battery, both responsible for creating the movement force. Comparison is facilitated by the detailed drawings, the same relative position of mappable features of the analogy (e.g., pump to dry cell), and the textual description. These
all help students to better understand and talk about electricity, an otherwise somewhat intangible concept, in terms of the water analogy.

This example of effective use of analogy in a textbook can inform analogy use in classroom based argumentation. In the text, Hewitt first explained and illustrated assumptions about the analogy that would be necessary to understand the larger system-based analogy above. He analyzed the resistance – pipe size aspect of the analogy, as well as the pump/water pressure – electromotive force aspect. Only then did Hewitt combine the two simpler analogies into the larger analogy above. The pictures, captions, and corresponding text and headings served to explain in detail how the water and electrical parts of the analogy corresponded.

Identifying and breaking down analogies, mapping out aspects from one part of the analogy to the other, and explaining how knowledge about one part of the analogy can scaffold or support our understanding of the other is not only important in textbooks. It is perhaps more important to provide students the opportunity to make sense of analogies themselves through argumentation, since analogies such as these, with their many aspects and correspondences to map, require time to fully understand.

Conceptual analogies in science can be complex and elaborate, having many mappable features. Teachers must also consider whether at least one part of the analogue is familiar to the students. Using the elephant in the first analogy described above was a safe bet, for example, since students most likely had seen and become familiar with an elephant prior to this activity. However, it is possible in other analogies that students may not understand the base, or supposedly better understood situation or analogue. This will no doubt hinder their understanding of the target, or new situation. Even when students do understand the base, they may not necessarily map the correspondences and gain the understanding the analogy affords. Their explanatory power is thus missed by students (Wilbers & Duit, 2006, p. 47).
The Importance of Explicitly Inviting Students to Use Analogical Mapping

Often teachers (and researchers) provide elaborate analogies that are assumed to be “insight” type problems in which a spontaneous understanding is assumed after an analogy is presented to students (Clement, 2008a, p. 25). Often this spontaneous understanding does not take place, as in a classic study by Gick and Holyoak (1980). In the study, twenty-seven participants were asked to read and memorize three stories. One of these stories was about an army attempting to attack a fortress with a large force of soldiers (p. 341). In the story there were five roads to the fortress; each contained landmines. Only a small number of soldiers could pass at a given time without setting off the landmines. The solution offered by the story was to divide the soldiers up and distribute them over the roads in sufficiently small amounts so that they would not set off the landmines. Along with this story, the participants also read two distracter stories. Then, they were given the following problem.

Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?” (Gick & Holyoak, 1980, p. 306).

After reading the three stories, including the two distracters, all participants were instructed to try to solve the radiation problem above. Twelve of the participants received the following hint: “In solving this problem you may find that one of the stories you read before will
give you a hint for a solution of this problem” (p 341). That single line did not appear in the materials given to the other fifteen participants. Eleven of twelve (92%) of the group receiving the hint produced a solution that showed what Gick and Holyoak refer to as “analogical transfer,” or application from knowledge from the army-fortress story to the new radiation problem. The successful participants produced the solution that stated the radiation could be sent in from multiple angles. This was analogical to the case of the soldiers separating to walk across the mined roads. In the group not receiving the hint only three of fifteen (20%) provided the same solution.

These results show that analogical transfer can be promoted by simply inviting people to compare two scenarios or analogues. Comparing the radiation problem to the fortress attack story yielded a successful strategy as defined by the authors. In another part of the study, only 8% of participants were able to produce the solution (separating the radiation) without being given any story at all prior to testing. It could be that participants do not know that radiation is divisible and can be aimed in from multiple points outside (p. 318). Maybe the “hint” to consider the past stories is like telling the participants, who may have had doubts about the divisibility of radiation, that it was okay to divide and concentrate the radiation to a point, as in the story about invading the fortress over the mined roads. In this case the knowledge or understanding from fortress attack story was transferred and applied, according to the authors, to the radiation problem. The authors show that a hint or invitation to consider something already there can result in significant improvement in problem solving, and arguably, understanding.

This research has immediate relevance to education because it provides evidence that just offering analogies and explaining them is not enough to promote learning; rather, it is important to encourage active comparison and mapping of correspondences through argumentation. Providing students the time and space for analogical sense making to occur is very important. And, rather than just offering students analogies in lecture or reading, making analogical mapping the explicit focus of an activity and providing the instruction, similar to but
more directing than Gick and Holyoak’s “hint,” is essential. Making students aware of potential analogues they may already be familiar with but would not necessarily bring to bear on a new science concept, such as in the case of students using their understanding of the elephant and the dozen concepts to understand the mole ratio concept in chemistry, is an important feature of creating the environment in which analogies are worked with effectively. In the case of the electricity analogy, discussed previously, students may not be familiar with either the water or the electricity part of the analogy. In this case, perhaps students could work with the water model experimentally, while at the same time working with the electrical analogy, thus creating a rich context that better allows for comparison of the water analogy that leads to learning.

The role of the context in which students work on analogical mapping must be given more consideration. In Gick and Holyoak’s research, both groups performed the same activity, the only difference being whether or not a “hint” was given. This “hint” to search the background became an element of the context in which the participants worked. Educators must consider and create the proper context for analogical mapping. Students may be already familiar with relevant analogies that they do not access because they are not instructed to do so or are not given sufficient time or cues to do so.

Models for Using Analogies in the Classroom

Four models for using analogies in the science classroom will now be presented in the order they were developed. Glynn’s (1991) “Teaching With Analogies” (TWA) model will be presented first. Following will be Treagust, Harrison, and Venville’s (1998) FAR (Focus, Action, Reflection) guide for teaching with analogies. Next, Nashon’s (2000) “Working with Analogies” model will be discussed. Finally, Else, Clement, and Rea-Ramirez’s (2008) guidelines for analogy using analogies in science teaching will be discussed. These models, as will be shown, have considerable overlap.

Glynn’s model, called “Teaching with Analogies” (TWA), was developed by analyzing:
43 science textbooks and an analysis of the analogies used in those textbooks. The most effective analogies from the standpoint of instructional design were identified. The authors of these analogies performed certain key operations that have been incorporated into a model which can serve as a guide for teachers and authors of science textbooks. (Glynn, 1991, p. 230)

Since Glynn’s model, Teaching With Analogies, was developed by examining, analyzing, scoring textbooks, its findings are thus limited to stating how textbooks can treat analogies well. Glynn states, “The most effective analogies from the standpoint of instructional design were identified” (p. 230) by the authors by examining the textbooks they were found to exhibit the six operations listed below:

1. Introduce Target (new concept to be learned)
2. Cue Retrieval of Analog
3. Identify Relevant Features of Target and Analog
4. Map Similarities
5. Draw Conclusions about Target
6. Indicate where the Analogy Breaks Down

Some books did not deal well with analogies, while other used few or none. The authors state, “we have found many instances in which authors suggested an analog to readers, but then left the readers to make sense (or nonsense) of it for themselves” (p. 233). It is very possible for analogies provided by textbooks, if not used well, to lead to misunderstanding. Again the authors stress the need for dialogue around the analogies, stating:

When this model has been used in science education classes to dissect an author’s analogy, the discussions that ensued between the teacher and students, and the students themselves, enabled the teacher to identify students’
misconceptions and knowledge gaps that otherwise would have gone undetected. (pp. 233-234)

Again, the need for time, space, and purpose in interpreting and comparing the parts of an analogy are shown.

The authors end the paper by acknowledging the inherent limitations of a textbook analysis based model and advise of the need for empirical studies to validate the model (p. 238). One such follow-up study by Harrison & Treagust (1993) examined a 10th grade lesson on refraction. The analogy the class used came from Paul Hewitt’s Conceptual Physics textbook. Hewitt’s analogy notes that when two wheels on a single axle are rolled from a smooth hard floor onto a carpet at an angle that is not perpendicular to the carpet the axle will shift, since the wheel to hit the carpet first is slowed down before the other wheel, which for a brief time can continue rolling on the hard floor. This is offered as being analogous to light refraction or bending that occurs when light enters glass.

The teacher in this study followed the steps in Glynn’s TWA model. However, the order of steps 5 and 6 was reversed. It was deemed more important that the students “identify the comparisons [or mappings] for which the analogy breaks down” before they could “draw conclusions about the target concepts” (Harrison & Treagust, 1993, p. 1300-1). As students completed the lesson, they were video recorded. Interviews were done with the teacher and students after the lesson, and these were also recorded. Also, students completed an analogical mapping worksheet both before and after the lesson.

Interviews with students found a “consistently high level of understanding.” And, the teacher said, “the students had understood refraction better than on any previous occasion that she had taught this concept” (Harrison & Treagust, 1993, p. 1303). The researchers concluded that the “TWA model did, through some mechanism, enhance student conceptual understanding of refraction” (p. 1303). The authors do not speak more specifically about the “mechanism.”
In work that further develops on the Teaching With Analogies model, the FAR guide for teaching with analogies was developed (Treagust et al., 1998; Venville & Treagust, 1997). FAR stands for Focus Action Reflection. This model can apply both to textbooks and to classroom discourse. According to Treagust, Harrison, and Venville (1998), “the purpose of the FAR Guide is to help teachers maximize the benefits and minimize the constraints of analogies when they arise in classroom discourse or in textbooks (p. 93). The steps are paraphrased below.

1. Focus – “In teaching with analogies, teachers should initially consider the difficult aspects of the concept to be taught, whether or not the students already know something about the target concept, and whether or not the students are familiar with the analog.” (p. 92)

2. Action – “…the features of the analog and target are socially negotiated …” “and ways that the analog and target are not alike are explicitly identified.”

“This is the Action phase of analogical teaching and usually involves no more than three cognitive steps:

(a) familiarity with the analog.

(b) mapping of the shared attributes, and

(c) showing the students where the analogy breaks down.” (p. 92)

3. Reflection – “…teachers reflect on the clarity and usefulness of, and conclusions drawn from, the analog and consider ways in which the analog, the mappings, or the analogy’s position in the lesson may be improved.” “This Reflection phase may take place within the lesson itself or after the lesson as later preparation occurs. In practice, these phases are not distinct but run into one another.” (pp. 92-93)

By focusing more on teaching and interaction with analogies, the FAR guide builds on the TWA model. Here again though, the FAR guide emphasizes teacher-student interactions over student-student interactions. The FAR guide also does not provide much detail on how the
mapping of shared attributes of analogies should best be carried out or what it might look like in a classroom.

Later empirical work by Glynn and Takahashi (1998) found that analogies in texts can improve learning over texts on the same content without analogies. Eight graders who had used analogy based science textbooks to study biological cell parts and functions were able to better remember them two weeks later. Six graders using analogy-enhanced science text also had better recall of the same content and also found the cell parts and functions to be more understandable than students using the non-enhanced book (pp. 1135-1138).

Again building upon the TWA model guide to teaching with analogies, Nashon (2000) proposed the follow model, he called Working With Analogies, or WWA.

1. Assess students’ prior knowledge of the analogue
2. Assess students’ prior knowledge of the target
3. Identify analogue and target attributes
4. Map similar attributes
5. Point out unmapped attributes
6. Draw conclusions about target (p. 220)

Rather than simply introducing the new concept to be learned (target) and cuing retrieval of analogue (base), as in Glynn’s TWA’s first two steps, Nashon invites us to “assess students’ prior knowledge of both. It is of course, not appropriate to assume that students will already be familiar with the simpler half of the analogy simply because it is the simpler half. Nor is it appropriate to assume that students know nothing of the target concept. Unfortunately, however, this model does nothing to further develop what the mapping process and what the identification of analogue and target attributes should look like in a classroom. How exactly conclusions should be drawn about the target is not discussed either.
An improvement over earlier work, some of the most recent guidelines are laid out in a work titled: *Using Analogies in Science Teaching and Curriculum Design: Some Guidelines* (Else et al., 2008). They are listed below.

1. Before beginning, call attention to the fact that the learning tool that will be used is an analogy.
2. Call attention to the purpose of each analogy before beginning the analogy.
3. Have students spend time familiarizing themselves with the mappable parts of the base.
4. Keep the analogy and its discussion as simple as possible.
5. Use drawings, diagrams, and tables to show which elements correspond in the base and the target.
6. Call attention to the parts of the analogy that do not map.
7. Make analogy use as student-active as possible.
8. Assess understanding.

(pp. 223-224)

Many notable improvements are present. First, calling attention “to the purpose of each analogy before beginning” is an important aspect that previous models have ignored. The explanatory ability sought from the analogy is implied but left unstated without this important step. Students could easily come away from misconceptions. In the earlier elephant-methane analogy, for example, if students believed that the elephant was included to convey details about the shape of the methane molecule, they would be mistaken and this could lead to false assumptions and future difficulty learning. Instead, students should be made aware that the analogy is provided simply to make talking about and imagining ratios easier. Criteria five, the use of “drawings, diagrams, and tables” to show correspondences is also an important feature of working with analogies that other models neglect. Listing correspondences in a table (as shown in the elephant-methane example) along with a rationale for each correspondence can help ensure that student understanding is guided maximally by the analogy to the benefit of
learning. For example, if elephant legs map best to hydrogen atoms of the methane molecule, then they cannot also best map to the carbon atom. Tables, drawings, and diagrams are good ways to provide a negotiable artifact around which students can argue and learn. Errors such as mismapping, overmapping, and failure to map can be more easily avoided. The analogy can be made persistent and tangible by such important features of analogical instruction.

All models have certain aspects in common, as represented in the diagram below. For example, all models have a phase in which they would introduce the analogy to students and attempt to assess and bring to bear prior knowledge. TWA has two steps around this idea. I have paraphrased them as “Introduce New Concept,” and “Cue Retrieval of Analog.” The FAR guide calls this the “Focus” stage, and it invites teachers to “Consider whether students already know something about the target concept.” WWA adds that we should not only assess students’ knowledge of the target concept, but should also consider students’ knowledge of the easier part of the analogy (the base). This may be a safe bet in the case of the elephant-methane analogy Moog and Spencer offer, but less sure when considering student knowledge of water pressure in a system, as in Hewitt’s water-electrical analogy example. Else et al. take
things a step further adding, “Call attention to the purpose of each analogy before beginning.”

This type of meta-talk about analogies is an important step and is neglected in the other models. Students might benefit, for example, from knowing that the dozen-mole analogy is offered due to its ability to make mole, a number so large it is hard to fathom and is not easily visualized, easier to talk about, understand, and remember. Both mole and dozen are words that represent numbers and can be used in sentences similarly. If students know the cognitive purposes of the analogy, they might be less likely to later overmap or mismap aspects of the analogy, such as believing mole and dozen to be the same number. And, although it is nuanced, Else et al. differ in another way; they state to “call attention to the learning tool as an analogy.” This is not the same as simply introducing the analogy. Rather, this step sets the stage for the step that follows, teaching students about the cognitive purposes of the analogy and perhaps the use of analogies generally could be dealt with here when necessary (e.g., such as when students have little or no experience using analogies).

Else et al. have provided more detail in another important aspect of all the models, the part in which similarities or correspondences between the easier more familiar part of the analogy and the new part to be learned. TWA calls this part, “map similarities.” The FAR guide has “mapping of the shared attributes.” WWA says to “map similar attributes.” Whereas, Else et al.’s guidelines break this middle part of the model down into three steps. First, they suggest students should “spend time familiarizing themselves with the mappable parts.” They then suggest the analogy should be kept “simple.” Next, they assert that students (and teachers?) should “Use drawings, diagrams, and tables to show which elements correspond in the base and the target.” As mentioned previously, this step has the important role of making the analogy a persistent artifact, at all times accessible, modifiable, and interpretable by the students. The very meaning of the analogy itself thus becomes negotiable, increasing the likelihood that misconceptions are addressed and corrected and learning is guided by the analogy.
Dealing with unmappable parts of analogies is an inevitable part of their use. And so it is that all three models include a section that speaks to addressing parts of an analogy that don’t map or correspond. This too is important so that students can avoid misconceptions caused by overmapping. In the electricity-water analogy, for example, students might be inclined to think that since a punctured pipe leaks water, then so too must a wire without insulation must also leak electrons. This, of course, is untrue and could hinder students learning and understanding about electricity. Calling early attention, as Else et al. suggest, to the purposes of the analogy can also alert students to the fact that the explanatory power of the analogy has limitations.

Although all the models discussed here agree on many aspects of using analogies in science classes, including the use of analogical mapping, they are short details on exactly how best to accomplish this. What types of interventions might best suite analogy use in classrooms? Should argumentation be involved? What about experimentation, inquiry, student presentation making?

Analogical Mapping Promotes Learning

Importantly, various studies have shown that analogical comparison and mapping in particular have been effective in promoting learning in individuals. Some of these studies will now be described and discussed with an eye toward using them to better inform how an analogy-based argumentation intervention should be developed and executed.

One such paper showing the benefits of analogical mapping is an empirical study by Kurtz et al (2001), which provided the diagram to the right. In it we see two pictures or
“situations” given. On the left are pancakes shown cooking in a pan and on the right, a metal bar is placed in hot coffee with an ice cube at the end. Heat transfer can be seen in both. This is especially seen when the scenarios are viewed together. Heat is passing from the gas stove, through the pan, to the pancakes just as heat is passing from the hot coffee through the metal rod to the ice cube. Note the spaces below the pictures and the invitation to write corresponding features on the left. Superficially, without an analogical lens or without heat transfer as a guide, one could easily suppose that the pan corresponds best to the cup, since both are containers. However, when heat transfer is considered in both, the pan more accurately maps to the metal rod, since both are conductors of heat.

The focus of this research activity as the authors intended was to assess understanding of the scenarios arrived at in four different ways from four groups of participants, including a control. For the final assessment of their understanding all groups were asked to consider the mapping activity as it is shown above. They differed only in their prior related training. For training, the first group, was shown pictures of the scenarios separately at different times and asked to interpret them. The second group was invited to interpret what was occurring in each picture separately but while seeing both at the same time. The third group interpreted both and then explicitly mapped correspondences. The final group, the control, was given no prior training before the exercise. Later, on a different occasion, all participants were asked to map the correspondences as shown above and also explain their reasoning. Forty-eight percent of the participants in both groups that compared in the training session before the exercise used all three “key terms” (as defined by the authors to be heat, transfer, and cause), whereas only 23% of the of the participants in the two non-comparing groups did (Kurtz et al., 2001, p. 432). Although, more time was spent in these groups and the effect of increased time cannot be neglected, the authors conclude that “learning can be invited by inviting comparison” (p. 438). Furthermore, they postulate that “mutual alignment may hold promise as a scaffolding technique

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within a broader pedagogical approach” (p. 439). This “promise as a scaffolding technique” is indeed worthy of further investigation.

More work supports the notion that comparison promotes understanding. In a different study by Kurtz & Lowenstein (2007) the goal was to learn “whether comparing two unsolved problems encouraged spontaneous retrieval” of a previously read analogous story problem (p. 335). In the study, the participants were provided a story problem with a description and complete solution. Later, the participants were provided two unsolved story problems and asked to solve them. They were given instruction to compare and solve the problems. The unsolved problems were analogous to the first story that had been provided with a solution. However, they were not told to search their memories for the analogue story. The authors hypothesized that comparing the two new unsolved stories would cause participants to call forth the analogous story they had just read. It did. The authors conclude, “Comparing [and mapping] two problems led to greater success for participants who read a prior analogous story than those who did not, demonstrating specifically that comparison facilitates retrieval” (p. 334). Another finding was that participants who compared the two unsolved stories better solved the problems than participants who attempted to solve only one of the problems. This work shows that inviting students to perform analogical comparison can promote retrieval of prior analogues that students may have learned. Bringing prior student knowledge to bear on new science content is an invaluable step that facilitates understanding and learning.

The research just discussed has shown that analogical-mapping-based-comparison can lead to learning and understanding in individuals. The prior two studies show, in essence, that comparison facilitates retrieval of prior analogues, and comparison can lead to better problem solving. These two findings speak to the power of analogical mapping in promoting learning. This analogical mapping research suggests that the TWA, FAR guide, WWA, and Else et al’s Guidelines for working with analogies in science education were right to include a step on mapping analogies actively, rather than just receiving them passively.
Exploring and Reflecting on Analogies: An Intervention

Although analogical mapping can lead students to recall prior analogues, do better problem solving, and learn, as has been discussed, sometimes analogical comparison is too difficult for students to see and map. Gick and Holyoak (1980) showed that a simple hint can help. However, in practice such a hint may not always be sufficient. Clement and Brown (2008) discuss an intervention that gets students reflecting and exploring analogies. The researchers did “teaching interviews” around an analogy. They present them as two case studies. Their “teaching interview” took place with two students who had never taken a physics class, neither high school nor college. The students were told to consider the “book on a table problem” shown in the figure on the previous page. The authors note that most students who have not studied physics “typically view the table as passive and unable to exert an upward force” (p. 140). Whereas, students readily recognize that the spring (shown at left of diagram) does exert a force on the book. Clement and Brown call this spring-based diagram the “anchor.” Students’ understanding of the spring-based diagram (the anchor) is both intuitively and normatively correct, since a force is in fact exerted on the book. The intervention starts from the fact that students do recognize the force imparted from the spring to the book but not the force from the table. Since the table is rigid and does not appear to move, to students it does not appear to exert a force on the book.

The authors offer the “teaching interview” as an intervention. However, little or no direct instruction is done in the in the teaching interview (p. 141). Instead, a series of questions are asked to the student the interview to get them to compare the diagrams. First, the instructor asks the student to make an explicit comparison between the “target” and the “anchor” as shown above. If the student is still unable to understand that they are comparable, and that
table, like the spring, exerts upward force on the book, the interviewer next offers what the researchers call a “bridging analogy,” in this case the book on a flexible board, as shown in the diagram above in circle 3. The interviewer questions the student as to whether he believes the “book on a flexible board” situation is analogous to the spring, since both appear to bend or deform under the weight of the book. The students in the two case study interviews come to believe this after some questioning and reflection, invited by the interviewer. The next step is to ask students to reflect on the “book on a flexible board” situation as being analogous to the “book on a table.” Again, both students interviewed came to accept this as a valid analogy. As a result, they came to learn that the table does indeed exert a force on the book. At the beginning of the interview, when asked if the table exerted a force on the book, Mark stated, “No, it’s just, ah, a barrier between the floor and the, um, the position the book is at right now.” (p. 142) He ended the interview by stating, “

“Uh, the board is flexible and, yeah I guess that’s, that’s essentially it, the board is flexible and, ah, it probably isn’t different, um, I’m starting to realize how technically it probably isn’t different, it just appears different. Ah, you know, because it’s a thin board, it’s flexible and you can see easier that it’s, um, the board is pushing up on the books.” (p. 144)

The authors state,

“whereas the traditional use of analogy would involve presenting the base explicitly as an analogous situation, in this case the tutor simply suggested situations without stating that the situations were analogous. The purpose of the interview was to engage the student in a process of analogical reasoning, and not simply to present an analogy.” (p. 144, emphasis original)

Many researchers have suggested that simply presenting an analogy in a lecture or text is not likely to lead to desired learning outcomes (D. E. Brown & Clement, 1989; Clement, 2008a; Else et al., 2003; Theile & Treagust, 1991; Wilbers & Duit, 2006). Rather, learning with
analogies should be promoted by inviting reflection and analysis of analogies. In this regard, Clement and Brown’s (2008) teaching model was effective. As enacted, however, it was too teacher intensive to do for a whole class.

Teaching with Multiple Analogies

In the previous examples, learners benefited from comparing and reflecting on multiple analogies. Teaching with multiple analogies has been shown to improve learning over the use of one analogy alone (Else et al., 2003; Dedre Gentner et al., 2003; Harrison & Treagust, 2000; Podolefsky & Finkelstein, 2007). Podolefsky and Finkelstein (2007) provided three groups of 25 physics students instruction on sound waves. One group received instruction based on a concrete representation of sound waves in which the sound wave was represented as air particles being compressed and spread by the sound wave. This is shown in part A of the diagram. It is argued to be a sort of analogy, or analogical model, by the authors. A second group of students received instruction based on what the authors called the abstract model, or analogy, of sound waves, shown in B above. This is just a sine wave. A third group received instruction with both models. This was called “blended” instruction. Instructional time was controlled for. Findings showed that students taught with blends learned more about sound waves and understood better than students taught with abstract representations, shown above, alone (Podolefsky & Finkelstein, 2007, p. 14). The authors state:

[O]ne cannot escape the conclusion that, of the three treatments examined, the blend treatment is generally more productive of correct student reasoning. Students taught with blends achieved post-test scores three times those of
This research provides two findings. First, the type of analogy used can have an impact on student learning. And, providing students two analogies can be better than providing one alone.

Another study by Else, Clement & Ramirez (2003) shows that students' use of multiple analogies to represent the same concept can benefit learning. In this case, the researchers provided students multiple analogies on energy in the human body (shown to right) to help them in a unit on understanding energy in the human body. As students worked with these analogies in various ways over time, the researchers considered: classroom observations; informal discussions with teachers and students; formative assessments; student interviews; and analysis of students' classroom work (p. 4). The authors consider the analogies as quite varied. They break down the analogies as “near vs far, simple vs complex, familiar vs unfamiliar, and visual/structural vs functional” (Else et al., 2003, p. 4). The authors provide the following general features of analogy and later apply them to the analogies listed in the table.

<table>
<thead>
<tr>
<th>Analogy</th>
<th>Primary mapping(s)</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car analogy</td>
<td>Fluids added to car repeatedly → things that people need continuously</td>
<td>We need food for energy in the same way that cars need gas for energy. We also need sleep, water, and exercise, but we do not need them for energy. This is similar to a car, which needs oil and water for other things but not for energy.</td>
</tr>
<tr>
<td>Ear of corn analogy</td>
<td>Kernels in ear of corn cells in body</td>
<td>The arrangement of kernels in an ear of corn is like the arrangement of cells in the body - both are patterned with little space in between.</td>
</tr>
<tr>
<td>School analogy</td>
<td>School parts → cell parts</td>
<td>The functions of some school parts are similar to the functions of some cell parts. For example, the nucleus controls the cell in a way similar to the way the office controls a school.</td>
</tr>
<tr>
<td>Popper analogy</td>
<td>Energy contained in party popper → energy contained in ATP</td>
<td>A party popper contains energy which can later be released in the same way that ATP/mitochondria contain energy that can be released.</td>
</tr>
<tr>
<td>Fire analogy</td>
<td>Fire inputs and outputs → mitochondria inputs and outputs</td>
<td>A fire consumes O₂ and fuel and releases energy. CO₂ and water. Mitochondria obtain energy from glucose using O₂ with CO₂ and water as wastes.</td>
</tr>
<tr>
<td>River delta analogy</td>
<td>River delta branches → artery branches</td>
<td>A river branches into many smaller branches in a way that is similar to the way blood vessels branch into smaller vessels after leaving the heart.</td>
</tr>
<tr>
<td>Water/sewer pipes analogy</td>
<td>Water pipes and wastewater pipes → vessels going to cell with needed elements and taking wastes away</td>
<td>Branching water pipes in a city bring water to houses. Wastewater leaves through different pipes. Blood brings needed elements to cells through branching vessels, and waste is taken away by different vessels.</td>
</tr>
<tr>
<td>Grape analogy</td>
<td>Grapes in a bunch → clusters of alveoli in the lung</td>
<td>The arrangement of grapes and their stems is similar to the arrangement of alveoli and bronchial tubes in the lung.</td>
</tr>
</tbody>
</table>

(Else, Clement, & Ramirez, 2003, p. 6)
Else et al’s Features of Analogy

Near vs. far: Analogies which share more object and/or relational similarities in Gentner’s (1989) sense are “near,” analogies which are dissimilar are “far.”

Simple vs. complex: base to target comparisons in which only one or two elements or relations map to the target are simple analogies. Complex analogies are more elaborate analogies, with a number of elements and/or relations transferred.

Familiar vs. unfamiliar: Analogies may differ in the extent to which students are familiar with the elements of the base that are intended to map to the target.

Visual vs. functional: Some analogies are meant to help students understand what a target looks like, possibly including geometric structure, while others are meant to illustrate what it does or how its elements relate to each other. Some analogies serve both purposes. (Else et al., 2003, p. 4)

Else et al suggest that the “fire analogy” (fire being analogically compared to the mitochondrial energy production) is “near,” since both fire and mitochondrial energy production have the same input and output materials (p. 7). The “school analogy,” which compares the parts of a school to the parts of a cell, is a “far analogy” since few actual features or literal similarities are found between the two (p. 7). Also, the school analogy is said to be “complex,” since there are many parts (p. 7). On the other hand, the “ear of corn” analogy is said to be simple, since the relationship between the shape and arrangement of cells compares easily with the ear of corn, as they are relatively similar (p. 7). Most of the analogies are judged to be “familiar,” since most students have seen many of the base analogies. However, for example,
the authors did consider the sewer pipe analogy and river delta analogy were “intermediate,” since students likely had only cursory understanding of these. The “visual” vs. “functional” demarcations were based on whether students were aided in visualizing the target analogies or whether their visualization was to be improved. The “ear of corn” analogy was deemed to be “visual,” and the “fire” analogy was deemed to be functional (p. 7).

As mentioned and discussed in this paper (see p. 29), overmapping, mismapping, failure to map, and retention of a base feature are types of errors students can make when using analogies. Else et al considered the four types of errors in their research. The researchers hoped to determine which types of analogies led to which type of errors.

In one part of the research, students were provided the “water pipe” analogy and “river delta” analogy near the beginning of the lesson on the circulatory system. They consider that the “river delta” analogy for the circulatory system is a more visual analogy, since the overall appearance is similar to arteries, veins, and capillaries. The “water pipe” analogy, however, is more functional according to the authors. Students in small groups were asked to draw a group model of how water would get from a reservoir to the rooms of a house. About the analogies, the authors state:

- Vessels branch, and they branch from big to small. This is so they can get from a large main source to many small specific locations. This reinforces the river delta analogy and adds functional and relational components to it.

- Pipes/vessels that carry “good” and “bad” material are separate because otherwise waste and needed elements would mix (Else et al., 2003, p. 9)

Several mistakes were made in the application of analogies. Student groups had difficulty dealing with keeping waste water separate from fresh water in their models. (p. 9) Groups were also asked to make a “water pipes” model out of pasta of different thicknesses. The authors not that students had difficulty in the transitioning of pipes from large to small, in that their transitions were often from a large pipe to a small pipe, when several small pipes or
intermediate size pipes would be necessary to account for pressure changes (p. 9). It became obvious to teachers that students had “not all successfully mapped all relevant elements of the water pipes and river delta to the vessels leaving the heart” (p. 10). The authors suggest that understanding and analogical transfer would have been greater if students and teachers had explicitly “mapped the portions of both analogies that provide explanatory power” (p. 10). They suggest that,

This could have been done by asking students to vote on and discuss ill designed alternatives to the standard water pipe model, in the same way this was done for the blood stream. This relationship could then have been mapped explicitly from base to target. Our formative observations suggests that explicitly mapping the relations in the pipes analogy – the ways in which water flows through the pipes – rather than just the elements, the pipes themselves, would have been helpful. (Else et al., 2003, p. 10)

How exactly the relationship should have been mapped is not discussed. Yet clearly a process what helps students to avoid the errors associated with learning from analogies is in order. The authors claim that the most common error overall was “failure to map,” as in, for example, the case in which students did not allow for pipe width transitions in their pasta-pipe models. Making thinking visible here and encouraging students to compare the delta analogy and pipe analogy and to arrive at consensus may have prevented this “failure to map” adequate pipe dimensions.

Finally, the authors conclude of the two circulatory system analogies, “…we cannot separate out the effects of the two analogies, and consider them synergistic.” And, “…we would suggest that having dual analogies was, in this case, useful, and that the familiarity of both bases and the relative familiarity of the target was a plus. The pipes analogy may act as a bridging analogy between more familiar but more distant river analogy and the target” (p.11).
The fact that the authors considered the analogies to be “synergistic” means that both are seen to have worked toward the same goal, which was helping students to learn about, talk about, visualize, and otherwise represent the circulatory system. The fact that the two analogies, the “water pipes” and the “river delta,” had both overlapping and different features helped to provide depth and context to student discussions that would have been very difficult to provide if the circulatory system had been discussed without analogies or if just one analogy had been used.

Clearly, there is value in offering multiple analogies for the same science concept, as both Else et al., Podolefsky and Finkelstein, and others (Dedre Gentner & Gentner, 1983; Dedre Gentner et al., 2003; Gick & Holyoak, 1983) have shown. Whereas Podolefsky and Finkelstein provide pre and post-test data that quantitatively supports the notion that multiple analogies support learning about sound waves better than one alone does, Else et al. provide a qualitative picture of students’ false steps taken when working with pasta-circulatory models and “failure[s] to map” or “mismapping.” Both speak to the advantages of comparing two or more analogies.

Choosing the Right Analogy

What is the right analogy? In the works just discussed by Podolefsky and Finkelstein and Else et al. the analogies were selected by the teachers for the students. Indurkhya (2007) makes a note about studies on analogy, such as those discussed in this paper,

what we can conclude from these experiments is that reasoning from a source [analogue] that is similar to the target [analogue] can be effective provided that the "right" source is given. For real-world problems, when no such oracle [or teacher] is available for consulting, it is far from clear whether reasoning with similarities bring about any pragmatic success. (Indurkhya, 2007, p. 20)
In the real world, we have no “oracle” to tell us which analogy to use. Instead, a rich, interactive, socially negotiated, and guiding context permits us to try out the usefulness and explanatory power of an analogy.

An analogy is an idea that can lead us to understand a concept in a new way. Indurkhya recounts a story of scientists attempting to use a new fiber in a paintbrush and having difficulty. The fiber simply did not produce good results when painting. The scientists had difficulty understanding this, since their analogical model for painting was smearing; and these fibers were certainly able to smear paint onto a surface. Later, the scientists realized that in fact the bend in the bristles of a paintbrush actually squeeze the paint between the bristles toward the tip of the brush like toothpaste in a near empty tube. A better and more productive analogy for painting, they found, was pumping. This analogy allowed the scientists to understand the process of painting differently and more toward better ends for a more appropriate fiber. Indurkhya states, the analogies “underlying the structures are different. For example, the space between the fibers plays no role in the structure of painting-as smearing model, but is a key factor in painting-as-pumping model” (Indurkhya, 2007, p. 22).

What it means to paint, a seemingly simple process, changed through the development of this “painting-as-pumping” analogy. This is at once ontological and also epistemological. What painting means and what painting is become recontextualized and redefined. Not only how the scientists talk about and make decisions about painting fundamentally changes, but what painting actually is changes for those of us who would endeavor to understand it. The analogy guides our thinking toward productive interaction with the environment, in this case successful painting – painting as pumping.

The fact that scientists’ pre-existing ideas about painting changed completely is an example of conceptual change. Conceptual change research pays particular attention to students’ pre-existing ideas and how they change or evolve during instruction (Duit, 2003; Posner, Strike, Hewson, & Gertzog, 1982). This conceptual change in the scientists came
about from comparing evidence produced through interacting with the environment (i.e., the scientists tried to paint with various materials) with a new analogy, which proved successful at explaining painting. The production of the analogy was guided by the comparison of the actual performance of the various bristle fibers with the painting-as-pumping analogy. Again, comparison, argumentation, and time for reflection are shown to be key in learning.

Gathering Direction for the Present Research from the Literature

The present research builds on the literature discussed in this chapter. In order that science education lead to productive engagement (i.e., learning) (R. A. Engle, & Conant, F. R., 2002), it must contain more communication and social negation of concepts. One way to accomplish such social negotiation of concepts toward learning is argumentation. Argumentation can allow students to better appreciate the tentative nature of scientific knowledge and the context which gives rise to it. Unfortunately, argumentation has some remaining problems. Chiefly, students do not talk about what they do not understand. If argumentation is to lead to learning, then clearly students must be supported while engaging in it. One such way to support students is to scaffold them. The word “scaffolding” has come to mean many things, from problematizing and structuring, to coaching, to modeling, etc. More interesting as a type of scaffold is distributed cognition (Pea, 2004). No one has any real expectation that ubiquitous devices such as airplanes and calculators will ever be faded as scaffolds, leaving human beings to accomplish unaided the tasks they allow us to complete. Although this may seem obvious, it is less obvious how to fade educational scaffolds. Can electricity, quantum mechanics, or similarly intangible phenomena really be understood without a scaffold in the form of a model – mathematical, conceptual, or otherwise? Maybe it will always be useful for those of us who would understand electricity to refer to the water-electricity analogy. Along those lines problematizing and structuring tasks to allow for student analogical-comparison-based argumentation in science class be a process that might have a longer lasting
impact than just a particular day’s lesson. Its impact might instead last a lifetime. Comparison, reasoning by analogy, endeavouring to find the right analogy, and communicating around these are important aspects of understanding.

Scientists such as Oppenheimer, Kepler, and Priestley have all used analogies to develop models (Glynn, 1991). Just what the difference is between the solar system model for the atom and the solar system analogy is unclear (Harrison & Treagust, 2000). Scientists use analogies for scaffolding their thinking as do real people in their everyday lives (Dunbar, 2001). Models are but one type. Educators and students should use these as well. Rather than being a feature of lecture, however, analogy use must become a process.

According to Kelly and Duschl (2002) “analogies, metaphors, etc. can be viewed as interactionally accomplished through discourse processes” (p. 14). The process of negotiating analogies socially toward explaining and learning can have many benefits. Like concept maps, for example, the analogical mapping process has the potential to allow groups of people to develop a shared understanding (Cardellini, 2004). Advantages are myriad. Analogies are persistent, which means they can be accessed, pointed to, referenced over time by all group members. Unlike concept maps, however, analogies have the potential for more internal consistency.

Analogical mapping activities have the potential to provide a rich context for argumentation that allows students to share meanings, pick up on one another’s comments, and engage in argumentation and explanation that leads to learning. This is important for argumentation, as Sampson and Clark (2008) suggest, in their review of argumentation literature:

As researchers in our field move into new areas of research focusing on argument and conceptual change, however, we will need new tools with more explicit focus on the content, logical coherence, relevance, and explanatory power of the claim/assertion/explanation. (Sampson & Clark, 2008, p. 21)
Analyses have “logical coherence” and “explanatory power” as well as other features that Sampson and Clark (2008) suggest are important. And Heywood (2002) suggests that research should focus on “the role of analogy in generating engagement in the learning process.” (p. 233) The need to make analogy more of a process for student engagement and the need to scaffold and support argumentation come to a confluence which suggests that argumentative analogical mapping in small groups is worth investigating.

Coll (2006) states, “There have been comparatively few studies about actual use of analogy during instruction” (Coll, 2006, p. 73). Similarly, Gadgil and Nokes state, “the role of analogies has not been extensively examined in collaborative settings” (Gadgil & Nokes, 2009, p. 3116). The quantitative research that shows that learning is improved with analogies (Gadgil & Nokes, 2009, p. 3120; Dedre Gentner et al., 2003, p. 403; Kurtz et al., 2001, p. 438) is helpful, but is lacking in specifics that can inform instruction and the development of interventions and curriculum broadly.
Works Cited


Chapter 3
Design Rationale and
Methodology
Design Rationale

This research was undertaken with the belief that the use of comparative tasks, such as analogical mapping, has the potential to scaffold students’ argumentation in three important ways. Comparative tasks could scaffold students by: providing a process, contextualizing content, and allowing for the use of relative language. These will each be introduced in this paragraph and further explained below. First, comparative tasks provide student small groups a process through which their argumentation is scaffolded. Next, as students make analogical correspondences they are literally making connections between elements of simple machines. The connections students make allow students to understand the context of each simple machine element. Finally, students, when comparing simple machines are able to employ relative language, the language of comparison (e.g., similar to, larger than), which can make new science concepts such as simple machines easier to talk about.

Analogical mapping within a comparative task can scaffold students by providing a process toward evaluating a whole system and the relationship of the parts within it; in this case a simple machine is a system. Scaffolding students by embedding a process in the task can be an important way to help student groups attempting argumentation to avoid awkward silences while pondering the next step or not knowing how to proceed. The process based nature of analogical mapping can help student groups find a next step.

The process of analogical mapping scaffolds students in making correspondences between parts of simple machines. As they do this, they are also making connections. These connections form a set of interrelationships and thus are allowing students to develop a sense for the context in which a given simple machine or its parts work together and how those simple machines are like other simple machines. Understanding of context is necessary for meaningful learning and understanding (Brown, Collins, & DuGuid, 1989; Greeno, 1997).

Learning, by definition, involves dealing with new concepts. Students can have difficulty arguing about concepts they do not yet fully understand (von Aufschnaiter, Erduran, Osborne, &
Comparative interventions can offer a scaffold to students’ argumentation around new concepts by allowing them to use relative language. Relative language is language that explicitly compares, such as: similar to, bigger than, alike, different from, etc. It has been shown to be easier to make an argument about new concepts by comparing them and using relative language (Mussweiler & Epstude, 2009).

The Activity Described

All three of types of scaffolding offered by the comparative activities – providing students a process, contextualizing content, and use of relative language – can be addressed by one type of comparative intervention. This intervention invites student small groups to argue in favor of one best analogue to a science concept given a possible two (see figure 3.1). Although, in this research the concepts and analogues are various types of simple machines, any case in which multiple analogies could be offered to students could be used in creating a similar comparative intervention.

Simple machines were chosen for this research for two reasons. First, they represent about half of the content in the course in which the research was done. Second, they are all analogues in a sense, since they have parts that work as a system to accomplish the same task – usually to lift an object – in similar ways. They all require manual input that can be measured in both force and distance (i.e., effort force and effort distance). They all move a load which also provides a force and moves a distance (i.e., resistance force and resistance distance). And, they all trade distance for force; usually, effort force is reduced while effort distance is increased.
A Sample Activity

This type of comparative intervention invites students to first perform analogical mapping between the new concept and both potential analogues and then to make an argument in support of which potential analogue is most like the new concept. Consider the activity handout shown in figure 3.2 as an example. It was used as activity four of seven in this research. Student groups are asked, “Which simple machine is most like the lever in the way it works? Why? The wheel and axle or the inclined plane?” They are also instructed to use analogical mapping between the lever and each of the other simple machines. In this case the students had already worked with levers and inclined planes. They had not yet worked with or studied the wheel and axle.

Although at first glance the lever and the inclined plane appear more similar since they have roughly the same shape, the lever and the wheel and axle are more analogically related as

<table>
<thead>
<tr>
<th>Effort Arm Length</th>
<th>Ramp Length (Effort Distance)</th>
<th>Both, when increased in length, reduce effort force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance Arm Length</td>
<td>Ramp Height (Resistance Distance)</td>
<td>Both, when decreased reduce effort force</td>
</tr>
<tr>
<td>Load</td>
<td>Load</td>
<td>Moving the load is the purpose of both machines</td>
</tr>
</tbody>
</table>

Table 2.5: Analogical Correspondences between the Lever and the Inclined Plane
the correspondences will show. The correspondences between the lever and the inclined plane that students would likely come up with are shown in table 3.1. The list is not exhaustive. Other simple machine elements that could correspond could include: effort force, resistance force, effort force direction, etc. Note that the fulcrum, or point of rotation of the lever, has no analogically corresponding element on the inclined plane, whereas the wheel and axle does. This is important given the central position and functional role the fulcrum has in the lever.

Between the wheel and axle and lever many of the correspondences are similar; however, there are differences. Table 3.2 lists correspondences between the lever and the wheel and axle. And figure 3.3 shows labels for the wheel and axle. Note that the lever’s fulcrum corresponds well to the axis of rotation, or center point, of the wheel and axle. Consequently, a whole series of relationships also corresponds analogically. These include but are not limited to those listed in table 3.2 above. For example, the effort force directions correspond; both effort forces move downward. Resistance force directions also correspond; both resistances pull downward. There are numerous other correspondences as well.

Once student groups make correspondences between both pairs of machines they need to make an overall argument answering the question of which two machines are most alike in the way they work. Student groups can consider various things in making this final argument. There are more analogical correspondences between the lever and the wheel and axle, as shown by comparing the tables above. Perhaps more important is the fact that the wheel and axle have analogical correspondences that fit together as a system. Consider figure 3.4, which
shows a lever, a wheel and axle, and a lever superimposed onto a wheel and axle (bottom of figure 3.4). When shown superimposed like this, the functional and structural analogy can be more easily seen between the two machines. For example, as mentioned, both machines have a center point which divides the part of the machine supporting the load force and the part supporting the effort force. On the lever this is the fulcrum and on the wheel and axle it is the axis of rotation. Note also that on the superimposed diagram at the bottom that both the hand on the lever and the hand on the effort string of the wheel and axle would pull down.

The analogical correspondences between the wheel and axle and the lever fit together as a system better than those between the lever and the inclined plane. The correspondences are deeper and richer, as they correspond in function, structure and position. Although the lever and the inclined plane may look alike and there are actually some analogical correspondences between the lever and the inclined plane, these are less systemic. The center point of rotation found on the lever and wheel and axle can lead one to make more related surrounding analogical correspondences to the left and right (e.g., effort arm length to wheel radius). Such a point of rotation and surrounding correspondences is nowhere to be found on the inclined plane.

How the Activities Can Scaffold Student Small Groups’ Argumentation

The activity described above and others like it were expected to scaffold student small-group argumentation and learning in the three ways mentioned previously. The activities can provide groups a process to undertake, they can contextualize content, and they can allow for the use of relative language in learning. Each of these will now be related to the activity above more specifically.
Scaffolding by Providing a Process

Comparative interventions such as the one described above scaffold students’ argumentation and learning by providing student groups a process to undertake. This process, the process of analogical mapping, involves identifying elements of simple machines (e.g., fulcrum, effort arm, resistance distance, etc), finding correspondences between those elements and elements on another machine, and finally creating an overall argument that addresses the guiding question at the top of the handout.

Making arguments about science concepts that are not yet fully understood learning can be difficult (von Aufschnaiter et al., 2008). Having a process to undertake can scaffold students by helping them identify and take a next step when dealing with a new or unknown concept. This process can reduce the chance that argumentation ends in silence or without students having considered important parts of an argument. Thus, the possibility of learning through small group argumentation is increased.

Scaffolding by Contextualizing Content

Correspondence making between simple machine elements, an important part of analogical mapping, can scaffold students to argue and learn about the context in which a simple machine works. By making correspondences, students are making connections and arguing about relationships in context. Understanding how one simple machine element corresponds analogically to another necessitates understanding of the elements’ functions and structures and how they relate.

As student groups carry out the process of analogical mapping and argumentation about it, they are systemically mapping out relationships represented by the correspondences. At the end of this process it is likely that student groups will have considered, argued about, and mapped out correspondences for all or many of the simple machine elements. Thus it is likely that student will learn to relate simple machines to their context in two important ways. They
should be able to consider a given machine as a whole system in relation to other similar simple machines (e.g., a lever to a wheel and axle). Also, students should be able to relate elements within a given machine to each other (e.g., an effort arm to a resistance arm).

Scaffolding by Allowing for Relative Language

When making correspondences it is expected that relative language will be used. Relative language, for the purposes of this research, is the language of comparison. Examples include words and phrases such as “like,” “larger than,” “more than,” “similar to,” “different from.” This language can be more accessible to students than more appropriate formalized scientific definitions, which students will not yet have mastered as they are still learning about a concept.

Relative language can have an important scaffolding effect. Inviting students to make comparisons that employ relative language has been shown to increase reduce student need to for outside knowledge in making valid arguments (Mussweiler & Epstude, 2009). The need for additional materials is reduced and the activity can become more self-contained. Student argumentation can focus less on what may have been learned and forgotten months ago, for example, and more on the here and now. This can allow for a shared context among student small-group members – one in which meanings are likely to be shared and communication can be effective.

Context and Sample

This research took place in a course designed for pre-service elementary teachers as an elective to help them become more competent in teaching science. The course offered both science content and pedagogical content together. The science content consisted of four weeks of structural analysis and design, seven weeks of measurements with and use of simple machines, and three weeks of basic electrical concepts. Pedagogical content centered on the design principles informing the guided inquiry activities (example in appendix 2) around the
science content. Students were invited to evaluate their own learning experiences while doing the guided inquiry activities. They were also given assignments inviting them to design similar activities for their own teaching and asked how they might improve or modify the activities. Finally, readings dealing with teaching and learning with inquiry were assigned and discussed.

The course was offered to freshman elementary education majors at a large research university in the Eastern United States. For most of the preservice elementary teachers, it was their first science class at the university level. Two sections of the one-semester three-credit class met twice weekly for one and a half hours. All students had had a high school physics class.

The class was taught by two graduate students. One instructor, Mark Merritt (actual names used), had taught the course for two semesters prior. Before that he had taught another similar class. Mark taught one section involved in this research. The other instructor, Betsy Larcom, was teaching the course for the first time. She had, however, assisted with the course and others like it in the preceding three semesters. Betsy had two sections involved in this research.

All students in these three classes were asked to participate in this study. Each class was given a thirty-five-minute introduction the research by the principal investigator. In it they were told that they would be invited to make arguments about potential comparisons on simple machines, something they would be learning about anyway. They were also told that no additional work would be necessary, since all activities would be completed by the entire class anyway. Furthermore, they were instructed that if they were to participate, they would be audio and video recorded over the next seven weeks while doing activities and also asked to take part in optional individual interviews of about ten minutes.

Mark’s section had 15 students, of whom 11 participated in the study. In Betsy’s class of 24 students, 20 participated. And in her other class of 23 students, all students chose to participate. Overall, 54 students took part in the research.
Per Office of Research Protections, students were also told that if someone chose not to participate, his or her anonymity would be assured to the rest of the class and the instructor. In this case a minimum of one entire table would not be recorded. Only the principal investigator and the student him or herself would know who at the table had elected not to participate.

Classes were seated around small tables in groups of four, or in a few cases when necessary, three. (See figure 3.4.) Given the low number of males in the class – Betsy’s two sections each had only two males and Mark’s section had three males – most of the groups were all female. The groups did not change over the course of the semester in order to protect anonymity of nonparticipants. All work for this research was done in these groups.

**Design Process**

The comparison task activities on simple machines, shown in appendix 1, were designed by the principal investigator and the instructors. A few sample activity handouts were provided to instructors Betsy and Mark and several discussion sessions happened in which they and the principal investigator conferred to create the activities. These handouts contained activities in which students were provided a concept that was to be compared to two potential analogues, in other words, a model for the type of activity to be investigated. Overall, twelve activities were created and/or evaluated.
The activities were chosen by the instructors and the principal researchers based on creating a workable and logical schedule. Specifically, it was important that students receive exposure and the chance to use at least two of the simple machines involved in the comparative activities before undertaking them. To that end, the activities shown in appendix 1 were chosen and performed in that order.

**Methods**

Over the course of the seven-week unit on simple machines, seven comparative analogical argumentation activities, similar to the one described at the beginning of this chapter, were given to student small groups. These lasted from thirty minutes to seventy-five minutes.

Students also performed another type of activity on simple machines. This type of activity, of which there were five, invited students to build Lego® models of simple machines, use them to lift a load, and measure effort and resistance forces and distances in order to calculate ideal mechanical advantage. A sample handout for these can be found in appendix 2.

Before doing any comparative activities on simple machines, students received a total of 60 minutes of training on how to do analogical mapping. To maximize accessibility to students, two non-scientific examples were given to students to compare. One of these is shown in figure 3.5. This was taken from Holyoak’s (2004) *Analogy*. (p. 128) A class discussion, in which analogical mapping between the top and bottom scenario was done, was led by the principal researcher just before handing out permission forms. Thus, student work on it was not recorded. The
activity and surrounding discussion had two purposes. One was to inform students about what they would be doing throughout the course of the research if they were to choose to participate. The other purpose was to provide training on analogical mapping.

Analogical mapping training with this activity allowed for students to consider the difference between featural (or superficial) correspondences and relational (or functional) correspondences (called matches in the diagram). For example, there is a person shown in both the top and bottom scenarios. Both have two legs, similar height, similar appearance, etc. In other words, their features correspond; however, their respective functions do not. In the top scenario the person is restraining the dog, whereas in the bottom the person is being chased by the dog and the tree is holding back the dog. Functionally, the person on top corresponds to the tree on the bottom, since both have the same function. The person on bottom, on the other hand, as is being chased by the dog just as the cat is in the top scenario. Thus, the cat on top best corresponds to the person on bottom.

The contradictory superficial and functional features allow students to consider and discuss the whole system of relationships and how, when viewed as a system, it makes the most sense to make a correspondence between the person on top and the tree on bottom. If one were to instead make a correspondence between the two people, then function would be ignored. And, the cat on top would not be allowed to correspond to the person on bottom, since the person would already be accounted for.

The training also provided for students to encounter ambiguous correspondences. For example, consider the tree at the top. It has not apparent function in relation to the other elements in the scenario. Should it best correspond to the tree at the bottom? The cat? Nothing? The answer is not clear. Of course the tree in the top scenario shares superficial features with the tree on the bottom. However, both the tree on top and the cat on bottom have not apparent relationship to the other three elements in their respective scenarios. So, do they best correspond? Or, perhaps the tree in the top scenario has no corresponding element in the
bottom scenario. This element could only ever have an ambiguous correspondence. Regardless which correspondence one would choose to make, a supporting argument would need to be made. And there still would be remaining counter arguments.

Exposing students to this type of ambiguous correspondence in the training ensured that they would be less likely to expect the analogical mapping process to be straightforward. They would be prepared for some frustration. This was important, as the comparative analogical mapping activities differed greatly from the activities normally done in the class in which simple machines were built, used, and measurements were made.

A few days after the initial training and gathering of permission forms another training session was given on analogical mapping (see appendix 1). This one involved general science content that students had likely already learned in order to not affect later simple-machine-based tasks and to be accessible to students.
Timeline for Data Gathering

The order of events is summarized below in the timeline. The comparative argumentation tasks involving analogical mapping are emboldened.

I. **Week 1**
   a. Tues
      i. Participants Sought, Permission Forms Provided, **Training 1 – Comparative Argumentation Task 1** – Dog Scenario (Appendix 1)
   b. Thurs
      i. Pretest (Appendix 3)
      ii. Students Build, Use, and Make Measurements with an Inclined Plane (See Appendix 2)

II. **Week 2**
   a. Tues
      i. **Training 2 – Comparative Argumentation Task 2** – General Science Concept (Appendix 2)
      ii. **Comparative Argumentation Task 3** - Inclined Plane vs. Screw (Appendix 1)
   b. Thurs
      i. Students Build, Use and Make Measurements with a 1st Class Lever (See Appendix 2)

III. **Week 3**
   a. Tues
      i. Students Build, Use, and Make Measurements with All Classes of Levers (Appendix 2)
   b. Thurs
      i. **Comparative Argumentation Task 4** – Lever vs. Wheel and axle and inclined plane (Appendix 1)

IV. **Week 4**
   a. Tues
      i. Students Build, Use, and Make Measurements with Pulleys (Appendix 2)
   b. Thurs
      i. **Comparative Argumentation Task 5** – Pulley vs. Couch Lifters (Appendix 1)

V. **Week 5**
   a. Tues
      i. **Comparative Argumentation Task 6** – Wheel and axle vs. Pulley and Lever (Appendix 1)
   b. Thurs
      i. Students Build, Use and Make Measurements with Pulleys 2 (Appendix 2)

VI. **Week 6**
   a. Tues
      i. Students Build, Use, and Make Measurements with Gears (Appendix 2)
   b. Thurs
      i. Test Review Discussion

VII. **Week 7**
    a. Tues
       i. **Comparative Argumentation Task 7** Part 1 of Unit Test – Screw Jack vs. Inclined Plane and Wheel and Axle (Appendix 1)
    b. Thurs
       i. Part 2 of Unit Test on Simple Machines (Appendix 4)
Providing Comparison Task Activities - Methods

About a week after the initial training sessions, comparison activities involving simple machines began. The instructors introduced them all with an approximately three-minute discussion on the guiding question. For example, the guiding question in the activity handout shown in figure 3.6, “Which simple machine is most like the wheel-and-axle in the way it works? The pulley or the lever?” was read to students. They were then reminded to use analogical mapping to find correspondences between the elements of the machine pairs and to use these correspondences in their arguments. Finally, students were provided instruction on the use of each simple machine, two of which they had already built and worked with. For example, in the activity shown in figure 3.6, students had already built, used, and made measurements using the pulley and lever. The wheel and axle was a still a new concept to them.

During the activities both instructors circulated to help students. The principal investigator was also present primarily to verify the proper functioning of recording equipment. Help was restricted to procedural questions. No analogical correspondences were given or corroborated, for example. After the activities, student-group results were shared and whole-class discussions were held on what had been learned and points of difficulty.
Data Collection

All participating groups were recorded with a digital video camera affixed to a tripod about one foot away from the desks and for redundant but clearer sound, an iPod equipped with a microphone. See picture 3.2 at right.

In all, 48 hours, 38 minutes, and 6 seconds of video were captured, not including the first training session. Across all the groups, an average of 9 hours, 44 minutes was collected for each of the activities. This averages to 42 minutes per group per activity. Of this, student small-group argumentation from each group was transcribed resulting in transcripts for 24 hours, 21 minutes total. Due to technical issues with equipment, one group’s data was not transcribed for two activities.

Roughly half of all video data was transcribed. Parts that were not related to argumentation were not transcribed. Side conversations longer than about five utterances were not transcribed. Instructor talk, since it was present on each group’s recording, was generally not transcribed. If it was, it was transcribed on one group’s videotape only. In those cases, however, where instructor talk served to redirect student group argumentation or otherwise affect it, it was included. Finally, as students were filling out related papers and posters for the comparative activities there were often periods lasting several minutes with no talking.

Units of Analysis

In order to do this analysis, it was important to break large transcripts of over 400 utterances into smaller pieces which can be separated and organized. For this Pontecorvo and
Girardet’s (1993) categories were used. Moving from broader and more encompassing to more focused categories, the authors offer the following three: “frames of discourse,” “reasoning sequences,” and “idea units.” Each of these units of analysis will now be discussed and related to the present research.

Frames of Discourse

The authors define “frames of discourse” as “general mood of the discussion.” They continue, “a part or a phase of a discussion that is characterized by a discursive activity and by a related cognitive function. Such functions are usually pursued by the teacher, who proposes her or his general goals to the children’s group” (Pontecorvo & Girardet, 1993, p. 370). In other words, a frame of discourse is a large encompassing category, of which Pontecorvo and Girardet had only two, that can delineate the general goal of the discourse.

For this research, there are three “frames of discourse” relating to “cognitive functions.” These were known before analysis began, since they were steps necessary to complete the activities. They are:

1. identifying elements of simple machines (e.g., effort arm, fulcrum, resistance distance, etc)
2. finding correspondences between elements of two simple machines (e.g., the lever’s effort arm length corresponds to the radius of the wheel)
3. comparing overall systems of simple machines (the wheel and axle analogically corresponds better to the lever than the pulley)

Together, these can account for nearly any given moment of discourse students might have during their argumentation.

Identifying elements of simple machines means, through argumentation (assertion, questioning, rebuttal, etc), to attempt to describe, define, find or otherwise indicate an element
or part of a simple machine. For example, statements such as, “this is the wheel,” “the effort arm of the lever is between the fulcrum and the effort force,” “No. I think the effort arm is really…,” or even “Is this the axle?” would all fall under the category of the identifying and defining elements of simple machines frame of discourse.

The next frame of discourse, finding correspondences between elements from two simple machines, means to assert that one element on one simple machine corresponds functionally to an element of another simple machine. Examples would be comments such as, “I think the fulcrum corresponds to the center of the wheel and axle,” “Does this correspond to that?,” and “That’s wrong. In fact this corresponds to…” These all would be categorized as finding correspondences between elements from two simple machines frame of discourse.

Finally, comparing whole systems of simple machines means to assert or question that one simple machine as a whole is a better functional analogue to one simple machine versus another. For example, statements such as, “I think the wheel and axle works more like the lever than the pulley because…,” or “The screw jack works more like a wheel and axle than an inclined plane, since…” would be examples of student groups comparing whole systems

Reasoning Sequences

Pontecorvo and Girardet (1993) state, “embedded in the [frames of discourse], consists of smaller, well-identified reasoning sequences in which particular epistemic actions (or subactions) are pursued” (Pontecorvo & Girardet, 1993, p. 370). Reasoning sequences in the present research were found to last from a few utterances up to dozens of utterances over several minutes. Nearly all reasoning sequences contained discourse of students performing argumentation in order to put forth, consider, and or refute a given correspondence between elements of two simple machines (e.g., the effort arm of a lever corresponds to the radius of the wheel). Fewer utterances involved student argumentation to identify elements of simple
machines (e.g., this part is the effort arm of the lever). Figure 3.8 represents both as they were analyzed in actual data.

Specifically, figure 3.8 shows a screen capture from a program called StudioCode®, available for the Mac®. This program was used to transcribe and code video. With the program one can keep transcripts and codes in the same StudioCode® file folder as the video itself. These can then be accessed and worked with in tandem. Note the transcript on the upper right, the video window on the upper left, and a timeline with codes along the bottom. Also, the timeline is shown enlarged below the screen capture for clarity.
On the timeline, which represents about fifteen minutes of argumentation analysis, two frames of discourse are shown - *Identifying elements of simple machines* (blue) and *Finding correspondences between elements from two simple machines* (yellow). Although frames of discourse provide the flavor of the utterances, the reasoning sequences are larger blocks of time.

On the transcript, utterances seeking to identify an element of a simple machine were less frequent than utterances seeking to establish a correspondence. This is likely because, in many cases, students in a group shared a common understanding, or at least thought they did, about what a given element of a simple machine was. Cases where utterances were directed at discerning what exactly a given element was almost always occurred within larger reasoning sequence whose goal was to find a correspondence for that element. Thus, reasoning sequences, for the purposes of this research, contain utterances related to finding a correspondence, and utterances related to discerning a definition for a simple machine element, if it became apparent that a definition was unshared.

There are 13 reasoning sequences coded above and represented by the blocks that are uninterrupted by spaces. In all of these but one, number 10, most of the time was spent on the correspondence making (represented by the lighter color (yellow)). Nonetheless, most reasoning sequences consisted of utterances of both of the first two types of frames of discourse - *Discerning elements of simple machines* and *Finding correspondences between elements from two simple machines*.

The third frame of discourse, *comparing overall systems of simple machines*, was not shown in this diagram, as it occurred later. In the comparing whole systems, reasoning sequences and the frame of discourse were coded as running concurrent. These necessarily occurred at the end of the transcripts, after correspondences had been made. Three examples of this type of frame of discourse will be shown in the fourth section of analysis in this chapter.
Idea Units

Pontecorvo and Girardet (1993) describe the “idea unit” as “the smallest units in which the discourse is analyzed” (p. 370). “At this level, we have also marked what was unexpressed by speakers and left at an implicit level” (Pontecorvo & Girardet, 1993, p. 370). Two or more idea units may appear in a single utterance. For example, the sentence “this is the effort arm because it is longer” contains two idea units. The first idea unit is “this is the effort arm.” And, the second idea unit is, “because it is longer.” Or, sometimes no idea unit may be present in an utterance. For examples, place holders or incomplete utterances such as, “ummm” and “I...I...think” convey no ideas and thus have no idea units.

This unit of analysis is highly dependent on context and requires individual analysis. Since idea units are the smallest unit of analysis, they are largest in number and thus represent the bulk of the analysis text offered in this chapter. The results chapter of this work provides excerpts of transcripts with an analysis of each idea unit that is present immediately following.

Units of Analysis in Relation to Each Other

As in Pontecorvo and Girardet’s work, reasoning sequences were each coded simply as “reasoning sequences” and indicted on the transcript as lasting a certain duration (see p. 96, line 1 – reasoning sequence). The analysis in the current work added the additional step of labeling the reasoning sequence in a phrase or sentence to capture the gist. Example labels include: “Group argues about possible correspondence between lever’s fulcrum and wheel-and-axle’s axis of rotation;” “Group argues about correspondence between effort arm length and wheel radius;” and “Group argues about whether the lever or the pulley is most like the wheel-and-axle.” In all, there were over forty such labels. As these three examples were somewhat obvious to most groups upon detailed consideration and follow up argumentation, they occurred among all groups. Other labels for reasoning sequences, however, were shared less frequently; some were applied as few as one time. There were two primary reasons for this. First,
relatively rare mistakes were made either in identifying a simple machine element or making a correspondence. Only one group, for example, attempted to make an analogical correspondence between the axis of rotation of a wheel-and-axle and an axis of rotation of a pulley wheel. Second, a few groups came up with correct correspondences that were rarely thought of, because they were not germane to the analogical mapping task at hand.

Figure 3.9 below shows the relationships between Pontecorvo and Girardet’s units of analysis and the reasoning sequence labels also employed in the present work. Pontecorvo and Girardet’s units - Frames of Discourse and Reasoning Sequences were used as codes. Whereas, reasoning sequence labels, of which there were over forty, were used as labels on the transcripts, as these would be cumbersome to apply as codes. So, too, idea units were applied in the analysis individually during discourse analysis as these make up the bulk of the discourse analysis on an utterance by utterance level in Chapter 4.
What Counts as Evidence?

This research seeks evidence that student learning through argumentation is scaffolded by the comparative argumentation activities used. Specifically, in this research evidence will take the form of discourse showing that student learning and argumentation is “channeled” and “focused.” As discussed in the literature review of this work, Pea (2004) describes “channeling and focusing” as:

reducing the degrees of freedom for the task at hand by providing constraints that increase the likelihood of the learner’s effective action; recruiting and focusing attention of the learner by marking relevant task features (in what is otherwise a complex stimulus field), with the result of maintaining directedness of the learner’s activity toward task achievement. (Pea, 2004, p. 432)

The goal of this research was to problematize and structure simple-machine-based content in order to channel and focus student argumentation. Thus, suitable evidence consists of examples of this occurring. Initial codes must therefore address this also. Consider how the codes were developed to address this.

Initial Codes

Initial coding and transcription was performed using StudioCode®. As mentioned previously, StudioCode® is a program for the Mac® which permits one to view, code, and transcribe video all on one screen. Coding is done by assigning keys on the keyboard which, when pressed while viewing the video, turn on and off a code. A complete screen shot of the program is shown on the next page in figure 3.8.

Since it was hypothesized that analogical-mapping-based comparison activities would: provide students a process to scaffold their argumentation; contextualize content for students; and allow students to use relative language, any coding would need to begin with these in mind. As a result, initial codes were:
1. Reasoning Sequences (unit of analysis)
2. Comparative Language (e.g., like, analogous to, larger than, different from, etc)
3. Identification of Simple Machine Elements (e.g., this part of the machine is the…)
4. Claims (any assertion put forth as true)
5. Justification (any rationale or reasoning for a claim)
6. Misconceptions (a claim or justification that is false)
7. Questions (student to student questions)
Some of these codes may overlap. A few other place-holder codes such as “interesting,” and “clarification” were used in some early coding but discontinued after nine videos (each averaging 42 minutes) were coded. Since they were too general, they were replaced by the codes above. The codes are visible along the left side of the timeline. In the approximately fifteen-minute timeline in figure 3.8 there are twelve reasoning sequences (see top line of codes). Most lasted about a minute; but a few, consisting of fewer utterances, lasted only a few seconds.

The reasoning sequences, well defined sequences “in which particular epistemic actions are pursued,” (Pontecorvo & Girardet, 1993, p. 370) became the main code. Other codes, as can be seen in figure 3.8, were concurrent with the larger reasoning sequences.

During nearly all reasoning sequences, student groups spent the bulk of their time and their utterances engaging in argumentation around potential analogical correspondences (mappings) from one simple machine element to another simple machine element. And as can be seen on diagram 3.8 and in the excerpt below, which shows a complete reasoning sequence, identification of simple machine elements was also a common code found within reasoning sequences.

The excerpt below exemplifies several codes. In it Susan and Valerie (two other group members do not speak in this reasoning sequence) are arguing about a possible correspondence between “the ball” to be rolled up the ramp and “the wall.” These both provide resistance forces to their respective simple machines (see figure 3.9, next page). The terms are in bold in the excerpt below in the first utterances by Susan. Consider the rest of the transcript.

00:18:34:75 Susan Ummm. And, I guess like the... if we could technically use like that ball right there could be equal to the wall. Because that ball is what you're trying to get up the incline. And the wall is what you're trying to get onto the screw. You know? Or, whatever it is that you're screwing.. it into?

00:18:52:30 Valerie So, either the wall is equal to this (points to ball in inclined plane picture)
Susan’s first utterance has multiple idea units corresponding to multiple codes. First, she puts forth the claim that the “ball right there could be equal to the wall.” Second, she identifies (by pointing; see bottom right of figure 3.9,) “that ball right there,” which was coded as identification of a simple machine element. Finally, she provides a justification from the word “because” and through the end of the utterance.

Valerie’s utterance, the second in the reasoning sequence, was incomplete, since it began with the word “either” but had no “or.” Susan ends the reasoning sequence with, “Yeah, whatever you’re like screwing into. So, I’m just gonna put wall.” The group members decide to adopt this and writes it on their poster to be shared at the end of class.

Developing More Encompassing Final Codes

Upon analysis of over one-hundred reasoning sequences, four general patterns emerged, necessitating larger more specific codes to further specify the type of reasoning sequence. First, students often appealed to prior analogical correspondences in order to make new correspondences. Second, students had miscommunications due to use of insufficiently specific words such as “effort” in lieu of “effort force” or “effort distance.” Third, two or more students sometimes were able to argue in favor of various positions without final resolution due to ambiguity in the analogical correspondence. Both of these types of reasoning sequences led to frustration and no argument in favor of a correspondence. Instruction addressed both of these also, leading to improvement in discernment and dealing with ambiguity, as will be
discussed in the results chapter. Fourth, at the end of an activity, students would need to generate a final argument that addressed the guiding question (i.e., this machine works most like that one). A reasoning sequence in which this happened facilitated reflection in the form of restatement and relating of prior correspondences (i.e., since both the arms of the lever correspond to the radii of the wheel and the axle then the lever and the wheel and axle analogically correspond). The development of each of these code types will now be discussed.

**Code 1:**

**Reasoning Sequences where Student Groups are Scaffolded by Prior Correspondences**

This code in which student groups are scaffolded by prior correspondences showed student groups 1) stating a prior agreed upon correspondence 2) using situating words for a new correspondence such as “so then...,” “if that’s true then...” and the like and 3) stating a new correspondence. Since this phenomena occurred within a whole reasoning sequence, the reasoning sequence itself would be coded as “students scaffolded by prior correspondences."

Consider the reasoning sequence below. In it, Haley, Joan, and Riley are making a new correspondence on the heels of another. Important parts are in bold

**Excerpt 3.1 – Task 3 of 7**

Haley: And the threads were the incline. We got that, right?
Joan: Yeah, the threads were the incline.
Haley: (coughs; self talk) I knew I shouldn't have done that.
Riley: So then... is like the length of the screw is the... height of the incline?
Joan: I think that makes sense. Cause then if the threads are what we say... what we were saying the incline was then...
Haley situates the reasoning sequence the analogical correspondence between the “threads” and the “incline” (see figure 3.10). Riley later asks, “is like the length of the screw is the… height of the incline?” Figure 3.10 shows that once one accepts that the threads are like the ramp surface, it becomes easier to see that the screw shaft length is like the resistance distance on the ramp. Joan further corroborates the new correspondence connecting back to the prior correspondence with her utterance including, “Cause then…”

**Code 2:**

**Reasoning Sequences with Insufficiently Discerning Words**

Two codes dealing with discernment were used. The first one, Reasoning Sequences with Insufficiently Discerning Words, was created due to the fact that students used words that were insufficiently specific, and this lead to misunderstandings between group members. Once the researchers and instructors became aware of this lack of discernment, instruction was tailored toward students, inviting them to be more discerning in their language and arguments. This second code was called Explicit Discernment Present. These will both be discussed below.

Reasoning sequences in which students used words such as “effort” in lieu of a more specific term like “effort distance” or “effort force” resulted in miscommunications between students. For example, one student would mean “effort force” while another would mean “effort distance,” yet both would say simply “effort.

Another example is shown in the single utterance below. This utterance began a reasoning sequence with a lack of discernment, a problem from which the reasoning sequence never recovered. Consequently, it did not produce an argument in favor of what might have been a reasonable correspondence. Consider the utterance:
Susan OK. The threads are [analogically similar to] the effort distance.

“Threads,” of course, are a concept, whereas “effort distance” is quantitatively measurable. As such, these are not appropriate for an analogical correspondence. However, it would make much sense to compare “thread length” of a screw to the “effort distance” of an inclined plane, since both of these are measureable quantities that affect their respective simple machines in the same way.

The Reasoning Sequences with Insufficiently Discerning Words code represented reasoning sequences in which miscommunications happened due to insufficiently discerning words being used. Once this code was identified during the data collection phase of this research, instruction was tailored toward inviting students to be more discerning in their word choices and to ask questions around what to call a given simple machine element.

Tailoring instruction to make students aware of the need to discern necessitated a related code. Contrasting with the code Reasoning Sequences with Insufficiently Discerning Words was the code Explicit Discernment Present. This code was used when the need for discernment was explicitly acknowledged in the discourse and the discernment was produced. Consider the excerpt below:

Excerpt 3.3 – Task 6 of 7

00:12:34:38 Melissa The pulley has like a stationary (3 s) like....
00:12:39:07 Beth Yeah, I can't think of a word either.
00:12:40:16 Bree Has a stationary side. Right?
00:12:46:54 Beth I wanna say force. But I know that's not it.
00:12:49:81 Bree Force could be it. I feel like the force could be it.
00:12:51:57 Beth A stationary force.
00:12:54:40 Melissa A pulley has a stationary force.
00:13:00:59 Beth Look at us.. Using science words.
Melissa begins an utterance she cannot finish. Beth specifically acknowledges the need for a word, “Yeah, I can’t think of a word either.” Bree suggests “force could be it.” Beth later suggests “a stationary force.” And Beth later confirms a “stationary force.” The excerpt ends with satisfaction at the discernment that has just happened. Beth says, “Look at us.. Using science words.”

The excerpt shows explicit attention to and need for a “word.” This need represents improved discernment when compared to excerpts 3.1 and 3.2.

**Code 3:**

**Reasoning Sequences with Ambiguity in Analogical Correspondences**

Ambiguity in correspondences presented a problem to student groups in some reasoning sequences. The code, Reasoning Sequences with Ambiguity in Analogical Correspondences, was applied to reasoning sequences in which there was no clear analogical correspondence. Either there may be no correspondence, or there may be multiple correspondences. As a result, student argumentation ends in frustration. Again, instruction improved student small group argumentation, reducing frustration and increasing learning. Therefore, another code was needed. This code was called Explicitly Identifying Ambiguous Correspondences. Both codes will now be discussed.

One such reasoning sequence was begun with the utterances shown below. In them, Nora and Gisel are attempting to find an analogical correspondence between the radius of pulley wheels and the radius of the wheel of a wheel and axle.

**Excerpt 3.4 – Task 5 of 7**

<table>
<thead>
<tr>
<th>Time</th>
<th>Participant</th>
<th>Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:50:23:30</td>
<td>Nora</td>
<td>Well maybe it's the size of the wheels. Maybe it's the radius of the pulley. Do you think?</td>
</tr>
<tr>
<td>00:50:44:51</td>
<td>Nora</td>
<td>Maybe it's the radius of the pulleys.</td>
</tr>
<tr>
<td>00:50:56:84</td>
<td>Gisel</td>
<td>You might be right.. only cause the fact that like.... yeah I don't think you compare these lengths.. because I mean axle's to axle. They're the same. Like it's still pulling string</td>
</tr>
</tbody>
</table>
Although superficially similar – both are wheels and have radii – the two do not correspond. The radius of a pulley wheel has no effect (see figure 3.11) on the way a pulley works, whereas the radius of a wheel on a wheel and axle is central to the working of a wheel and axle. The reasoning sequence continues along these lines and then ends approximately two minutes later in frustration.

Like with the prior code, the researcher and instructors became aware of this phenomenon during data collection. As a result, instruction was made to address the issue. Specifically, students were told that they need not make a correspondence for every element of a simple machine they could identify; some simple machine elements have no correspondences on other machines. The code for reasoning sequences in which this happened was Explicitly Identifying Ambiguous Correspondences. Consider the excerpt below in which Rachel and Joan decide not to make a correspondence on an inclined plane to a lever's fulcrum.

**Excerpt 3.5 – Task 4 of 7**

00:21:52:17 Joan Yeah. Should we do anymore?
00:21:56:75 Riley I don't think there are anymore. Cause what other aspects of the inclined plane are there?
00:21:59:60 Joan I don't think there's a fulcrum
00:22:05:12 Riley So there's nothing really else. To talk about with that. So I'm just saying the lever.... *(begins to write)*
In spite of the superficial similarities (see figure 3.12) in appearance (e.g., similar shape, load at bottom left) Joan says simply, “I don’t think there’s a fulcrum” on the inclined plane. She is correct. There is no analogical correspondence on the inclined plane for the fulcrum of the lever. When an ambiguous correspondence is dismissed as Joan has done above, this code is applied.

**Code 4:**

**Making a Final Argument Scaffolds Reflection**

Having made the analogical correspondences, student groups next had to argue in favor of an answer to the guiding question, “Which, from among these two simple machines, works most like simple machine X?” Although this was described as a frame of discourse, when witnessed in the transcripts, this also fit the form of a reasoning sequence (or multiple reasoning sequences). This type of reasoning sequence would inevitably find student small groups looking back across the analogical correspondences they had made in service of their final argument.

Below are two utterances from the beginning of a reasoning sequence in which reflection across previous correspondences is scaffolded in service of the final argument. The group has already made correspondences between both pairs of simple machines shown in figure 3.13. Now they are evaluating these correspondences to make an argument about which – the inclined plane or the wheel and axle – works most like the lever. Consider the utterances.
Skyler asserts that between the lever and the wheel and axle “there’s more like technical similarities.. like they move.” She is referring to the fact that both the wheel and axle and the lever move, whereas the inclined plane does not. Serena agrees, adding that there are “technical and movement similarities instead of just placement similarities.” With this utterance she is referring to the similar shapes of the inclined plane and the lever. But, she argues, there are more “technical and movement” analogical correspondences between the lever and the wheel and axle. She is reflecting on prior analogical correspondences in order to make the overall argument that the lever and wheel and axle work most similarly.

The type of reasoning sequence represented by this code often found students recounting specific correspondences they had made and also evaluating them in service of the argument in favor of one machine over the other. This will be described further in the results chapter of this work.

**Applying the Codes**

In order to facilitate the viewing of large pieces of transcripts at one time, all forty-eight hours of transcripts were copied and pasted into Microsoft Excel®, as this made transcripts and reasoning sequences persistently viewable and comparable across various classes and groups, something that is not possible in StudioCode®. A sample screen shot is shown in figure 3.14.
Reasoning sequences were put in bold font and the codes (abbreviated forms; e.g., Discern/P for Explicit Discernment Present) were labeled in the column to the left of the timestamp for the utterances in the reasoning sequence. Once the reasoning sequences were identified and coded, they were copied and pasted as complete reasoning sequences into a separate document where they were labeled and scored on a 1 to 10 scale for their ability to represent the code. Factors for why a given reasoning sequence would lose a point included: multiple interruptions to the reasoning sequence; longer than many dozens of utterances; multiple argumentation foci present; audio problems leading to incomplete transcripts; someone standing in front of the camera limiting ability to determine what students are doing; etc.
All sixty-one reasoning sequences scoring a six or higher were placed into a separate document. From these, three reasoning-sequence-excerpts of each code type were selected to be provided and discussed in the results chapter of the present research. They were selected based on a few factors, including: length (reasoning sequences of a few dozen utterances or fewer were best), meanings shared between multiple group members as evidence by use of same words. The choice of reasoning sequences was also affected by a need to show improvement across time for a single group.

The application of the codes is discussed in greater detail in the following Results and Analysis Chapter, which follows.
Works Cited


Chapter 4

Results, Analysis and Discussion:

Analogical-Mapping-Based Comparison Tasks

as a Scaffold for Scientific Argumentation
**Results: Introduction**

Findings emerged from discourse analysis of: videotape transcripts, artifacts made by students during interventions (e.g., pre- and posttests, posters, worksheets), and student interviews. Evidence for simple machine content learning and for learning about argumentation through the interventions was found in pre- and posttests as well as through discourse analysis and artifact analysis. Specifically, discourse analysis and coding of transcripts provide four principal findings that represent the nature of the scaffolding provided by analogical-comparative argumentation tasks such as those carried out in this research.

**The Findings Were as Follows:**

1. After one or more correct analogical correspondences had been made, analogical-mapping-based argumentation tasks and associated instruction *scaffolded students toward making more correspondences that were correct*, increasing the possibility that argumentation leads to learning.

2. Analogical-mapping-based argumentation tasks and associated instruction *scaffolded student small groups to become more discerning and precise with their definitions and descriptions of simple machine elements*

3. Analogical-mapping-based argumentation tasks and associated instruction *scaffolded small groups in becoming better at identifying ambiguous analogical correspondences that were ambiguous* and not likely to lead to new understanding. In later activities they avoided them, saving time and resources.

4. Analogical-mapping-based argumentation tasks and associated instruction *scaffolded student small groups in making reflections by evaluating whole systems analogical correspondences* in order to find the best analogue from among two possible choices.
The findings show that comparative analogical argumentation tasks and associated instruction provided scaffolding to promote learning and understanding in four ways. The findings will be described and examples of each will be given. First, in comparing and evaluating one potential analogue against another, students benefited from scaffolding in which one correct correspondence begets another. It was found that by making one correspondence, other correspondences often become supported or more logical. Second, students became more discerning and precise with their definitions and descriptions of simple machine elements. In order to make correspondences, it was found, students must first define well what element exactly they are talking about. Third, over the eight-week intervention, student groups became better at identifying possible correspondences that were ambiguous and unlikely to lead to better understanding. Not all elements in analogies correspond, therefore analogies eventually break down. Thus, in these interventions student groups inevitably considered potential correspondences between analogues that did not necessarily lead to better understanding and learning. Early in the intervention these presented themselves in the discourse as being frustrating correspondences for groups that usually ended in dissatisfaction. Over time, however, groups learned to identify ambiguous correspondences, evaluate them, and dismiss them as non-helpful for understanding. Fourth and finally, student groups were scaffolded in making reflections as they evaluated the overall systems of relationships in order to find the best analogue from among two possible choices. This evoked in student discourse, consideration and evaluation of the functional similarities versus more superficial appearance based similarities.

In the following sections each finding will be further explained. First, a brief example of each category of finding will be offered. Next, in the analysis section each finding will be shown by three or more excerpts from transcripts and their analysis.
Examples of Each Category of Finding

Figure 4.1 (the handout used in activity number five of seven) will be used to provide general descriptions and examples for each category of finding. Transcripts of actual reasoning sequences from each category and detailed analysis will be provided later in this chapter. At the top of the diagram is the question, “Which simple machine is most like the lever in the way it works? Why? The wheel and axle or the inclined plane?” Also the instructions state, “Answer the question below using analogical mapping as learned in class. List the correspondences in the table below.” In doing the activities, students were also given the actual simple machines to use. To the top left of the paper, a lever, which can lift the block pictured at the bottom left, is represented with the parts labeled (e.g., resistance distance, effort distance, fulcrum, etc). On the right side is pictured a wheel and axle, which reduces the force to lift the block on the left. And, on the bottom left is shown an inclined plane which allows the block represented at the bottom to slide up, thereby making it easier to lift.

One finds, when attempting to find correspondences between the wheel and axle and lever, for example, that the fulcrum of the lever corresponds well to the center of the wheel and axle, more appropriately referred to as the axis of rotation. Both, after all, are points around
which something rotates. Both machines have parts that go up on one side of their respective rotation points. The wheel of the wheel and axle turns clockwise when lifting and therefore goes down just as the effort arm of the lever. Diagram 4.2 in which the lever is shown superimposed on a wheel and axle, reveals the wheel and axle to be a type of lever.

Finding 1: One Correct Correspondence Scaffolds Another

In the example, upon mapping the fulcrum to axis of rotation correspondence of the analogy, further correspondences became easier to make for students. This important scaffolding effect can help students to learn through argumentation. For example, moving to the right from both the fulcrum of the lever and the axis of rotation of the wheel and axle, one finds the hand that provides the effort force. Between the machines’ respective center points and their respective hands is a distance – the wheel radius on the wheel and axle and the effort arm on the lever – that, when increased in length, makes both simple machines require less force to lift a given object. In other words, the machines’ respective mechanical advantages would be increased. Also, moving left, toward the loads on both machines, allows for another correspondence. This distance – the radius of the axle on the wheel and axle and the resistance arm on the lever – also represents a similar quantity in both machines. In this case, reducing the respective distances in both machines increases the simple machines’ mechanical advantages, also.

Once a group had made one of the correspondences above, as well as others (e.g., load, effort force location, effort distance, etc) it became easier for them to make the others. Following the analogical mapping instructions, students were scaffolded toward making further correspondences. Making, for example, correspondences between the locations of effort forces above (i.e., the hands) would scaffold students toward further correspondences such as the
effort arm to wheel radius correspondence. Furthermore, when students made the load to load correspondence, a literal as well as functional correspondence (they function in the same way and are called the same thing), making the fulcrum to axis-of-rotation correspondence becomes supported. Or, sometimes the opposite occurred, making the fulcrum to axis-of-rotation correspondence guided students toward other correspondences. Also, if the fulcrum, for example, best corresponds to the axis of rotation, then it cannot also best correspond to another element of the wheel and axle. Constraint is imparted. In these ways students are scaffolded in making correspondences.

Although found in every activity and among each group to some extent, evidence for this type of scaffolding was varied, as each case was different. Often found were words such as “so” or “then,” after a stated correspondence. For example, a simple version might be: “so if the fulcrum corresponds to the axis of rotation, then the effort arm length corresponds to the wheel radius.” Those words (and others) served to bridge the gap from what was known or decided to what seemed a logical extension scaffolded. Of course, real dialogue is messier, usually requiring many utterances to tease apart the scaffolding sequence. In the first section of analysis, examples will be given using excerpts from actual transcripts.

Finding 2: Scaffolding Toward Discernment of Definitions and Descriptions

Over the course of the analogical comparison interventions, students began to discern important differences and nuances between elements of simple machines. Discernment, for the purposes of this research, will be defined as distinguishing something as being different from something else. Although, this is related to the process of defining or generating a definition in context, the process of discernment is not limited to defining. Pointing out with one’s hand explicitly the effort distance of a lever, for example, by moving one’s finger along it will also be considered discernment. In order to make a correspondence an element of a simple machine, it is important to know what the element is (e.g., effort distance, fulcrum, load, etc.). It is also
important to know what it is not. Discernment is this process. And in the activities in this research discernment – describing something or pointing it out – is a necessary first step in order that students can make appropriate and useful correspondences in analogical mapping.

Transcript excerpts in the second section of analysis will show examples of early non-discernment among groups in which they might, for example, use the word “effort” to mean either “effort distance,” “effort force,” or even “effort arm,” all of which are very different things. This type of non-discernment caused communication problems, as other students in the group were not always aware to which the speaker was referring. These excerpts ended with dissatisfaction or an agreement to make a perfunctory choice for some sort of analogical correspondence get on with the activity and fill in the blank.

Next, successful discernment from later interventions will be shown with various excerpts. In these, groups explicitly discerned important differences between things such as “shaft” and “shaft length,” which are very different things but accounted for with similar words. In the transcript excerpts, students will be shown explicitly recognizing the need for discernment. Although, they may not use the word discernment, they do perform argumentation around definitions, asserting the appropriateness of one and inappropriateness of another, for example. Discernment plays out over many utterances, with each serving to refine, add to, or subtract something to the definition of a given simple machine element.

Recognizing the need for discernment and knowing how to achieve it is fundamental to any meaningful learning. The comparative interventions in this research along with instruction on the need for discernment scaffold students’ argumentation so that they can do just that. Excerpts, of non-discernment and later successful discernment, are representative of large class of findings in which student groups became better at discerning what an element of a simple machine was and was not. There was also explicit discussion about the need for discernment both in small groups and in the whole class discussions as well.

Finding 3: Scaffolding for Dealing with Ambiguity
Over the course of the eight weeks, the interventions and instruction helped students to improve in their ability to recognize and dismiss ambiguous correspondences that will not lead to better understanding. These will be called ambiguous correspondences because, as discussed in finding one, student groups are often led to consider correspondences. Sometimes, however, these have only superficial appeal. Ambiguous correspondences might initially seem likely to lead toward understanding. If simple machine elements around another element correspond well, then it stands to reason that that one should as well. In some cases, however, an element that looks as though it should correspond does, in fact, not.

Consider an ambiguous correspondence in activity five (figure 4.1), which was discussed previously. In it, the inclined plane and the lever are represented similarly positioned. This makes the inclined plane superficially appealing as the answer to the question, “Which simple machine is most like the lever in the way it works?” After all, the inclined plane and the lever look alike. There are many correspondences to be made, of course. One is given to the students, the “Resistance Arm Length” to “Resistance Distance.” Both, when lengthened increase the force required for the machine to move the load. Alternatively, it can be said that increasing both reduces the mechanical advantage. In this way, they correspond. They can also lead to a whole series of correspondences between the inclined plane and the lever which are functionally similar (e.g., “effort arm length” to “effort distance” and “the load” to “the load”). However, as in all analogies, there is eventually a break down.

When trying to find an analogical correspondence on the inclined plane for the lever’s fulcrum, for example, one comes up short. The inclined plane simply has no compelling analogue to this element of the lever. In some of the early interventions in this research, this posed a problem for student groups. Much time was spent in arguing to find a suitable correspondence only to have the reasoning sequence end in dissatisfaction with any possible choices. Nonetheless, in early activities most groups did write a correspondence for ambiguous elements such as these if for no other reason than to fill in the blank. Awareness of this by
instructors and the principal researcher set the stage for teacher conversations about the matter with both small groups and the whole class, an example of which will be shown analysis section two.

After making a few these correspondences that did not lead to better understanding, such as the one above, and after discussing ambiguous correspondences in class with instructors and learning that a correspondence is best not made if improved understanding from functional analogy does not result, small groups began to identify potential correspondences that were best left alone. Small-group argumentation became about finding or refuting evidence in support the worth or lack thereof of a potential correspondence. Learning to not pursue what at first can appear to be important correspondences, such as the lever’s fulcrum to a part of the inclined plane, allowed student groups to become better at managing their argumentation time and focus and contributed to better understanding of simple machines.

Both the activity type and the instructors themselves provided scaffolding in learning to deal with ambiguity. The comparative activities, by their very nature, provided student groups with the opportunity to argue around various superficially appealing yet ambiguous correspondences over the course of the activities. Scaffolding also was provided by instructors in the form of conversations on the importance of recognizing and dismissing possible correspondences. Also, in some cases peers who had learned to recognize correspondences as ambiguous also provided scaffolding to other students. In this way, students learned that although helpful in explaining, analogies can have pitfalls. They learned to argue about these and ultimately avoid them.

Finding 4: Scaffolding for Reflection

Student small groups were scaffolded in making reflections. Upon having made as many analogical element correspondences between two sets of machines as possible, students next had to make a final argument about which machine overall worked most like the lever.
This will be referred to as an overall system-based comparison. Groups’ arguments needed to consider the analogical mappings as a whole system and the alignment between each set of two simple machines. The best aligning simple machine pair will be the final argument and the answer to the guiding question of which machine works most like the lever. Alignment, in this case, refers the degree of analogical relationship based on function and structure. This final argument making inevitably invited reflection.

For example, in the activity five discussed previously (see figures 4.1 & 4.2), there is a high degree of functional and structural alignment between the wheel and axle and the lever. On the other hand, there is little between the lever and the inclined plane. As noted in finding three, there is no compelling correspondence between the lever’s fulcrum and a functionally and structurally related element of the inclined plane (see figure 4.3 to the right). There is a correspondence on the wheel and axle, the axis of rotation. The axis of rotation on the wheel and axle is both a functional and structural analogue. It is situated at the heart of the machine’s rotation, as is the lever’s fulcrum. And, it marks a center point demarcating between two important distances on the wheel and axle (the radius of the wheel and the radius of the axle), which is analogical to the lever’s fulcrum’s demarcation of the effort arm length and resistance arm length.

As mentioned in finding one, one correspondence can scaffold other correspondences between the wheel and axle and the lever, whereas between the lever and the inclined plane correspondences do not have similar structural alignment and functional alignment. For example, although both the effort distance (ramp length) of the inclined plane and the effort arm length of the lever both provide a greater mechanical advantage when increased (in this way they correspond) they have important differences. The ramp is stationary; the effort arm moves. The load moves along the inclined plane’s ramp; it moves in the opposite direction of the lever’s
effort arm. Thus, correspondence between the inclined plane and the lever is limited. The structural and functional alignments are simply not present. The better choice for an overall argument would be to state that the lever and the wheel and axle work most alike. Excerpts of argumentation on overall-systems-based comparisons will be analyzed in the fourth section of the analysis.

Analysis

Introduction

From among hundreds of possible excerpt candidates, three or four were chosen to represent each type or subtype of finding. Transcript excerpts analyzed in this chapter were chosen for their clarity and quality. For example, although instructors and the researchers were circulating responding to questions, albeit as minimally as possible, transcripts were chosen specifically because they did not have teacher or researcher utterances that affected the thinking of the groups represented in the transcripts, except in cases where the desire was to show teacher input. Excerpts were also chosen to be as continuous as possible – minimizing side conversations, trips to the bathroom, and other interruptions was a consideration. Selecting the excerpts that were easiest to follow was important. It was also important to balance the need to minimize redundancy (e.g., in some cases all fifteen groups had a very similar discourse pattern around a comparison) with the need to justify an excerpt’s presence as being emblematic of a larger category. Therefore some excerpts are on the same simple machine element correspondence or from the same activity, whereas other excerpts show the same finding in a different context.

Units of Analysis
In the next four sections, each covering one of the findings introduced earlier, excerpts of transcripts representing reasoning sequences will be presented, whenever possible as contiguous utterances. These will range from a few to several dozen utterances. Before the reasoning sequences are presented there will be brief description of the reasoning sequence and how it is representative of the category of finding in which it is placed. After the reasoning sequence is presented, discourse analysis at the idea unit will follow. In this analysis, each utterance will be analyzed with an eye toward articulating its function within the reasoning sequence and how it contributes to the whole reasoning sequence. Finally, the reasoning sequence will be related to the category of finding. After each of the four analysis sections, a discussion section will relate each finding to its role in learning and understanding.

Transcripts Analysis

Finding 1 – One Correct Correspondence Scaffolds Another

As introduced previously, this category of finding deals with the way in which student groups are scaffolded to make one correspondence having already made another. This section of analysis will provide evidence for this phenomenon.

The following excerpt is from a group containing Riley, Joan, Haley, and Andy (pseudonyms will be used exclusively in this research), although Andy does not speak in this excerpt. This intervention was the third of seven. As it was the first dealing with simple machines, students had not yet mastered the process of analogical mapping. Thus, this activity was simpler than those that would follow, since it required only one pair of simple machines to be analogically mapped rather than two.
The handout given to each student is shown to the in figure 4.5. The instructions read, “Using the correspondence mapping technique we learned about in class, your goal is to answer the question, ‘How is a screw like an inclined plane?’ List the correspondences in the table below.”

This reasoning sequence begins after the group had made a correspondence between the threads of the screw and the incline. This is scientifically correct, since a screw is considered to be a shaft with an inclined plane wrapped around it. Figure 4.4 shows the conceptual “unwrapping” of the thread of a screw. Although this would not really be possible under normal circumstances, this permits one to see elements of the screw that correspond to the elements of the inclined plane. For example, the top surface of the inclined plane corresponds to the thread of the screw (shown in figure 4.4 as being unwound).

The following excerpt shows the entire reasoning sequence in which the group decides that the “length of the screw” is like the “height of the incline.” First, however, the group invokes prior knowledge, which shows they had already accepted that the threads correspond to the inclined plane top surface. Consider transcript 1.1 below.

Excerpt 1.1 – Task 3 of 7

00:08:06:68 Haley And the threads were the incline. We got that, right?
00:08:07:82 Joan Yeah, the threads were the incline.
00:08:11:35 Haley (coughs; self talk) I knew I shouldn’t have done that.
00:08:16:52 Riley So then.. is like the length of the screw is the... height of the incline?
00:08:22:06 Joan I think that makes sense. Cause then if the threads are what we say... what we were saying the incline was then...
00:08:29:09 Riley Um Hmmm.

In the first utterance, Haley states “And the threads were the incline.” Although she says the “threads were the incline,” she means this as a correspondence. The use of this type of construction – “this is that” to mean “this corresponds to that” – is prevalent in the data for this
study. Yet, from the context and transcript it is evident that a correspondence is understood among group members. The next part of Haley’s utterance “We got that, right?” seeks to elicit agreement for that correspondence among other group members. Joan agrees stating, “Yeah, the threads were the incline.” It is unclear what exactly Haley’s next utterance, “I knew I shouldn't have done that” was intended to mean. Her gaze was maintained at her paper during the utterance, and it went unacknowledged by fellow group members. She may have misspelled a word or perhaps written something wrongly.

Riley’s comes in with her first utterance, “So then.. is like the length of the screw is the...height of the incline.” Although, Riley’s words could have been clearer, with her beginning words “So then,” it was clear that she was attempting to situate her coming words in a near shared context. Thus, one can interpret “So then” to mean something like, “Since we have accepted that the threads are [like] the incline as you say Haley, then...” The final part of her utterance, asserted a new correspondence between the “length of the screw” and the “height of the incline.” This is a scientifically accurate statement, as can be seen in figure 4.4 above.

So there are two parts to the utterance. The first part serves two functions: to legitimize the coming postulate, which could, of course, as far as she knew, have been wrong; and also to save face in the event she would have been wrong. Had she been wrong, others would have known her reasoning thereby any loss of face might be reduced had she missed unseen factors indicating a contrary position.

The argumentation in this reasoning sequence led to scientifically accepted argument that was agreed up on by the group. Joan’s utterance, “I think that makes sense. Cause then if the threads are what we say... what we were saying the incline was then...” attests to the fact that she agrees with Riley. Joan’s “Cause then” also situates this new correspondence in the prior correspondence, just as Riley’s earlier utterance did. Her utterance suggests that meanings were being shared between group members. Joan had understood the “So then” part
of Riley’s prior utterance as well as the new correspondence Riley suggested. The height of the inclined plane is like the length of the screw, Joan agrees.

This reasoning sequence provides evidence for the scaffolding of student argumentation in an important way. Making one correspondence between the threads and the inclined surface of the inclined plane led this group to make another correspondence, the height of the inclined plane to the length of the screw.

The reasoning sequence in the next transcript also provides evidence supporting this type of scaffolding. Group members Melissa, Beth, Bree, and Dory (also pseudonyms), doing the same activity as the group in the prior transcript, first assert a correspondence between the threads and the effort distance. Effort distance is a technical way to refer to the length of the ramp surface of the inclined plane. This is much the same way the group in the prior example began. However, in this case the group is scaffolded toward a different, but also correct, correspondence between the point of the screw and the point of the inclined plane. Consider the transcript.

Excerpt 1.2 – Task 3 of 7

00:16:16:91 Melissa I think that the threads are the effort distance. (2 s) Cause they’re the.. the part that inclines. You know what I’m saying?

00:16:26:77 Beth They’re like mini.... (3 s) That was really scientific of me. (2 s) They're mini inclines.

00:16:31:98 Melissa And they gradually increase. Like, they start off smaller and they gradually increase in size.

00:16:47:35 Bree So it was effort distance because... it increase... wait.. they both

00:16:49:01 Melissa They gradually increase in size.

00:17:03:45 Bree And they’re both used to...

00:17:06:45 Melissa Get something to the top of it. You know what I’m saying. Like, you start off at the point of the screw.

00:17:15:30 Dory So then the point would be the ... also the point... the initial start of moving something upwards toward the top.

00:17:22:50 Melissa Yeah

00:17:27:01 Beth Oh I have a sneeze stuck right here. (2 s) Oh it's driving me nuts
In the first eight utterances, the students argue in support of the thread to effort distance correspondence, which is correct. Melissa begins the reasoning sequence by stating, “I think that the threads are the effort distance. (2 s) Cause they’re the.. the part that inclines. You know what I’m saying?” This utterance serves to state the correspondence and then provide a justification. Melissa’s justification is that “they’re the… the part that inclines,” which refers to the fact that both elements of the machines start run at an angle from one end to the other of their respective machines. Again, this can be seen in figure 4.4. Beth follows up with, “They’re like mini… (3 s) That was really scientific of me (2 s) They’re like mini inclines.” Since the group had inclined planes (lego base with a ruler) and a small screw, it is probable that Beth was referring to the fact that the screw threads, which were much smaller than the inclined plane, analogically corresponded to the surface of the inclined plane. This statement both agrees with and provides a further justification for Melissa’s opening utterance.

Melissa’s next utterance, “And they gradually increase. Like, they start off smaller and they gradually increase in size” builds on the prior two utterances. Although her language is technically inexact – neither threads nor the inclined plane start off small and “gradually increase in size” – it can be said that they both increase in height. That is likely what she meant.

The following three utterances serve to revoice and clarify the correspondence. Beth’s “Wait” is a place holder or pause request to allow for processing to occur or a question to emerge. Bree interjects, “So it was effort distance because… it increase… wait.. they both..”
This utterance suggests she realized a correspondence had been accepted in the group, but she had not understood or followed. Her utterance conveys that she had understood part of the correspondence but ending with “wait.. they both..” is an invitation to others in the group to finish the utterance thereby restating the correspondence. Melissa responds by repeating, “They gradually increase in size.” These utterances together represent the idea that both the threads and the incline gradually increase in height.

Bree’s next comment, “And they’re both used to…” shifts the focus of argumentation to the use of the threads and the use of the incline. Unfinished, it serves to invoke use rather than complete the thought. Perhaps she had a partially completed idea, but her lack of a place holder such as “umm” or “wait” suggests the comment best served as an invitation to the group to take up and argue the idea toward completion. This would function to provide further justification for the correspondence, that of similar use. Melissa, who had furnished the initial correspondence and justification in her prior two utterances, follows up with a response on the use, stating, “Get something to the top of it. You know what I’m saying. Like, you start off at the point of the screw.” This means that a load begins at the left point of an inclined plane and a wood block, for example, begins at the point of a screw, and the thread and inclined plane surface correspond analogically based on use or function. Although the purpose of this comment was to provide further justification for the thread to incline correspondence, it also provided support toward another correspondence. This came from Dory’s next utterance.

Having been lead to a new correspondence, Dory states, “So then the point would be the ... also the point... the initial start of moving something upwards toward the top.” Note the use of “So then,” as in the first excerpt from the other group analyzed in this section. It has the same function here, serving, in context, as a logical extension marker along the lines of: since it has become accepted among us that the threads of the screw correspond to the incline (ramp) of an inclined plane, so then too must the point of the screw also correspond to the starting point of the inclined plane (shown to the left of the inclined plane on diagram 4.5 shown previously).
Dory’s comment also provides justification, “the initial start of moving something upwards toward the top.”

There is an interesting perspective shift implied in her comment, since one doesn’t normally think of something (wood, metal, etc) as moving up a screw. Rather, usually it is considered that the screw moves down into it (assuming one is screwing downward). Nonetheless, this perspective shift is appropriate and plausible. One could actually move a block upward on a screw by turning it onto the screw.

She has been scaffolded in making the screw point to inclined plane point correspondence by the prior shared context of the argumentation dialogue, the presence of the simple machines and diagrams of them, and, as is the principal argument of this section of analysis, by the very nature of the task itself. Making one correspondence leads the group toward making another more easily.

Continuing with the analysis we find that Melissa agrees with Dory’s assertion in her utterance, “Yeah.” The next utterance, by Beth, is unrelated to the argumentation. The next three utterances beginning with Dory’s “All right so the point would be,” find the group looking for labels. Melissa offers, “tip” to which Dory’ clarifies the intent behind her prior utterance. She states, “Would be the… (2 s) what’s that called?” Bree offers, “An actual starting point.. Like the…” Beth builds on the utterance with, “Starting point of the ramp…or plane.. whatever.” With this it becomes clear the group is dissatisfied with “starting point” as a label. They wish to find out if one of the group members knows a more appropriate name. From a scientific point of view there is not an agreed upon term for this. “Starting point” and “tip,” when well defined and pointed out as they are here, are fine labels.

Bree’s next utterance, although beginning as a question, is incomplete “Ummm.. Couldn’t we say like because they’re both ummm… the very…” Then, Melissa’s “I would say it’s where the…” is also incomplete, yet the utterance could potentially be an opening to direct the argumentation away from finding a better label for the “tip” or “starting point” toward providing
more justification. Dory’s final utterance both better discerns a definition as well as provides justification for the correspondence.

The group members recognize that in lieu of a desired scientifically sanctioned and more exact word that is not forthcoming, their words must provide detail. All group members added this correspondence to their paper. Dory’s paper is shown in figure 4.6. In it she states “point/tip” under the screw column, “initial starting point of inclined plane” under inclined plane, and under the column called explanation she writes, “Initial starting point that begins the object’s movement to the end of the plane.” Other group members’ papers were nearly identical.

Figure 4.6: Student Correspondence

As in the first excerpt, one correspondence, the one between the thread and incline, led to another between the starting point of the inclined plane and the point of the screw. This is an appropriate and scientifically accurate correspondence based on deep structural similarities of function. The following excerpt also shows scaffolding in which one correspondence leads to another.

Rhodora, Julia, Katie, and Hannah are also scaffolded when attempting to perform the comparison activity shown in figure 4.7. The instructions read: “Your goal is to answer the
question: Which simple machine is the jack (top) most like? The inclined plane or the wheel-and-axle? List the correspondence in the tables below.” The back of the paper called for an explanation, as students were invited to finish the following: “The jack works most like the ___ because…” A screw jack, when turned with the handle on top, can lift something such as a car. It’s mechanical advantage derives from the inclined plane wrapped around its shaft and from the wheel-and-axle-type rotating handle on the top. Through its use, less force is required than would be required without it.

In the transcript excerpt below, the group first looks at, the screw jack (as in figure 4.8). By considering it from above, its relationship to the wheel and axle becomes more apparent in two important ways. Consider figure 4.8. When the wheel and axle and the screw jack are viewed from the angles represented by the eyes, one can see on both a larger part that spins (handle of screw jack and wheel of wheel and axle) as well as a smaller part that spins in conjunction with the large part (shaft of the screw jack and axle of the wheel and axle). Identifying one correspondence (i.e., handle : wheel) scaffolds students to make another (i.e., shaft : axle).

Excerpt 1.3 – Task 7 of 7

00:13:58:86  Julia  Umm... I think.. like if you look at it.. from like this perspective (screw jack viewed from top) sort of ish
00:14:05:72  Katie  Yeah
00:14:06:35  Julia  The.. the length of the handle is like the wheel.. like the diameter of the wheel.. the effort distance.. and the diameter of the shaft.... is like the diameter of the axle.. the resistance distance.. Like.. Like that... You know what I mean?
00:14:24:27  Rhodora  No
00:14:25:33  Julia  So without the playdough [base of the screw jack].. do you see this and this sort of together (points to parts of screw jack)?
00:14:28:59  Katie  Yeah
Julia kicks off the excerpt by suggesting an important perspective shift: “Umm... I think.. like if you look at it.. from like this perspective (screw jack viewed from top) sort of ish.” To which Katie agrees, stating “yeah.” Julia, having established and attempted to convey the perspective shift, follows up with, “The.. the length of the handle is like the wheel.. like the diameter of the wheel.. the effort distance.. and the diameter of the shaft.... is like the diameter of the axle.. the resistance distance.. Like.. Like that... You know what I mean?” This is a lengthy utterance. First, it does convey scientifically accepted information. It is true that the “length of the handle is like the wheel [radius].” See figure 4.10 above. Both of these, the wheel and the handle, are the larger parts of their machines to which effort force is applied. Also, both, when increased in size or length increase the mechanical advantage of their respective simple machines. The sole problem is the word “diameter.” (Radius, which is more correct than diameter, comes to be accepted by the group later in the transcript.) Next, Julia offers, “and the diameter of the
shaft.... is like the diameter of the axle..” This is perfectly reasonable when viewed from the perspective shown in figure 4.10. Looking along the perspective offered by the eyes, one can see that both the shaft of the screw press and the axle of the wheel and axle are the smaller parts of their simple machines to which are closer to the respective resistances (i.e., weight on wheel and axle or material being pressed by screw) than wheel or handle.

The correspondences (wheel:handle and axle:shaft) were offered together, which implies a sort of mutual scaffolding. As the excerpt continues, Julia, who attempts to explain her ideas to the rest of the group, will use one correspondence to reinforce the other. This, it seems, is necessary, as the other group members do not understand initially. By talking about one and then the other, Julia is attempting to help group members by enabling them to understand the correspondence using another as a scaffold. This is evidenced by the fact that throughout the rest of the excerpt, the two sets of correspondence are considered in tandem.

In spite of the perspective shift and detailed prior utterance by Julia, Rhodora responds to Julia’s “You know what I mean?” with a “No.” She has not understood the correspondences at this point. Julia suggests imagining removing the playdough base of the physical model of the screw jack (it was made using a playdough base and top, and a nut and bolt). She states, “So without the playdough [base of screw jack].. do you see this and this sort of together [points to parts of screw jack]?” With this question, she is focusing group attention on the screw and the handle on top of the screw. The base has been stripped away, mentally, at least. Both Katie and Hannah state, “Yeah.” They have understood that the handle and screw are connected.

Next, Julia directs group attention to the correspondence between the screw jack handle and the wheel on the wheel and axle. She states, “Like you know how this is... I don't.. like this.. I don't think the handle matters at all... the handle doesn't really.. it doesn't reallly matter like what size it is.. But it's like that sort of.. (points to and turns wheel on wheel and axle) Like this is the wheel.. the handle is like..” This utterance is unclear. One could read its meaning two ways. First, when she says “I don’t the handle matters at all....” and “it doesn't really matter
what size it is,” Julia could be suggesting that the handle’s radius (as opposed to its length) is not relevant to the simple machine’s performance. Scientifically this would be correct and appears to be validated by further utterances. Or, she could be simply asserting that the handle could conceivably be of any length, which is also true.

The stage is set for a co-construction across the next three utterances. Rhodora’s “OK. So the length of the handle on the jack,” Julia’s “And then the... the” and then Rhodora’s “Length of the handle...on the jack.. matches with the diameter of the wheel?” when put together suggest something like “The length of the handle on the wheel and axle corresponds to the diameter of the axle,” which essentially amounts to half the content of Julia’s second utterance earlier in this excerpt.

Julia’s “Yeah.. Or just like the effort distance..” suggests she agrees but would like to modify one of the terms to “the effort distance.” “Effort distance” does not fit here as it would be the distance the hand moves, which is related to the diameter of the wheel and the handle, but is not the same. This utterance’s suggestion that “effort distance” be used was not taken up by the group in the argumentation and “effort distance” is not written on any of the group member’s papers in this correspondence.

Julia next asks for a term from the group. She asks, “And then... I called it the diameter of the shaft.. Is that what you would call it? Or the diameter of the screw?” The “And then” part of the utterance shows she is building on prior discourse. It has the effect of “now that we have decided that the handle length corresponds to the wheel diameter, we can see the next one is a correspondence between the screw shaft diameter and the axle diameter” She hardly bothers to explain the direction her utterance is moving in, suggesting it has become obvious. Rhodora says, “Hmmm” and Julia continues, “Is equal to the diameter.. is.. corresponds to the diameter of the..” Rhodora adds, “The axle.”

Rhodora, at least, has understood as is clear from her co-constructions with Julia. Evidence for understanding for both Katie and Hannah is limited. Although Hannah adds, “axle”
as a follow up to Rhodora’s “axle,” this adds not new information or insight. It is not clear whether this is a question or a clarification. Nominally, at least, she has come to accept this correspondence. In response to Julia’s final question ending, “Does that make sense though? Like do you think that..” Hannah replies, “Yeah.” All group members, in the end, did write similar responses on their papers. Katie’s is shown in figure 4.9.

These last few utterances of the excerpt have established the second correspondence, which is scaffolded by the first. If the handle length corresponds to the wheel diameter, then it follows that the screw shaft diameter corresponds to the axle diameter. It is worth noting that little justification is provided in this excerpt or in other parts of the transcript. All the same, a correct and confident choice was made. Scaffolding allowed for this. Were only one correspondence to have been presented, the result would likely have been unsatisfying for the group.

Discussion of Finding One – One Correspondence Scaffolding Another

In the previous three transcripts groups were scaffolded in making a correspondence once another had been made. Understanding simple machines as a collection of parts or elements and as a system can take place when students are scaffolded to make correspondences that are supported by earlier (and later) parts of an activity. This scaffolding effect was not limited to one or two correspondences supporting each other. Rather, when systems are compared based on the relationships between their elements as in the case of simple machines, continuing correspondences become made with more and more confidence.
As elements become corresponded, they become unavailable, in most cases, for further correspondences.

To scaffold argumentation is to scaffold a learning process. Learning, by its very definition, involves exposure to new concepts. And since people do not usually talk well about new concepts, words, and ideas that they do not yet understand, scaffolding is necessary. Scaffolding as described in this finding, reduces the possibility that students’ argumentation will result in awkward silences in the small groups and no learning. Argumentation around systemic analogical comparisons and the resultant scaffolding that occurs directs students’ subsequent correspondences and is an important and effective form of scaffolding.

Furthermore, correspondences are connections. Meaningful learning and understanding involves connecting knowledge to its context. When students are scaffolded to make correspondences, they are really connecting concepts – in this case, elements of simple machines and the machines themselves – to other concepts. Through making connections, as this research invites students to do, context is moved to the fore. This aligns with a situated model of learning, which places emphasis on learning and use of knowledge in context. Comparative analogical argumentation, such as in this research, with its scaffolding for connection making and context emphasis, can be important tools that shift science education away from memorization and toward knowledge understanding and use in context.

Finding 2 – Analysis of Groups Being Scaffolded Toward Better Discernment

As mentioned in the introduction to this chapter, in order to know what to map as a correspondence one must first define well what exactly what one is referring to. This occurs through discernment, which will be defined as distinguishing something from being different from something else – in this case simple machine elements (e.g., effort length, effort force, etc).
In early interventions in this research students did not communicate well exactly what they were referring to when attempting to generate a correspondence. That is, they did not discern. They used words that were insufficiently specific, assuming other group members would understand. Often they did not. This resulted in dissatisfaction with correspondences. The first three excerpts are of groups that are not discerning well. Consequently, their reasoning sequences end in dissatisfaction.

Over the course of the eight weeks of research, however, students began to better discern between different but related elements of simple machines. For example, they avoided using words such as “effort” in favor of “effort force” or “effort distance.” The four final excerpts will show that student groups actually do begin to get better at discernment.

Groups Displaying Lack of Discernment in Early Interventions

In the following excerpt Chavon, Charlie, Sally, and Laura are attempting to determine whether the lever works more like an inclined plane or a wheel and axle. See figure 4.11 (to left). The reasoning sequence presented in the excerpt hinges on the first utterance in which Sally presents the idea to the group that the “effort arm length” might be like “the wheel.” Figure 4.10 (above) shows a lever superimposed upon a wheel and axle. In fact, the wheel’s radius does correspond
to the lever’s effort arm length, as shown by the superimposed diagram. Both, when made larger, for example, reduce force required to work the machine. However, it is inappropriate and inexact to compare a qualitative physical element of the simple machine – the wheel – to a quantitative measurement – the effort arm’s length.

Sally begins the reasoning sequence, “Wouldn’t the effort arm length be (2s) the wheel? Does that make any sense... to you? Cause it's the.. (motions twisting).” Her justification, indicated by the “Cause” in “Cause it’s the..” followed by a twisting motion shows she understands that both the effort arm and the wheel are turning about their axis. What is more, her decision to use “effort arm length” as opposed to just “effort arm” suggests she has some sense that the length is important. It is. However, the wheel’s size, best measured by the radius in this case, is equally important. This piece is missing from Sally’s utterance and, in fact, from the rest of the reasoning sequence as well.

Excerpt 2.1 – Task 4 of 7

00:17:13:37 Sally Wouldn't the effort arm length be (2s) the wheel? Does that make any sense... to you? Cause it's the.. (motions twisting)
00:17:23:45 Chavon You mean like this part? (points to wheel)
00:17:25:87 Laura Cause it's wrapped around?
00:17:24:05 Sally Yeah cause it's as far as it has to travel. You know what I'm saying? Like that's how.
00:17:29:64 Laura But it.... changes.
00:17:34:10 Sally What do you mean?
00:17:35:90 Laura Cause it wraps around several ...
00:17:34:87 Sally But this also changes (points to lever) if you change where the fulcrum is. Do you see what I'm saying. I don't know. That's just my thought.
00:17:42:62 Laura Maybe.
00:17:45:73 Sally I might be... totally wrong on that but...

After Sally's initial utterance, Chavon asks, “You mean this part?” She points to the wheel during the utterance. Chavon must verify what Sally was referring to. The word “wheel” alone was evidently insufficient. Already one can see that this type of activity invites students to
discern one element of a simple machine from another in their communication verbally and with gestures.

The next four utterances, beginning with Laura’s “Cause it’s wrapped around?” are somewhat unclear. Laura’s talk of it being “wrapped around” does not specific what “it” is. But, it likely refers to the fact that both the wheel and the effort arm of the lever are moved about a center. Sally’s “But this also changes if you change where the fulcrum is” utterance further suggests emphasis on the fact that both the wheel and the effort arm relate to their respective simple machine centers in the same way.

Finally, the reasoning sequence ends with evidence of dissatisfaction. Sally’s utterance continues, “Do you see what I’m saying. I don’t know. That’s just my thought.” Laura responds, “Maybe.” And Sally states, “I might be… totally wrong on that but…” All three of these utterances suggest indecision. The correspondence holds appeal due to the very similar, would-be-valid comparisons the group might have made either between the wheel and effort arm or between the wheel radius and the effort arm length. But without discernment the group could not bridge the gap between the wheel and the wheel radius.

Lack of appropriate discernment vis-à-vis the wheel contributed to the lack of a productive reasoning sequence in this case. Early in the intervention the stage had been set. The “effort arm length” was being compared to the “wheel.” Comparing a physical element such as the “wheel” to a measureable quantity such as the “effort arm” simply is not analogical. Had Sally begun with an assertion that the wheel’s radius corresponds to the effort arm length, the argumentation would likely have produced a more satisfying argument.

The next group’s reasoning sequence also showed lack of discernment between resistance force and resistance distance. The group members used the term “resistance” indiscriminately. By not discerning between resistance force and resistance distance the group’s argumentation in this reasoning sequence, the group talked past each other. Miscommunication resulted.
Excerpt 2.2

The next excerpt also shows a lack of discernment. By not discerning very important differences between resistance, resistance force, and resistance distance, communication about these features is near impossible, as the excerpt will show.

First, some general explanation is in order. Both the threads and the top surface along the inclined plane, the effort distance, allow for a resistance to travel a greater distance than if it were moved straight up, thereby reducing necessary effort force for lifting. As mentioned in the first analysis section, making one correspondence can lead to another. In this case, this group is led to make a correspondence between the resistance distance of the inclined plane and an element of the screw. Consider figure 4.14 above.

The upper and lower part of figure 4.14, are positioned similarly to show alignment. Note that the diagram given to the group (shown in figure 4.6 on page 15) had no labels. The vertical distance of the screw and the resistance distance as labeled on the inclined plane both represent the distance that a resistance would move up as a useful output. This means that although the resistance would travel along a larger distance along the threads or the effort distance, at the end of the day it has really moved much less. This vertical distance can be correctly called the resistance distance in both the screw and the inclined plane.

The resistance distance, however, is different from the resistance itself. In the case of the inclined plane, the resistance force would be the force provided by the weight of the load at the bottom left. For the screw, the resistance force would be provided by something into which the screw was being turned, a wall, for example. It could also be said that the resistance itself would be the load, in these cases the weight or the wall. Consider the excerpt.
Transcript 2.2 – Task 3 of 7

00:20:16:47 Serena I think the resistance is gonna be whatever it's going into.
00:20:22:08 Evan The shaft would be...
00:20:22:87 Serena But that's the resistance.
00:20:25:17 Evan Is the shaft not the resistance?
00:20:31:11 Serena I don't think so.
00:20:32:21 Sheri I think this (points to resistance distance on inclined plane) would be like the shaft
00:20:36:38 Serena Yeah
00:20:35:82 Evan Why would that be like the shaft?
00:20:36:68 Sheri I don't know. Cause it's constant.
00:20:38:59 Evan Yeah but.... the only reason thee.. the threads are.. have to do with the effort distance is cause they're going up the shaft. So, I feel like.. the shaft would have to do with this piece (points to resistance distance on inclined plane)
00:20:50:77 Serena But that's not gonna be... but that's the resistance
00:20:51:23 Sheri But that wouldn't be resistance
00:20:52:40 Evan That's not what the piece is called.
00:20:56:62 Serena Yeah huhh
00:20:54:98 Sheri Yeah. It is.
00:20:55:49 Serena It's resistance
00:20:56:94 Evan That would also be the explanation.
00:20:58:06 Serena But it wouldn't be resistance....the shaft isn't
00:20:59:15 Sheri The wall would be resisting the threads.
00:21:03:45 Evan How is it...
00:21:11:29 Evan Why are you talking about wall?
00:21:12:76 Sheri I don't know. Cause I don't see how anything else makes sense.
00:21:14:24 Serena Like whatever it's going into it's gonna be resisting the effort.
00:21:17:94 Sheri Yeah. And, I'm assuming it's going into a wall.
00:21:20:93 Evan But that's not what it's at. There is no wall in this picture.
00:21:25:33 Serena It says a screw (inaudible)... So whatever it's going into... I think would be that.
00:21:29:27 Evan I completely disagree because there is no wall or anything.
00:21:36:73 Sheri I'm not saying it has to be a wall. But, it's implying that it's...
00:21:39:16 Serena You’re thinking outside of the box. Like in the other picture there was no pancake batter.
00:21:40:41 Evan Yes there was.
No there wasn't. But, there was no pancake batter.
Pancakes are made... pancakes are made from pancake batter therefore..
But you have to imply that... Like you have to infer it, I guess.
Yeah but like there was something there that you could look at. There is nothing here but a screw. (2 s) You know what I'm saying? (2 s) Like, you can look at a pancake and you don't.. you don't say oh there's not pancake batter there.
(overlapping) I don't care what we write. I don't understand this.

Serena starts off the excerpt stating the “resistance is gonna be whatever [the screw is] going into.” This is, in fact, correct. Other group members, however, do not discern that resistance is different than resistance distance or resistance force, and the argumentation, does not bear out this correct initial assertion. Evan follows up with, “The shaft would be..” This is left unfinished suggesting he knows it relates to the resistance in some way. It does. The shaft could be compared to the resistance distance of the inclined plane. Both share the same function in their respective simple machines. They are the useful distances the load moves. Evan is influential in this argumentation, yet he is unable to hold sway without the proper discernment between resistance and resistance distance. Serena reiterates, “But that’s the resistance.” Evan, likely knowing that the shaft length relates to the resistance distance but insufficiently discerning, asks, “Is the shaft not the resistance?” Serena answers, “I don’t think so.”
Sheri continues, stating, “I think this (points to resistance distance on inclined) would be like the shaft.” Serena agrees stating, “Yeah.” This, again is nearly correct, but it again lacks discernment. These two do have the same function on their respective machines. However, the language is inexact. Note that Sheri’s use of “this” and her pointing to the area of the incline plane in which the resistance distance is measured suggest that she is pointing to the resistance distance. And remember that the resistance would be the weight being lifted so
Sheri’s assertion is incorrect. Had she said the “resistance distance” was like the “shaft length,” this would have been correct. It is likely, since the referred to “the shaft” of the screw and pointed to the resistance distance of the inclined plane, that she intended to convey this idea.

During the next few utterances the opportunity for discernment was provided. It did not happen, however. Consider the utterances. Evan next asks, “Why would that [resistance distance] be the shaft?” Sheri states, “I don’t know cause it’s constant.” This is an unclear response to Evan’s question. Evan states, “Yeah but.... the only reason thee.. the threads are.. have to do with the effort distance is cause they’re going up the shaft. So, I feel like.. the shaft would have to do with this piece (points to resistance distance on inclined plane).” This utterance has two important functions. First, Evan situates the new potential correspondence within another previously made one – that of the threads [length] and the effort distance. This attempt to support to the new correspondence might have been effective. Evan even hedges somewhat with his use of “the shaft would have to do with this piece.” The phrase “would have to do with” suggests the need for further discernment through argumentation. Evan still has not used the word resistance distance, although he has pointed to it.

Serena counters, “But that’s not gonna be... but that’s the resistance.” She lacks discernment with this utterance. In fact, as has been pointed out by Evan, it is the resistance distance, not the resistance. The argumentation was put on a trajectory toward discernment with Evan’s “would have to do with.” The following utterances focus less on the potential correspondence and more on what is meant by “resistance.” Sheri, in response to Serena’s “that’s the resistance” utterance, offers, “But wouldn’t that be the resistance?” Neither Serena nor Sheri point to anything, which most likely means by “that” she is borrowing the prior reference in which Evan indicated resistance distance by pointing but without stating “resistance distance” verbally. This is argumentation to determine what is “that” and what is “resistance.”

Consider the following utterances:

00:20:52:40  Evan  That’s not what the piece is called.
With the first utterance above Evan seems to know that the vertical side of the inclined plane is not called “resistance” as Serena and Sheri have asserted. He offers no term however, and Serena and Sheri insist stating, “Yeah huhh,” a variation on uh huh, and “Yeah. It is,” respectively. Serena even reiterates the idea, “It’s resistance.” In actual fact “it” is not resistance. Serena’s “it” is resistance distance. The “resistance” is actually the weight at the bottom of the inclined plane. The group assumes they are talking about the same thing. They are not.

Serena offers, “But it wouldn’t be resistance… the shaft isn’t,” which seems to mean the shaft does not correspond to the resistance in its function. This is true. As has been stated resistance would best mean the weight on the inclined plane or a wall into which the screw goes. Sheri invokes the wall, stating, “The wall would be resisting the threads.” This has the effect of stating something like “The wall is the resistance for a screw,” which would be fine. However, without discernment between resistance, which is used in this case as a proxy for resistance force, and resistance distance, the group does not communicate what they intend.

Evan questions that the “wall” corresponds to the “resistance.” Most of the remainder of the reasoning sequence consists of the Evan continuing to assert that the “resistance” corresponds to the shaft and Serena and Sheri continuing to assert that the resistance force for the screw is the wall and as such, the wall
corresponds to the weight (also called resistance) on the inclined plane. These would both be correct assertions. The problem is a lack of discernment. Both groups are using the term “resistance” in lieu of “resistance force” (Sheri and Serena) or “resistance distance” (Evan).

Evan asks, “How is it?” and “Why are you talking about wall?” in response to Sheri’s invocation of the wall, which must be imagined since is not pictured in the diagram. Sheri responds, “I don't know. Cause I don't see how anything else makes sense.” Finally, Serena attempts to provide some justification stating, “Like whatever it’s going into it’s gonna be resisting the effort.” This has the effect of better discerning just what “resistance,” in her eyes is. Sheri explains here logical extension of the diagrams provided, “Yeah. And, I’m assuming it's going into a wall.” Evan takes issue with the reasonable imaginary wall because he is still considering that “resistance” means resistance distance. To the girls, it means resistance force provided by a wall. Evan uses the fact that “there is not wall or anything” in the diagrams or paired with the actual simple machines the group has at their disposal as ammunition to dismiss the girls’ assertion. The next several utterances -

00:21:36:73 Sheri I'm not saying it has to be a wall. But, it's implying that it's...
00:21:39:16 Serena You're thinking outside of the box. Like in the other picture there was no pancake batter.
00:21:40:41 Evan Yes there was.
00:21:43:36 Sheri No there wasn't. But, there was no pancake batter.
00:21:44:56 Evan Pancakes are made... pancakes are made from pancake batter therefore..

- refer to an earlier comparative activity the group had done that dealt with the state of pancakes when cooking. The utterances debate the appropriateness of logical extensions of the diagrams in making assertions. Sheri summarizes, “But you have to imply that.. Like you have to infer it I guess.” This provides the grounds for her and Serena's assertion that there could be a wall, and if there were, it would be the “resistance”. Evan refers back to the pancake activity in which it was unclear whether pancake batter had yet turned to a pancake in a picture. He attempts to defend his early assertion that, in fact, a pancake did exist and at the same time
dismiss the assertion that in the current activity, a wall could exist. The reasoning sequence ends in dissatisfaction when Sheri states, “I don’t care what we write. I don’t understand this.”

The frustrating ending for the group is unfortunate. This is especially true since so many assertions that would have been correct had only more discerning language, definitions, or pointing been used. Unfortunately, explicit discernment of definitions did not become the focus in this reasoning sequence. Nonetheless, given the near correctness of their assertions, it is all but certain that important understandings were held by all three members (the fourth member did not participate during this reasoning sequence). As these were not accompanied by discerning language, important learning did not occur through this argumentation.

**Excerpt 2.3**

The following excerpt shows a short reasoning sequence in which Melissa, Beth, and Bree make a correspondence between the “shaft” of the screw and the “resistance distance.” It is, of course, inappropriate to state that a qualitative element of a simple machine, the shaft, corresponds to a measurable value of the inclined plane, the “resistance distance.” The shaft length, on the other hand, corresponds well. As mentioned in the previous excerpt analysis and shown in figure 4.14 (p. 33), the “shaft length” and the “resistance distance” are both the distance through which a resistance force would be usefully moved. This group accepts that correspondence, albeit without a more appropriately discerned definition of “shaft.” To the group “shaft” means “shaft distance.” Consider the transcript.

**Transcript 2.3 – Task 3 of 7**

<table>
<thead>
<tr>
<th>Time</th>
<th>Name</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:19:22:08</td>
<td>Melissa</td>
<td>Yeah. And, then I was gonna say that the umm.. shaft of the screw would be.. would be the resistance distance. (1 s) Cause it's like..</td>
</tr>
<tr>
<td>00:19:30:90</td>
<td>Beth</td>
<td>It's what's</td>
</tr>
<tr>
<td>00:19:32:99</td>
<td>Melissa</td>
<td>It's what it's going up. It.. You know what it... Yeah. I don't know how to explain that.</td>
</tr>
<tr>
<td>00:19:40:05</td>
<td>Bree</td>
<td>The shaft is one with the resistance distance.</td>
</tr>
</tbody>
</table>
Melissa states, “Yeah. And, then I was gonna say that the umm... shaft of the screw would be... would be the resistance distance. (1 s) Cause it’s like...” Beth agrees but is unable to further develop the idea, offering, “It’s what’s.” Melissa adds, “It’s what it’s going up. It... You know what it.. Yeah. I don’t know how to explain that.” In fact, she did justify somewhat when she said, “It’s what it’s going up.” Yes, the useful distance a resistance moves “up” can be represented by the shaft length or the resistance distance in spite of the fact that a resistance moves a greater distance along the effort distance (surface of the ramp) or threads of a screw. Bree concludes the reasoning sequence with “The shaft is one with the resistance distance.” This is a way of stating a correspondence. Although the group adopts it confidently, it is insufficiently discerned due to the use of “shaft” in lieu of “shaft length.”

After this activity, the third of seven, was finished, it became apparent when groups were asked to share their correspondences that insufficient discernment between such simple machine elements as “shaft” and “shaft length” was a problem. Nearly all groups did this or something very similar. This led to a discussion on the need to use exact language and also to avoid correspondences between quantitative values and non-measurable qualitative features.

Increasing Discernment Over Time

Discernment among student groups improved greatly in later activities. On the heels of instructor-led class discussion and numerous conversations between instructors and small groups on the need for exact discernment through verbal, gestural, and diagrammatic means, groups began to explicitly engage in discernment as a subactivity in and of itself. Consider the very next activity (four of seven) performed by the same group as the last activity. The handout for this activity is shown in figure 4.13 (p. 30).

In this reasoning sequence the group argues about a correspondence between the effort forces in both the lever and the wheel and axle. Although the same in name and in function, the
group needed to perform argumentation to make the connection confidently. The group was able to do this due to the discernment made between effort force, effort distance, and effort.

Beth begins the reasoning sequence by suggesting a relationship between the “hand pulling down” and the “hand pushing down.” She states, “Well. (2 s) Let’s stick to the lever and the wheel-and-axle (2s) because I think the hand pulling down could be equal to the hand pushing down so maybe the effort. See now what do you call that.” In her final phrase, Beth, explicitly directs the group’s focus to what they should call “that.” In her utterance she had used the word “hand” as a proxy or a placeholder. By asking what to call it, she suggests the need for further discernment. Consider the rest of the excerpt below.

Excerpt 2.4 – Task 4 of 7

00:12:15:35 Beth Well. (2 s) Let’s stick to the lever and the wheel-and-axle (2s) because I think the hand pulling down could be equal to the hand pushing down so maybe the effort. See now what do you call that.
00:12:32:42 Bree Effort force. (2 s) Right?
00:12:32:58 Melissa Yeah.
00:12:34:02 Beth Wow. Look at you!
00:12:36:52 Bree Yeah. I know. Sometimes I get them right.
00:12:38:00 Beth What would you call that on the other one, effort force?
00:12:42:81 Bree Yeah. Actually.
00:12:46:56 Beth I’m just gonna put hand coming down, hand pulling in parentheses.
00:12:52:67 Bree They’re both effort forces right?

............

00:13:28:25 Dory But is there a difference between effort and effort distance? I think there is.
00:13:33:72 Melissa There’s effort force and effort distance
00:13:32:97 Bree Yeah. So I don’t know which one it is.
00:13:34:11 Melissa Well that’s effort distance (points along effort distance). Effort force is what.. the force that it takes to pull the thing up the effort distance.
Picking up on Beth’s question, Bree offers “Effort force. (2 s) Right?” The next three utterances convey confidence in Bree’s assertion. Melissa follows with, “Yeah.” Next, Beth adds, “Wow. Look at you!” Bree then states, “Yeah. I know. Sometimes I get them right.” The term “effort force” has been correctly discerned and appropriated and the students know it.

The next few utterances serve to verify the fact that the label applies to both hands, not just one. The “hands” can be seen in figure 4.16 below. Beth asks, “What would you call the other one, effort force?” And Bree says, “Yeah. Actually.” Then Beth, apparently to hedge somewhat if the “effort force” term should be insufficient, says, “I’m just gonna put hand coming down, hand pulling in parentheses.” Bree, in spite of her previous utterance solicits further verification, “They’re both effort forces, right?” Combined with the previous several utterances, perhaps this utterance was made to further convince other group members of the correctness of her idea, or perhaps it was made in order to refute Beth’s need for the additional detail “in parentheses.”

After about thirty seconds of unrelated dialogue, Dory, who had not yet spoken in this reasoning sequence, sought additional discernment. Dory asks, “But is there a difference between effort and effort distance? I think there is.” Melissa responds, “There’s effort force and effort distance.” Interestingly, once the discernment between “effort distance” and “effort force” had been offered, Bree seems to question her prior utterances stating, “Yeah. So I don’t know which one it is.” One might infer that when she had stated “effort distance” in her earlier utterance that she did not realize there was an effort distance. More likely, however, she did not know what exactly was best represented by the hand (see figure 4.16 above). Melissa reaffirms her initial assertion stating, “Well that’s effort distance (points along effort distance). Effort force is what.. the force that it takes to pull the thing up the effort distance.” This utterance offers an
important discernment between “effort distance,” “effort force,” and just the word “effort” which is unclear.

The comparison activity scaffolded the students’ co-constructions in the discernment of a definition for effort force in context as can be easily seen in this reasoning sequence. First, Beth began the sequence using the “hand” in an attempted correspondence then suggested these might relate to “effort.” She then asked for more discernment around the word “effort.” Bree then offered “effort force.” Dory explicitly next asked the group to discern between “effort” and “effort distance.” Melissa offered further discernment to Dory’s “effort,” stating there’s “effort force” and “effort distance.” Finally, Melissa offers a clearly discerned definition of both “effort force” and “effort distance.”

Comparative tasks promote explicit discernment. The same group was used in the previous two excerpts. The first one showed the group not discerning between “shaft” and “shaft length,” while the second transcript showed the group discerning, over the course of several utterances, the difference between “effort force,” “effort,” and “effort distance.” Comparative tasks, such as the analogical mapping offered here, seem to scaffold students in improving discernment over time. In the first excerpt there was dissatisfaction with the resultant argument, whereas in the second, the group discerned various differences until an explanation was accepted by all with no further reservations.

Excerpt 2.5

The next excerpt, from Heather, Nathan, Audrey, and Jenn, shows another example of explicit discernment. The group is doing argumentation on the same activity (activity four of seven) as the group in the previous excerpt. They are attempting to find simple-machine-element correspondences between the lever and the wheel and axle.
Audrey begins by asking, “The fulcrum and... the... the thing... isn’t that the same as the (points to wheel-and-axle) pivot point. Not pivot point. The center of the thinger.” Consider the transcript below.

Excerpt 2.5 – Task 4 of 7

00:10:37:00 Audrey The fulcrum and... the ... the thing... isn't that the same as the (points to the wheel-and-axle) pivot point. Not pivot point. The center of the thinger

00:10:46:59 Haley Yeah

00:10:47:81 Audrey Wheel and axle

00:10:48:63 Haley So the fulcrum... Should we just call it that the thinger? (laughs)

00:10:57:11 Audrey There has to be a smarter word for that. Center thingy. Come on Nate. We need your big words here

......

00:35:22:13 Haley OK. The fulcrum and the center are the same because ...

00:35:26:44 Audrey because that's like the pivot point of the... machine

Audrey’s utterance serves two functions. First, she introduced a possible correspondence between the lever’s fulcrum and the wheel. Next, she questioned her own use of “pivot point” as an acceptable term to make a correspondence to the lever’s fulcrum. This questioning made it acceptable to the rest of the group to engage in discernment around finding a better term. Her questioning of the term also allows her to save face should a better term emerge from further argumentation. Heather agrees, stating, “Yeah.” Audrey tries to clarify with, “Wheel and axle.” It is not apparent whether this was a question or a statement.

With Heather’s “So the fulcrum... Should we just call it that the thinger? (laughs)” The dialogue next turns explicitly toward discernment. Clearly, “the thinger” is insufficiently specific to correspond with the fulcrum. Audrey opines, “There has to be a smarter word for that. Center thingy. Come on Nate. We need your big words here.”
The contiguous reasoning sequence ends here. The group did, however, take up the matter when attempting to write final choices on poster paper for sharing approximately 25 minutes later, offering a final two utterances. Heather states, “OK. The fulcrum and the center are the same because…” to which Audrey responds, “because that’s like the pivot point of the… machine.”

The simple machine element in question would best be called the axis of rotation. The members of the group likely did not know this term. Regardless, their definition was exact and well discerned and referred unquestionably to the axis of rotation in spite of the use of different words.

Although in principle the argumentation in the end yielded a product much like that in the first utterance, the “center” of the wheel and axle or the “pivot point” of the wheel and axle are sufficiently specific and unique as to not be confused with any other element. Therefore, it is best considered that discernment took place between the words “pivot point,” “center,” and “thinger.” And although “pivot point” ultimately was adopted, the other choices as well as physically pointing out added to the communication and discernment process.

**Excerpt 2.6**

The next excerpt provides yet another example of good discernment. The reasoning sequence takes place over several minutes during which Haley, Joan, and Abe argue about whether it is appropriate to consider the force provided by the ceiling of a single moveable pulley (see figure 4.15 next page) as an a source of effort. They consider both effort force and effort distance. Eventually, the make a final argument which discerns very well between an effort force and what they call a “stationary force,” such as the one provided by the ceiling. In scientific terms this would be better called a normal force, however, aside from nomenclature, the group accurately discerns definitions for both types of forces.
For the part of the activity, the fifth of seven, the group was doing the instructions, state, “Using analogical mapping, list the correspondences between the couch movers and the pulley in the table below.” See figure 4.15.

Joan begins, “I feel like the fact that… these two are both moving where this one’s like more stationary… and this one’s like doing all the principal movement…” Joan is effectively saying that the couch movers, which she calls “these two,” are “both moving,” whereas in the pulley scenario, the string segment on the left attached to the ceiling, about which she says “this one’s more stationary” is somehow different than one of the two couch movers and, by implication, may not correspond to the couch mover on the left. Haley agrees, “That’s true.”

Transcript 2.6 – Task 5 of 7

00:10:52:32 Joan I feel like the fact that.. these two are both moving where this one’s like more stationary.. and this one’s like doing all like the principal movement..

00:11:01:78 Haley That’s true

00:11:04:94 Joan I feel like this is the effort distance in this one (points to effort distance along right string on pulley) on this one… but here both of them have effort distances.. cause they’re both applying an effort force

00:11:14:75 Haley That’s true. I concur

00:11:18:40 Joan I don’t know.. uhh

00:11:19:58 Haley Should we write that down? Like both movers have an.. effort force as opposed to the one hand that has an effort force?
Abe Let's go with it. One effort force and two effort forces

Joan All right... I'm gonna say the stationary thing. I mean they're probably the same thing but..

Joan So the hand is applying the effort force in the pulley system

Haley I said two effort forces of the movers versus one effort force of the hand.. because the string segment..

Joan Well the thing is I think these are both effort... I don't know. Now I'm like confusing myself. Cause I don't know. Are these both effort forces (points to both sides of pulley on diagram)? Cause they're both lifting.

Haley I mean they're both lifting.. but this one.. like one's.. like one is stan.. like when it's just stationary.. like when the hand's not moving.. when it's not being lifted it's.. like not.. You know what I mean? Like it's.. I mean it's distributing the weight so it's not as hard to lift. But it's still this is doing all the force to lift it. This one's just holding it up.

.....

Haley A ceiling.. I don't know (laughs) (3 s) Or the wall.. ceiling.. (to Betsy) Would you call that the ceiling...? Or something?

Betsy Yeah

Abe Non-resistant force

Haley What?

Abe Non-moving force

Haley The ...stationary string

Joan I just said stationary

Abe That works... uhh..

Joan further discerns between the forces acting on the two sides in both scenarios, stating, “I feel like this is the effort distance in this one (points to effort distance along right string on pulley) on this one... but here both of them have effort distances.. cause they’re both applying an effort force.” This utterance suggests that for the couch movers “both of them have effort distances,” which Joan reasons is because “they’re both applying an effort force.” This
both buttresses the assertion in her first utterance and provides more discernment adding the terms “effort force” and “effort distance,” where before there was simply movement.” Haley again agrees, stating, “That’s true. I concur.”

For all that has been said about what effort force and effort distance are, nothing has been said about what they are not. Specifically, is effort force or effort distance applicable to the string segment coming from the ceiling? Joan hesitates, stating, “I don’t know.. uhh.” Haley asks, “Should we write that down? Like both movers have an.. effort force as opposed to the one hand that has an effort force?” Again, the issue of what else the pulley has (from the ceiling) is left unstated. Abe says simply, “Let’s go with it. One effort force and two effort forces.” This is correct, of course, and the group could have left the argument here, yet the fact that the correspondence was inexact seemed to beg for more discernment, which was forthcoming in the next part of the reasoning sequence.

Joan seems to be the one, at least so far in this reasoning sequence, doing the discerning. In spite of Abe’s invitation to “go with it,” again, she attempts to discern between different types of forces offering an the term – “stationary.” Her full utterance is “All right… I’m gonna say the stationary thing. I mean they’re probably the same thing but..” “They’re probably the same thing” allows for other students’ desire to close the case. But “I’m gonna say the stationary thing.” makes it known that in her eyes anyway the response is left wanting.

From apparent simplicity with regard to what effort force is, the next three utterances show an increasing need for discernment.

00:12:56:62 Joan So the hand is applying the effort force in the pulley system
00:13:01:90 Haley I said two effort forces of the movers versus one effort force of the hand.. because the string segment..
Joan’s utterance, “So the hand is applying the effort force in the pulley system” is best understood as a think-aloud or perhaps a place holder to leave the matter unsettled. Haley differentiates, again, between the fact that the movers exert two effort forces and the pulley only has one effort. But the question of what to make of the other one remains. Why are there not two effort forces in the pulley scenario? What is the other force?

Joan gets to the heart of the matter. She states, “Well the thing is I think these are both effort... I don't know. Now I'm like confusing myself. Cause I don't know. Are these both effort forces (points to both sides of pulley on diagram)? Cause they're both lifting.” In this utterance, finally the question “Are these both effort forces?” emerges. The question becomes one of definition discernment. They are “both lifting” after all. Haley agrees but then borrows Joan’s word “stationary. She states, “I mean they're both lifting.. but this one.. like one's.. like one is stan.. like when it's just stationary.. like when the hand's not moving.. when it's not being lifted it's.. like not.. You know what I mean? Like it's.. I mean it's distributing the weight so it's not as hard to lift. But it's still this is doing all the force to lift it. This one's just holding it up.” Haley is mistaken on one thing. The hand is not “doing all the force to lift it up.” In fact, the force required by the hand is reduced by half because of the ceiling. Next, however, Haley keenly discerns between “lift[ing]” and “holding it up.” She says, “[the hand on the pulley] is doing all the force to lift it up” and “[the string segment attached to the ceiling is] just holding it up.” While, not entirely correct, it is nearly so. It is true that when hanging still, half of the weight is supported by the ceiling and half by the hand. Any movement, or “lift[ing], as Haley calls it, would require additional force to overcome gravity and friction. This additional force can only be initiated by the hand as the ceiling is incapable of spontaneous movement. Of course, the ceiling is always
supporting its half of the load, but it is not capable of providing an impetus. Haley, with her
discernment between “lift[ing]” and “just holding it up” is showing that she too recognizes the
difference between an effort force and that which the ceiling provides.

00:14:22:56 Haley A ceiling.. I don't know (laughs) (3 s) Or
the wall.. ceiling.. (to Betsy) Would you
call that the ceiling...? Or something?
00:14:32:36 Betsy Yeah
00:14:32:96 Abe Non-resistant force
00:14:36:08 Haley What?
00:14:37:02 Abe Non-moving force
00:14:38:96 Haley The ...stationary string
00:14:40:92 Joan I just said stationary
00:14:42:44 Abe That works... uhh..

Three unrelated utterances were skipped and the remainder of the reasoning sequence
is above. Again attempting to discern a better name for the force from the ceiling, Haley asks,
“A ceiling.. I don’t know (laughs) (3 s) Or the wall.. ceiling.. (to Betsy) Would you call that the
ceiling…? Or something?” With her “Or something?” the question of how to talk about the force
from the ceiling is again asked but this time to Betsy, the instructor, who happened to be waking
by. Betsy says simply, “Yeah.” Abe attempts to be more discerning with a response to Haley’s
question to Betsy, offering “Non-resistant force” and then “Non-moving force.” Haley then adds
the stationary string. And Joan finally says, “I just said stationary. Abe ends the reasoning
sequence with, “That works… uhh.”

Discussion of Finding 2 – Increasing Discernment

This analysis section has provided evidence that students were scaffolded in their
discernment by the activities and related instruction. The activity itself generates a need for
discernment of students. Instruction helps make students aware of this need. Making a correct
correspondence is just not possible without first knowing what it is exactly one wishes to
correspond. By providing students the opportunity to do comparative multiple analogical
activities over time such as those in this research, they began to become more aware of the need for discernment in communication.

The first set of excerpts showed reasoning sequences in which groups did not discern between two or more similar elements of a simple machine such as “effort distance” and “effort force,” for example. The second set of excerpts showed improvement in discernment during later comparative activities. In their reasoning sequences, groups managed to discern important but subtle differences between such things as shaft and shaft length or effort force and stationary force through their argumentation.

Not only were groups able to better discern between highly related simple machine elements such as “effort,” “effort distance,” and “effort force,” but, as shown in the final excerpt in this section, they also discerned a new category, such as a “stationary” force that had not been offered in the class at all previously.

This finding is particularly relevant to the science education community. Much time in science education and education generally is spent on definitions. Comparative analogical activities such as those in this research scaffold the learning of definitions in context through discernment. In this research the scaffold for learning to discern a definition arises from the expertise that is embedded in the activity. Students must, in order to make correspondences to complete the activity, discern well the definitions for the elements of the simple machines.

The definitions are “problematized” and “structured” by the comparative activities. “Problematizing” and “structuring” are the key functions of a scaffold, according to Reiser (2004), as discussed in the literature review of this research (chapter two).

Finding 3 – Learning to Deal with Ambiguity in Correspondences

Analogical correspondences scaffold one another, which is often helpful as described in finding one. However, since analogical correspondences eventually break down, students sometimes are led to consider correspondences that are incorrect. Correspondences that are
incorrect but are appealing on some level will be called ambiguous correspondences. Sometimes even very important simple machine elements do not have correspondences on other machines. These elements can be problematic for student groups who are looking for the one 'right' answer when there is none.

In early interventions, such as those from which the first three excerpts in this section are taken, student groups attempted to make correspondences to a part of a simple machine that had no clear functional correspondence on another machine. These usually ended in a choice made with trepidation and dissatisfaction expressed. Upon realizing this, instructors provided instruction (see excerpt 3.4; p. 168) on recognizing and dealing with ambiguity in analogical correspondences. In later interventions, such as those shown in the final three transcripts in this section, groups were better able to evaluate and dismiss a given simple machine element as not having a functional correspondence.

Comparing the first set of excerpts to the second set will provide evidence for student learning about dealing with ambiguous correspondences. Evaluating a possible correspondence as potentially relevant to a larger argument and then dismissing it is important skill, as students are invited to make initial judgments about the likely quality of an analogical correspondence before making it, thereby making the best use of their argumentation time.

Groups Having Difficulty with Ambiguous Mappings

**Excerpt 3.1**

In the excerpt below, Evan, Serena and Skyler are arguing about what simple machine element would correspond the lever’s fulcrum on the inclined plane. The group has already decided there is an analogue, the axis of rotation, on the wheel and axle. They have, as the excerpt will show, some difficulty with the correspondence, since no part of the inclined plane moves in such a way as the fulcrum on the lever (see figure 4.16 above) or
shares its structural features. The elements around the fulcrum (e.g., effort arm, resistance arm, load and effort) have correspondences. These seem to scaffold the group toward the fulcrum. Yet, they come to an unsatisfying argument. Consider the excerpt.

Excerpt 3.1

00:15:16:51 Skyler  Like what would be considered the fulcrum?
00:15:35:08 Skyler  I don't know like the fulcrum.. like... like depending on the fulcrum... for the lever.. depends on the fulcrum.. how it sits.. so that'd be like the ground?
00:15:50:70 Serena  You mean like the incline of the... like the angle of the... incline?
00:15:53:67 Evan  That makes sense to me
00:15:58:02 Skyler  I guess
00:15:59:22 Serena  Something like that
00:16:01:07 Skyler  Yeah. Degree of the incline.
00:16:04:06 Evan  Wait, so fulcrum position or just fulcrum?
00:16:08:11 Skyler  Yeah. We could put that
00:16:11:55 Evan  Fulcrum position?
00:16:12:75 Skyler  Yeah sure
00:16:16:51 Serena  (sings inaudible)
00:16:16:51 Skyler  I don't think we have to fill all of them in.. I think we just write what we have.

Skyler begins the reasoning sequence, “Like what would be considered the fulcrum?” and then a few seconds later, “I don’t know like the fulcrum.. like... like depending on the fulcrum... for the lever... depends on the fulcrum... how it sits... so that’d be like the ground [on the inclined plane]? The first utterance puts out there the question of “what would be considered the fulcrum?” on the inclined plane. Her choice of the word considered correctly implies interpretation. The word considered allows for more subjectivity than if she had asked which one corresponds to the fulcrum or, as in other transcripts, which one is the fulcrum on the inclined plane. Skyler’s second utterance, an attempt to begin answering her question, is unclear, however, and provides little new information or ideas. The end, “so that’d be like the ground?” seems to ask if the lever’s fulcrum is like the inclined plane’s ground. More would need to be said on this in order for others to understand.
Attempting to redirect, Serena follows with, “You mean like the incline of the…like the angle of the … incline?” This question is an attempt to build upon Skyler’s second utterance. By invoking the “angle of the…incline” Serena is speaking of the angle between the ground and the inclined plane’s surface. This both uses Skyler’s previous utterance and adds to it. Evan responds, “That makes sense to me.” Skyler hedges with, “I guess.” Serena hedges against her own assertion with, “Something like that.” Skyler adds, “Yeah. Degree of the incline.” It is starting to look as though the group believes that the angle of incline of the inclined plane is like the fulcrum.

There is a problem with the asserted correspondence that the fulcrum is like the angle of incline. The fulcrum is a physical point in space, whereas the angle of incline is a measurement. And, it requires two physical objects in order to exist – the ground and the top board making up the inclined plane’s surface. The group continues argumentation.

Evan requests clarity, perhaps realizing that one does not measure a fulcrum per se, stating, “Wait, so fulcrum position or just fulcrum?” Skyler, when asked an either or question, says the equivalent of “yes” with her, “Yeah. We could put that.” Attempting to clarify, Evan asks, “Fulcrum position?” Skyler replies unconvincingly, “Yeah sure.” Serena is singing yet attentive. She often sang for short periods while still attending to the conversation. Skyler asks, “Do we have to fill all these out?” This utterance likely indicates Skyler’s frustration with this correspondence and the correspondences generally between the inclined plane and the lever. Although it is possible that Skyler realized that fulcrum position can be measured and so it could align better with the angle of incline, it is likely that her two previous utterances beginning, “Yeah…” were simple attempts to end this reasoning sequence. The “Do we have to fill these out?” utterance fits with this pattern. The group is frustrated.
Serena offers, “I don’t think we have to fill all of them in… I think we just write what we have.” This has the effect of stating “let’s move on.” The group does. They write it down (see figure 4.17). The group’s presentation poster says that the “fulcrum position” corresponds to the “degree of incline.” Their explanation is that “both change effort distance. While potentially true, it is underexplained and could also be untrue given certain configurations.

In fact, there is no good analogue to the fulcrum on the inclined plane. The inclined plane and the lever are fundamentally different simple machines. The group may have sensed this incompatibility but questioned it due to their inexperience with the ideas. Or perhaps they simply did not give themselves proper license to not make a correspondence with an element as easily identifiable and clearly important as the fulcrum. The next excerpt shows a group considering the same correspondence.

**Excerpt 3.2**

In the following excerpt, as in the previous, the possibility of finding a correspondence for the fulcrum in some element of the inclined plane comes up. First, a few possibilities are offered, and like the group in the previous excerpt, this group expresses dissatisfaction with the possibilities they come up with. Consider the transcript.

**Excerpt 3.2 – Task 4 of 7**

<table>
<thead>
<tr>
<th>Time</th>
<th>Participant</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:07:41:53</td>
<td>John</td>
<td>What is the.. What would be the fulcrum? Hmm.. Fulcrum would be the corner? Just kidding.. no.</td>
</tr>
<tr>
<td>00:07:49:19</td>
<td>Nora</td>
<td>There’s no fulcrum on the inclined plane.</td>
</tr>
<tr>
<td>00:07:50:58</td>
<td>John</td>
<td>It’s the middle spot right here.. Right here. Believe me that’s the fulcrum right here (points to top of inclined plane). Kim come on. Where’s your imagination?</td>
</tr>
</tbody>
</table>
John begins the reasoning sequence asking, “What is the.. What would be the fulcrum? Hmm.. Fulcrum would be the corner? Just kidding.. no.” Nora responds confidently, “There’s no fulcrum on the inclined plane.” Literally this is true and obvious. However, students commonly
refer to correspondences not by saying X is like Y but by saying X is Y. In light of this, in this case, it is very likely that Nora’s remark was intended to convey the idea that, in fact, nothing corresponds to the fulcrum on the inclined plane, which is also true.

John disagrees, “It’s the middle spot right here.. Right here.. Believe me that’s the fulcrum right here (points to top of inclined plane). Kim come on. Where’s your imagination? Kim retorts, “Sorry dude.” John, half jokingly, expresses his frustration, “Pssh.” John, in lieu of providing justification, resorted to assuredness and the enlistment of others in attempting to persuade others that the “fulcrum” is in the middle of the inclined plane. In the picture the group received (see figure 4.20), the lever was shown in a similar position to the inclined plane. One can see the superficial appeal of John’s position that the fulcrum would be in the middle of the inclined plane.

Nora proceeds to justify her disagreement with John,

“Well if we were gonna label something fulcrum I think it would be here.. (points to left most corner of inclined plane) because... what we learned about levers is that the further from the fulcrum we move.. the... the more effort it takes.. So like if you had a fulcrum here (points to top corner of inclined plane) and you moved towards the fulcrum. But it doesn't so.. this would be you moving away from the fulcrum (if fulcrum were leftmost point on inclined plane) and it gets harder.. Cause it gets steeper..”

By beginning, “Well if we were gonna...” Nora reiterates that she does not think the fulcrum corresponds to any part on the inclined plane. However, if forced to make a comparison, Nora believes, a fulcrum correspondence would not be in the middle, as John said, but rather it would be one of the corners of the inclined plane. Her justification is essentially that if you move the fulcrum of the lever and if you move the corner of the inclined plane, the machine would require
different effort forces in both cases. This can be correct under certain circumstances and is somewhat akin to the assertion of the group in the prior excerpt in which they suggested the fulcrum best corresponded to the angle of incline.

John appears to want to move on offering, “OK...If we write that down then can you explain that?” Although he provides no evidence that he has understood Nora’s prior utterance, his rebutting is finished. Still Nora questions herself, realizing that although her prior utterance may be correct under certain circumstances, she had not made a correspondence from the lever’s fulcrum to a particular part of the inclined plane. Rather she had put forth a potential correspondence to a particular set of nebulous circumstances, thus she states, “But we... that doesn’t really refer to anything though. So...” John, desperate for closure, states, “But it’s an idea...”

Nora offers a new assertion, “I know... the fulcrum is equal to the angle (3 s) What do you think? The fulcrum... of... a lever is equal to the angle of the inclined plane...” This is essentially the same assertion that the group in the previous excerpt had. Although it holds appeal, its functional correspondence is limited by the fact that there is no movement about the angle of the incline as there is in the lever’s fulcrum. Kim, seems to agree but offers no evidence of understanding, stating “OK...” John adds, “Yes...I’m not...I...I...”

Nora talks with Mark, the instructor, to ask, “What.. What do you think of this (to Mark)? I’m suggesting that the fulcrum of the lever is like the angle of the inclined plane because the further you move from the angle the more effort you have to put in. And the same thing..if you were to move further from the fulcrum.. your load further from the fulcrum.. you would put more...” This restatement of her earlier utterance garners little input from Mark, who hedges. He states, “That's interesting.. I'm not.. like.. I.. I don't.. If you're.. If you're.. I you guys agree and that analogy works there's not a right answer.. So if you think that like.. like.. ummm..” He offers the somewhat unclear but potentially helpful, “…there’s not a right answer...” Nora insists, “Do you know what I’m saying though?” John interprets Mark’s earlier remark, “He can’t say
anything.” Mark then says, “I’m not going to... I don’t wanna respond to that... I don’t.. but I don’t.. If you.. If you...”

John interprets again, “It’s OK. You don’t have to get it right.” Mark offers advice, “Like...one thing I would do like if you struggle you can always go back and forth... sometimes I find that to be... instructive.” Nora states finally, “I don’t want to write a whole bunch of stupid stuff.”

In the end, the group does make a correspondence on their poster between the angle of incline and the fulcrum (see labeling on figure 4.19). Nonetheless, there was dissatisfaction evident from the beginning to the end, especially with Nora, who had the idea for the correspondence. First she stated, “There’s no fulcrum on the inclined plane” and then at the end of the reasoning sequence, “I don’t want to write a whole bunch of stupid stuff.”

The fact that there was dissatisfaction with the response but it was made anyway suggests a couple things. First, the group must have believed that this was the best response or deferred to Nora, who did not seem to have strong convictions on the matter. Or second, the group did not feel that they had license to not make a correspondence between the fulcrum, a very important element of a lever, and something on the inclined plane. They were either unwilling or unable to ignore this correspondence.

Excerpt 3.3

The next two excerpts from one group are put together to show improvement in recognizing and dealing with ambiguity in correspondences. In the first excerpt, the group struggles to make a correspondence between the head of a screw and an element of an inclined plane. This ambiguous correspondence ends in dissatisfaction, as did the prior two groups’ reasoning sequences. The second excerpt from the group, however, shows the group recognizing and dealing explicitly with ambiguous correspondences.
The head of the screw, some group members argue
is like the base of the inclined plane (see figure 4.22).
Others say that since it receives the effort force, it is like the
load on the inclined plane. Both points of view have merit. This excerpt was taken from the third activity of seven.

Dory begins by addressing the screw’s head, “Oh yeah. So what part’s the head? Oh that’s the head?” This was an identification of the screw’s head on the screw, not a search for a correspondence, which Melissa offers next. She states, “I think it’d just be like the head… would just be like the base of it.” Looking at figure 4.22 (prior page), one can see the appeal. Both, after all provide a base for their respective machines, at least as shown. Dory adds, “Yeah.” And Beth says, “Hmmm.” Melissa reiterates, “I think the head of the screw would be like the base of the inclined plane.”

Dory’s next utterance suggests she is considering the wood into which the screw goes as a resistance force. She states, “And then the wood is the cylinder.” Both are, in fact, loads or resistances, so this makes sense and is an appropriate functional correspondence. Beth clarifies, “I thought the tip was the starting point of the plane,” which the group had already accepted as a correspondence. This is appropriate, but it implies a shift of perspective in which the screw shown in figure 4.22 (prior page) would be turned upside down, as in figure 4.23 (to right). Both perspectives are reasonable but do require the need to clarify perspectives in order to avoid miscommunications. Talking within one perspective to someone who holds another perspective creates the opportunity for a systematic taking past each other, which happens in this reasoning sequence. Beth’s utterance is in essence a proxy, although she may not realize it, for perspective clarification. In order for her utterance to be true, the perspective offered in 4.22 would need to be in effect. Melissa’s utterance, however, requires that the perspective shown in figure 4.21 be in effect.

Melissa responds to Dory’s clarification that yes, indeed, “The wood is the cylinder.” Dory seeks further clarification on what exactly the base is, “Yeah, the base… the.. this part.” Melissa offers, “This is.. like the base (points to base of inclined plane).” Dory adds, “Like if you
were to put this on its base (points to inclined plane. Gestures as if moving it).” Melissa reasserts, “That would be the head of the screw. (2s) The head of the screw is the base.”

Beth rebuts Melissa’s assertion, vaguely stating, “Yeah, but I’m not really like relating... I don’t know. For some reason I’m not relating that.” This is not just a lack of understanding. Later utterances will show that she does not agree with Melissa’s assertion that the inclined plane base relates to the screw head. Melissa attempts to justify, “Well it’s cause the head of the screw doesn’t really do anything. You know what I mean? Like..” By, “doesn’t really do anything,” she may mean that it is not relevant in providing or calculating a mechanical advantage as, say, the thread length or shaft length would be. This time adding justification, Beth rerebuts, “That’s where force is applied though. Think about it. You don’t screw in a screw just from like putting it there. You have to push on the top.” She is adopting the perspective shown in figure 4.23 (prior page) in which the base of the inclined plane and the head of the screw do not align. Furthermore, she states that “you have to push the on the top.” Melissa, concedes and would like to rebut, “Yeah, like I get that but..” Beth’s next utterance continues to build up her past one, “Same way as you push on the cylinder..” She is basically saying that one pushes on the head of the screw and one pushes on the weight going up an inclined plane, therefore these correspond.

Melissa disagrees again, “But, it’s not really asking like what force you’re putting on it. It’s just asking like what the function of it is.” This is Melissa’s attempt to frame the activity in order to dismiss Beth’s assertion. Beth counters, “Yeah, it receives the force to create the screw.” Beth redirects Melissa’s critique stating that the head’s function is that it “receives the force.” In reality both assertions have merit and both are on equally shaky ground. In spite of the explanatory functional correspondences between the screw and the inclined plane, the head of the screw has no clear functional correspondence to any element of the inclined plane.

For the first time since Beth’s assertion, Dory comments. She says, “The cylinder like has to experience resistance.. and this... but like this part (not visible to camera) doesn’t. I think
the wall has to exert…” Unfortunately, as the comment is not a complete sentence. And since what she pointed to could not be seen, this comment adds little new.

Again, as with the groups in the prior two excerpts, the reasoning sequence ends in dissatisfaction. Melissa, it seems, feels the situation is irresolvable, stating, “I don’t know. I really don’t think it matters all that much.” Dory similarly states, “I don’t think it does either.” Melissa, seeking closure, asks, “Let’s just write something.” Dory responds, “OK.” The reasoning sequence ends. The group does not argue about the issue again. The members do not write either one of the assertions on their paper. Although both Beth and Melissa had valid points neither could dismiss the other. Although a frustrating end is perhaps not ideal, the next excerpt shows the same group in the very next activity (four of seven). In fact, the next three excerpts show groups that acknowledge ambiguity in correspondences early and for that reason decide, rather appropriately, to dismiss them.

Learning to Deal Well with Ambiguity

Excerpt 3.4

In the following excerpt the same group – Dory, Bree, Beth, and Melissa – argues about a correspondence for the lever’s fulcrum on the inclined plane. This excerpt, however, is different from the last three, because in it the group asks their instructor, Betsy, for help. Betsy gives them the license they need to not do each and every correspondence that the group might conceive of but rather to evaluate whether a potential correspondence is likely to lead only to frustration. This excerpt is representative of numerous instances of instruction that took place in small groups and among the whole class.

Consider the excerpt.

Excerpt 3.4 – Task 4 of 7

00:20:10:50  Bree  So what else is there on this?
00:20:11:64  Beth  This one’s tricky then.
Dory Fulcrum. Fulcrum. But there’s nothing the fulcrum could possibly be on here (inclined plane).

Melissa I feel like the wheel-and-axle are a lot more alike.

Bree Fulcrum would be the corner.

Melissa I think the fulcrum's the corner.

Beth The starting point.

Dory The tip.

Bree Ummmmmm

Melissa I don’t know if it’s this one or this one (points to left point of IP and top point of IP).

......

Beth Well, tell me what you really think. No. Would that be it?

Bree I don’t know.

Dory I think it is, because once it starts. At that point, then it starts like taking some effort to get it to the other side. And, it’s kind of like the fulcrum. Like once it gets over the fulcrum like on that other side like.. it’s like that’s when it starts using effort.

Bree I could see that.

......

Bree Like I feel like there’s not enough to correspond to with this (points to inclined plane). Like there’s more things on this (points to wheel and axle) then there are on this (points to inclined plane).

Betsy OK. That's OK. That's OK. Not everything's gonna correspond to everything.

Dory So we don’t... We don't all the boxes?

Melissa (overlapping) We don't need to fill in all the boxes?

Betsy No. You do not need to fill in all the boxes. They’re just there for you.

Beth Good cause I thought that we were really stretching for stuff.

Betsy So, if you do feel that things don’t correspond you might... you know...

Bree They might not.

Betsy Yeah, they might not.

Bree OK. Thank you.
Bree starts off the reasoning sequence asking what other correspondences might be made between elements of the inclined plane and lever. She states, “So what else is there on this?” Beth responds, “This one’s tricky then.” Dory offers up, “Fulcrum. Fulcrum. But there’s nothing the fulcrum could possibly be on here (inclined plane).” Although this is the same activity as in the first two excerpts in this analysis section (3.1 & 3.2), so far this reasoning sequence is playing out very similarly. The groups have all made other correspondences and are led to consider the fulcrum. There are early signs of frustration or the sense that there will be. Nonetheless, argumentation ensues.

Melissa attempts to take the argumentation to a larger scale, that of the whole machine to machine comparison. She asserts, “I feel like the wheel and axle are a lot more [alike].” Bree, ignoring Melissa’s comment, states, “Fulcrum would be the corner.” Melissa, takes up the assertion and apparently makes it her own, stating, “I think the fulcrum’s the corner.” Beth clarifies, “The starting point,” which makes it clear that they are talking about the left corner. Dory discerns further exactly what the group is considering with, “The tip.”

Melissa takes issue with, “I don’t know if it’s this one or this one (points to left point of the inclined plane and top point of inclined plane).” A few minutes of non-related dialogue were skipped. Beth picks up with, “Well, tell me what you really think. No. Would that be it?” Bree, “I don’t know.” Dory provides a justification for the fulcrum to the left corner of the inclined plane, stating,

“I think it is, because once it starts. At that point, then it starts like taking some effort to get it to the other side. And, it’s kind of like the fulcrum. Like once it gets over the fulcrum like on that other side like.. it’s like that’s when it starts using effort.”

Dory’s justification is extremely flawed and insufficiently explained, yet it is a justification of sorts, which is more than has been offered heretofore. Bree says, “I could see that.” Again, after some unrelated dialogue, Bree expresses frustration generally with the inclined plane to
lever correspondences generally, “Like I feel like there’s not enough to correspond to with this (points to inclined plane). Like there’s more things on this (points to wheel and axle) then there are on this (points to inclined plane).” Like Melissa’s utterance at 20:11:08, this utterance shows that Bree views the ambiguity of the fulcrum correspondence to some element on the inclined plane to lead as justification for an argument in support of the lever and the wheel and axle better corresponding. The functional similarities between elements of the lever and the inclined plane just are not there.

Betsy, the instructor, who happened to be passing by, responds to Bree’s remark, “OK. That’s OK. That’s OK. Not everything’s gonna correspond to everything.” Numerous such exchanges happened in the class. This provides the group the license they need to follow their initial ideas that, in fact, the fulcrum has no correspondence. Dory verifies, “So we don’t… We don’t need all the boxes?” Melissa follows suit, “We don’t need to fill in all the boxes?” Betsy reiterates, “No. You do not need to fill in all the boxes. They’re just there for you.”

Beth summarizes her, and likely the group’s, feeling about the reasoning sequence on the fulcrum, stating, “Good cause I thought that we were really stretching for stuff.” Betsy adds, “So if you feel that things don’t correspond you might… you know…” Bree adds, “They might not.” Betsy repeats and Bree thanks her. The group does not write the correspondence on their papers.

While clearly the group was helped by Betsy’s presence, this excerpt is very representative of small conversations that happened between instructors and students and even the researcher and students. Students seemed to feel the need to be validated in choosing to ignore some correspondences.

**Excerpt 3.5**

In the past excerpts in this analysis section, ambiguous correspondences were considered over up to a few dozen utterances. As groups had done more and more of the
activities in this research, each having ambiguous elements that lacked clear correspondences (ambiguous elements), and after conversations with instructors such as the one in the prior excerpt, groups began to dismiss potential correspondences more quickly. Interesting, groups did not dismiss simple machine elements that actually had a valid correspondence. This is noteworthy given the brief encounter represented in the very short reasoning sequence below. Consider the excerpt.

Excerpt 3.5 – Task 4 of 7

00:19:45:29 Haley What do you think the fulcrum is on a.. on a inclined plane?
00:19:46:47 Riley I don't think there is one... I think that's why they’re not similar. I'm gonna say that it's most like the lever and the wheel and axle..

Those two utterances represent the whole reasoning sequence. A correspondence with the lever’s fulcrum and an element of the inclined plane was not considered before or after these two utterances. Haley brought up the question of a possible correspondence. Riley responded stating, “I don’t think there is one...I think that's why they’re not similar. I'm gonna say that it’s most like the lever and wheel and axle..” The fact that the fulcrum was so central to the functioning of the lever and corresponded so well to the wheel and axle’s axis of rotation, as the group in this excerpt had already found, combined with the fact that the fulcrum did not correspond well to any part of the inclined plane was sufficient grounds for Riley to correctly make the assertion she made here.
Excerpt 3.6

The next excerpt, from activity six of seven, finds Susan, Mazy, Joy, and Valerie arguing whether the axis of rotation in a pulley wheel can be compared to a axis of rotation in a wheel and axle. See figure 4.24 (to right). This is superficially appealing, since these are both the rotating centers of their respective machines. But in fact, the axis of rotation of the pulley wheels has no functional correspondence on the wheel and axle in spite of superficial appearances. Consider the transcript below.

Excerpt 3.6 – Task 6 of 7

00:49:49:54 Mazy The lever is just another wheel and axle.. cause the pulley's not..
00:49:54:10 Susan The pulley is not. Yeah
00:50:08:31 Joy I think these (points to wheel and axle and pulley) are most alike
00:50:10:51 Valerie What would the fulcrum be (overlapping)? Are these considered a fulcrum?
00:50:12:64 Susan Really? I think the.. I think the other two..
00:50:13:94 Joy These are most alike (points to lever and wheel and axle)
00:50:15:69 Valerie Yeah. I think those are most alike.
00:50:17:24 Valerie We need to find what's... most alike to this one (points to wheel and axle) either the pulley..
00:50:22:22 Joy What do you think the middle point is?
00:50:24:38 Valerie That's what I'm saying.. is it the fulcrum?
00:50:25:97 Mazy That's what I was looking for. I can't find it
00:50:27:24 Valerie Probably it's the main one
00:50:29:10 Joy But there is not a main one
00:50:31:48 Valerie Main one yeah..
00:50:32:38 Joy See like in this.. (works pulley system) there's no main one
Mazy begins the reasoning sequence, “The lever is not just another wheel and axle.. cause the pulley’s not..” Although the utterance is left open by an unfinished sentence, Mazy has asserted that the lever is not a wheel and axle. The two machines appear quite similar, having strings and wheels. Nearly all groups began the activity stating they believed that the wheel and axle and pulley would be much related. They are not. Thus, Mazy’s utterance was fairly important in setting the state for comparison of the machines. Susan, seems to agree, “The pulley is not. Yeah.” Joy, on the other hand, disagrees stating, “I think these (points to wheel and axle and pulley) are most alike” The stage is set for argumentation. Susan responds, “Really? I think the.. I think the other two..” Joy asks, “These are most alike (points to lever and wheel and axle)?” Susan answers, “Yeah. I think those are most alike.”

Valerie restates the overall argumentation task, “We need to find what’s… must alike to this one (points to wheel and axle) either the pulley..” Joy suggests focusing on a correspondence to the “middle point” on the wheel and axle. She states, “What do you think the middle point is?” Valerie apparently had been thinking on the matter some. She wonders, “That’s what I’m saying.. Is it the fulcrum?” Mazy is unable to find a fulcrum clear correspondence on the pulley to a “middle point” or “fulcrum”. Valerie suggests, “Probably it’s the main one.” By “the main one” it is likely she means the top pulley wheel from which the other is partially suspended.” Joy refutes her, “But there’s not a main one,” referring to the fundamental difference between the pulley and the wheel and axle; the pulley has multiple wheels, and the wheel and axle only one. Valerie again suggests, “Main one yeah.” But Joy finally shows her the pulley in use, stating, “See like in this.. (works pulley system) there’s no main one.

In fact, Joy is correct. There is no main one. This stems from the fact that the pulley and wheel and axle work in very different ways. The pulley effectively splits up the load among multiple string segments. The more string segments (and consequently pulley wheels) the lower the effort force required to lift the load. On the other hand, the wheel and axle is only one
rotating unit. The larger the wheel or the smaller the axle the easier it is to lift a load – effort force is reduced.

In spite of a very compelling superficial and to some extent structural similarity, in this reasoning sequence, the group was able to argue effectively that that the wheel and axle does not work like a pulley. Although Valerie did not seem to buy into the argument, the rest of the group did. The group did not make the “middle point” of the pulley wheels correspond to the axis of rotation of the wheel and axle.

Discussion of Finding 3 – Ambiguity in Correspondences

Small-group were scaffolded in their argumentation around ambiguous correspondences by the activities in this research. At first frustrating for student small-groups, after some experience and instruction, later activities would show less frustration and less wasted time on argumentation that did not lead to a satisfying response.

The first three excerpts showed groups in earlier activities that spent time on argumentation about ambiguous correspondences and then, in spite of some reservations, made the correspondence on their papers or posters that were turned in. As the activities passed, however, groups began to decide, based on their ambiguity and the likelihood they would lead to dissatisfaction, against making potential correspondences. Many groups had direct conversations with their instructor in which they sought permission to not make a correspondence. All students were also involved in class-wide discussions that touched on the same issues analyzed in this section.

Learning to avoid wasted time and resources on correspondences that are unlikely to lead to enhanced understanding, as in the case of ambiguous correspondences such as those analyzed, is an important skill in learning to create an cogent argument that does not contain extraneous, irrelevant, or misleading information. Since students taking part in this research began to dismiss potential correspondences that were ambiguous, they were improving their
argumentation quality. This represents important learning both with respect to the argumentation process and with respect to the simple machines in question.

This research scaffolded student learning in three ways. First, student small-groups were brought into contact with ambiguity and instructed to perform argumentation related to it. Second, conversations were had either with the instructor directly or with the whole class. And third, student groups were provided the time and resources for repeated practice of argumentation around this type of ambiguous correspondence.

**Finding 4 – Scaffolded in Reflecting**

The final finding shows that student groups were scaffolded in making whole system-based arguments which encourage reflection. Once student groups had made their correspondences in both machine pairs, they still had to argue in favor of one set over the other in order to answer the question of which two simple machines are most alike. In order to do this, groups might consider such things as the number of correspondences or the degree of functional analogy among key machine elements such as a fulcrum or thread length. In this way the analogical comparison activities scaffold students’ reflection. In this case, the reflection was on the whole simple machine as a whole system and how it relates to another simple machine.

Scaffolding groups toward whole-system-based argumentation is fundamentally different from the first three findings. Those findings showed that students were scaffolded in smaller, non-system-wide, parts of their argumentation. In the first finding students, after having made one correspondence, were scaffolded in
making another. In the second finding students were scaffolded toward discernment of exact
definitions of simple machine elements in order to argue for their correspondences. And in the
third finding students were scaffolded in learning to recognize and dismiss ambiguity in
correspondences. For example, students might argue that effort distance corresponds to thread
length for a non-system wide argument; whereas they might argue that the screw is more like
the inclined plane than the lever as a whole-system-based argument.

For finding four student groups were scaffolded in considering all the correspondences
they had made as a system. In this section of analysis three excerpts will show reasoning
sequences in which student groups consider the correspondences they had made between both
pairs as they evaluate which simple machine pair is most alike.

**Excerpt 4.1**

The following excerpt shows a reasoning sequence between Beth, Dory, Melissa, and
Bree in which they, having made all the correspondences they could between both pairs of
simple machines, now attempt to answer the question posed in the activity shown in figure 4.25.
It asks, “Which simple machine is most like the lever in the way it works? Why? The wheel and
axle or the inclined plane?”

The group begins by simply stating the question. Next, the group argues whether or not
the wheel and axle can be considered a type of pulley. Finally, the group makes a system
based argument that considers that the lever and wheel and axle are more comparable and the
lever and the inclined plane have correspondences that were more ambiguous. Finally, the
group argues that the wheel and axle and the lever work more similarly. Consider the transcript.

**Excerpt 4.1 – Task 6 of 7**

00:24:34:97 Melissa Which simple machine is most like the lever? I
think the wheel and axle.

00:24:36:95 Beth The wheel and axle.

00:24:38:45 Dory The wheel and axle are... Isn't that a pulley?
Beth Yeah.
Dory They didn't teach us it's a pulley?
Melissa No. It's a wheel-and-axle.
Beth (Reads) Write a statement..
Melissa Do we need a marker? Or, do you know what I mean?
Beth OK, why do we feel as though....? I mean obviously the parts are more comparable.
Dory Ok... And, it's just like... I think because you.. it feels like it has a fulcrum is the reason why. Cause it feels like there are two sides. Like it feels like it has a resistance arm and res.. and effort arm, because there are two difference sides of it.
Melissa Wait, I don't think we... Oh yeah. Just kidding.
Dory Like there are two steps. Just like there are.. like.. it's like get it from one side to the other.
Bree What are we saying because it has two sides?
Melissa I said yeah like an effort or resistance. (2 s) Write a statement on the poster paper that was given to you explaining why you chose the simple machine pair you did (Reading). All right.
Beth Wait. What did you write for comparison? The parts are more comparable?
Melissa And that there are two sides like on each side of the axle or the fulcrum and an effort or resistance side. Somebody else go get the markers.
Brandon Which two do you guys think were most alike?
Melissa Wheel and axle and lever.
Brandon OK. Why?
Melissa Cause they have more parts that correspond to each other and they have like.. the lever has the fulcrum and the wheel-and-axle has the axle. They both have like two sides. They both have like one effort side and one resistance side.
Beth And we could not come up with anything for the inclined plane. Like when we were trying to compare it was so different.

Melissa begins the reasoning sequence, “Which simple machine is most like the lever? I think the wheel and axle.” Beth clarifies, “The wheel and axle.” Dory wonders if, in fact, the wheel and axle is a type of pulley. She asks, “The wheel and axle are.. Isn't that a pulley?”
Beth responds, “Yeah.” Dory asks again, “They didn’t teach us it’s a pulley?” Melissa answers, “No. It’s a wheel and axle.”

Beth begins reading the instructions, “Write a statement…” Melissa asks about making the poster paper for later presentation of the argument, “Do we need a marker? Or, do you know what I mean?” Beth asks the big question guiding the whole argumentation, “OK, why do we feel as though…? I mean obviously the parts are more comparable.” Although somewhat unclear, the gist of this utterances was something like, “The lever and wheel and axle work most similarly because ‘obviously the parts are more comparable.’” Dory agrees and offers some justification, “Ok... And, it’s just like... I think because you... it feels like it has a fulcrum is the reason why. Cause it feels like there are two sides. Like it feels like it has a resistance arm and res.. and effort arm, because there are two difference sides of it.” With this utterance, Dory is referring to the fulcrum, or center point, and its central role in dividing up the effort and resistance sides of the machine in both the wheel and axle and lever.

Melissa appears to ponder briefly a rebuttal then changes her mind. She states, Wait, I don’t think we... Oh yeah. Just kidding.” Dory next utterances is unclear but may have been intended to reiterate her previous utterances, “Like there are two steps. Just like there are.. like.. it’s like we get it from one side to the other.” Again she refers to the “side” of the machine. Bree requests clarification and seeks to legitimize Dory’s view with, “What are we saying because it has two sides?”

In the next part of the reasoning sequence the group considers the question of evidence for why the lever is most like the wheel and axle. Melissa repeats the instructions, “I said yeah like an effort or resistance. (2 s) Write a statement on the poster paper that was given to you explaining why you chose the simple machine pair you did (Reading). All right.” Beth, seeking to formulate a final response for writing, asks, “Wait. What did you write for comparison? The parts are more comparable?” Melissa adds, “And that there are two sides like on each side of the axle or the fulcrum and an effort or resistance side. Somebody else go get the markers.”
Finally, Brandon, the researcher, happens by asking, “Which two do you guys think were most alike?” Melissa responds, “Wheel and axle and lever.” Brandon asks, “OK. Why?” Melissa summarizes the groups whole-system-based argument, “Cause they have more parts that correspond to each other and they have like.. the lever has the fulcrum and the wheel-and-axle has the axle. They both have like two sides. They both have like one effort side and one resistance side.” Beth adds, “And we could not come up with anything for the inclined plane. Like when we were trying to compare it was so different.”

This group incorporated all the correspondences they had made between both pairs of simple machines to make their whole-system-based final argument. They realized that correspondences were less functionally similar between the inclined plane and the lever, in spite of similarities in appearance. They also stated that both the wheel and axle and pulley machines had two sides separated by a center point of rotation. Importantly, the group argued, “obviously the parts are more comparable.”

Excerpt 4.2

The next excerpt also shows whole-system-based argumentation, in this case Jill, Ali, and Haley are arguing about whether the wheel and axle works more like the lever or the pulley. Throughout the reasoning sequence the group argues that, in spite of similarities in the way they look, the wheel and axle and the pulley have less in common than the wheel and axle and the lever. Consider the transcript.

Excerpt 4.2 – Task 6 of 7

00:49:59:40 Jill I think it's easier to see it.. they look.. like the wheel and axle.. and the pulley they look more similar just because they have like strings..

00:50:05:04 Ali (overlapping) I said the actions are similar

00:50:08:37 Jill But the wheel and axle and the lever might be easier to compare just because they both have like the radiuses and like the lever arms.. and stuff
Jill begins the reasoning sequence by suggesting the pulley and the wheel and axle “look more similar just because they have like strings.” Ali adds, “I said the actions are similar.” By “actions” she likely is referring to the fact that in both a string is pulled and in both a suspended weight is lifted. Jill hedges, offering that the other combination could also be true. She states, “But the wheel and axle and the lever might be easier to compare just because they both have like the radiuses and like the lever arms.. and stuff.” It is likely that she is implying that the radii of the wheel and the axle correspond to the lever arm lengths of the lever, which is true. Ali joins the hedge against the former utterances both students had made, stating, “And like a single fulcrum,” referring to the fact that both the lever and the wheel and axle each have a single point about which the machine rotates, while the pulley does not.

The group comes to a final whole-system-based argument in the following two utterances, which they will adopt on their final papers to be turned in. The group has decided that the lever and wheel and axle work most alike. Jill considers that in spite of superficial similarities, functional analogy is more important. She states, “Yeah.. sing.. exactly.. Like it might be easier to compare them.. .when you look at the concepts.. even though they don't look the same visually..” Haley agrees, stating, “Yeah.”

Excerpt 4.3

This group, consisting of Serena, Evan and Sheri, has made the same number of correspondences between both the inclined plane – lever pair and the wheel & axle – lever pair.
They will now attempt to answer the question of which simple machine works most like the lever. Consider the transcript.

Excerpt 4.3 – Task 4 of 7

00:17:28:31 Evan All right. Is that enough? (3 s) (reads) Which simple machine is most like the lever?

00:17:43:55 Serena We have it even.

00:17:47:78 Evan Huh

00:17:47:19 Serena We have it even

00:17:48:97 Evan Yeah so that's enough. Let's answer questions. I think the wheel and axle is most like the lever

00:17:53:90 Sheri I would agree

00:17:57:92 Serena I agree.

00:18:01:17 Sheri Do we have to say why?

00:18:01:94 Evan (self talk) wheel and... Cause it was easier to find similarities

00:18:06:65 Serena There are more obvious similarities maybe.

00:18:13:87 Sheri For one they like... there's more like technical similarities.. like they move.. like this (inclined plane) doesn't move. I don't know.. how you would word that.. But I don't know..

00:18:22:14 Serena Yeah. I just feel like there's more like.. yeah like technical and movement similarities instead of just placement similarities.

00:18:26:90 Sheri That's good. I like that. (begins to write)

00:18:30:79 Evan More technical similarities. Right?

00:18:38:27 Sheri Than.. placement similarities

00:18:49:14 Serena Yeah

Evan begins the reasoning sequences by wondering out loud if the group had made “enough” correspondences between the two pairs of machines and then prompting the group to generate the whole-system-based argument. He asks, “All right. Is that enough? (3 s) (reads) Which simple machine is most like the lever?” Serena, referring to the fact that the group had made equal numbers of correspondences for both pairs, states, “We have it even.” Evan asks for clarification, “Huh?” Serena repeats, “We have it even.” Evan responds to Serena and
answers his own question, “Yeah, so that’s enough. Let’s answer questions. I think the wheel and axle is most like the lever.” Sheri states, “I would agree.” Serena too agrees.

Sheri suggests the need for justification, stating, “Do we have to say why?” Evan, although inaudible at first, states, “Wheel and … Cause it was easier to find similarities” as his justification. Serena interprets and adds, “There are more obvious similarities maybe.” Sheri attempts to take the justification deeper, stating, “For one they like… there’s more like technical similarities… like they move.. like this (points to inclined plane) doesn’t move. I don’t know.. how you would word that.. But I don’t know..” By “technical similarities” it is likely that Sheri means functional similarities or functional correspondences – elements that work alike (e.g., fulcrum of lever and axis of rotation of wheel and axle). Serena adds “movement similarities” to the groups reasoning sequence when she states, “Yeah. I just feel like there’s more like.. yeah like technical and movement similarities instead of just placement similarities.” With this important idea Serena is pointing out the need to consider the way things move and thus work in similar ways, going beyond mere appearances, or “placement similarities” as Serena calls them.

The group concludes the reasoning sequence, accepting the argument. Sheri states, “That’s good. I like that” and begins to write. Evan also seems to agree, stating, “More technical similarities. Right?” Sheri adds, “Than.. placement similarities.” Serena says, “Yeah.” With this the group ends the reasoning sequence.

**Discussion of Finding 4 – Whole-System-Based Argumentation**

In each of the excerpts in this section of analysis groups made whole-system-based arguments in which one simple machine was argued to work more like one from among a possible two choices. The principal goal of the activities, in fact, was to make a whole-system-based – in this case the simple machines – argument.
Whole-system-based argumentation scaffolded students’ reflection. Since the whole-system is considered only after the parts of the system – the elements of the machines – are corresponded, students necessarily reflect as they refer to prior correspondences and marshal them in service of their argument. And beyond reflection, as shown in the excerpts, students also considered the weight that a given element correspondence would have in a whole system. For example, the fact that there was no fulcrum correspondence on an inclined plane in excerpt 4.1 weighed heavily in the group’s decision to argue for a lever to wheel-and-axle correspondence in spite of superficial correspondences suggesting the pulley might better align. Other correspondences that were made between the pulley and wheel-and-axle, such as effort distance, evidently mattered less.

**General Discussion**

There are two categories of findings, one in which student performance evolves (discernment and dealing with ambiguity) with experience and instruction, and another in which students are consistently scaffolded in their argumentation and learning (correspondences scaffolding other correspondences and reflection through whole-system-based argumentation).

Betsy and Mark, the instructors, were invaluable to the process. First, they were the eyes and ears while students worked in small groups on the activities. They noticed consistent problems including lack of discernment and problems dealing with ambiguity among groups. As they continued to circulate among groups, they listed and were helpful. And, although they did not provide correspondences or assert the correctness of them for groups, they did invite groups to be more discerning with their language and to identify ambiguous correspondences that would not help understanding. They constantly circulated around the classroom listing and helping. As such their presence was a key aspect of this research. It was in large part because of them that groups could be more efficient and effective with their argumentation. Consider how this happened as the findings are discussed.
The first finding showed that students were scaffolded in making one correspondence on the heels of another. This scaffolded students in two ways. First, it reduced the possibility that argumentation ended in awkward silence. Student groups were able to use prior agreed upon arguments to support new correspondences. Second, students were scaffolded in relating elements of simple machines to one another both to understand the parts of a given simple machine functioned together as a whole and also to understand how that simple machine related to and worked like another simple machine.

The second section of analysis shows how comparative activities and instruction used in this research scaffolded students to generate well discerned definitions in a relevant context. Although frustrating for student groups at first, after a few comparative argumentation activities and related discussion around this with instructors and peers, groups began to discern definitions that were very accurate and exact. Scaffolding definitions by problematizing them as the analogical-mapping-comparison-based activities here have done makes defining simple machine elements a more active and germane process for students and provides a rich and relevant context for instructors to help students learn to use accepted terms and to be specific in communicating. Discernment of definitions has been shown in this research to result in better student to student understanding. This combined with pre (13%; Appendix C, p. 229) and post-test (90%; Appendix D, p. 232) results suggest it is very likely that students’ individual understanding of the definitions was improved.

The analogical-mapping-based comparison activities in this research scaffolded students by bringing them into contact with ambiguous potential correspondences again and again and created ripe opportunity for instruction. Identifying and dealing with ambiguity is an important scientific skill. Ambiguous correspondences occur when students find justification both for and against a correspondence. As mentioned, some correspondences in analogical-mapping-based activities can seem supported by earlier correspondences or by superficially similar features. Later, upon further consideration, they may prove inconclusive, such as the case of a screw
head correspondence on an inclined plane, for example. Ambiguous correspondences such as these proved to be an early frustration for students in this research. Later, however, by considering which correspondences were ambiguous, students were able to eliminate them, thereby saving important time and making a better final argument also.

Finally, as described in the fourth section of analysis, students were scaffolded in making reflections by whole-system-based argumentation. Problematizing and structuring content, as in these activities, invited students to work through a process that encouraged them to work systematically when making the correspondences. Then, at the end of the process, they were invited to reflect on the systems of comparisons they had made. This evaluative reflection encouraged the revisiting of important correspondences and led students to come away with a more system-based understanding about the simple machines in question.

Taken together, the findings show that comparative analogical activities and associated instruction scaffolded students’ learning through small group argumentation in four important ways. All of these, of course, depended on the instructors or teachers to provide good relevant instruction and help students appreciate the particular demands of the task. The choosing of specific analogues to map is also paramount to scaffolding student learning through related argumentation. Through the careful choice of analogues, an instructor can embed scaffolding that can make very specific relationships, definitions, and systems salient. Student attention can be channeled and focused on desired areas. Thus, analogical-mapping-based comparison activities have enormous potential to both problematize and structure science content. This is the very definition of embedded scaffolding.
Works Cited


Chapter 5
Conclusions, Implications, Limitations and Directions for Future Research
Conclusion

This conclusion chapter will first discuss how the findings address the research questions.

1. Answering the Research Questions

Next, it will situate this study’s findings in bodies of scholarship in science education upon which it draws and builds, including:

2. argumentation and related scaffolding research
3. analogy research

After these are discussed, the study’s:

4. contribution to teaching and curriculum design
5. policy implications
6. limitations
7. directions for future related research

will each be discussed;

Answering the Research Questions

The Research Questions

1. What does it look like to scaffold student small-group argumentation in science classes by inviting them to argue in favor of one potential explanatory analogy over another using analogical mapping?
2. How does this type of comparative intervention affect students’ interactions with one another?
The Findings

1. After one or more correct analogical correspondences had been made, analogical-mapping-based argumentation tasks and associated instruction scaffolded student small groups toward making more correspondences that were correct, increasing the possibility that argumentation leads to learning.

2. Analogical-mapping-based argumentation tasks and associated instruction scaffolded student small groups to become more discerning and precise with their definitions and descriptions of simple machine elements.

3. Analogical-mapping-based argumentation tasks and associated instruction scaffolded small groups in becoming better at identifying ambiguous analogical correspondences that were ambiguous and not likely to lead to new understanding. In later activities they avoided them, saving time and resources.

4. Analogical-mapping-based argumentation tasks and associated instruction scaffolded student small groups in making reflections by evaluating whole systems analogical correspondences in order to find the best analogue from among two possible choices.

Each of the four findings provides an answer to the research questions listed on the previous page. The first research question seeks a description of the processes that occur during student small-group argumentation, whereas the second focuses on how student-student interactions are affected. Consider how each finding specifically addresses the questions.

As stated in Finding 1, scaffolding small-group argumentation with analogical-mapping-based comparison tasks becomes easier as groups go through the process. Just as when doing a puzzle the last few pieces are the easiest to place, so too do analogical correspondences become easier to make on the heels
of previous analogical correspondences. There are two reasons for this: simple machine elements are used up by the process and no longer available for future correspondences reducing the possibilities; and also, contextual features become more evident. This is described in excerpt 1.1 in chapter 4 (p. 122) when the three group members build upon a prior correspondence, that of the inclined plane surface to the thread of a screw (see figure 5.1), to make a new correspondence, that of the screw length to the resistance distance of the inclined plane.

Finding 2 addresses both research questions. Early student-student interactions were marred by miscommunications due to insufficiently discerning language. One example of this was when “wheel” was used in place of a more discerning “wheel radius” (excerpt 2.1; p. 136; chapter 4) or “shaft” in lieu of “shaft length” (excerpt 2.3; p. 144, chapter 4) But, with instruction and continuing engagement in argumentation scaffolded by analogical-mapping-based comparison tasks, interactions can be marked by more discernment and consequently more meaning sharing between group members and better communication and argumentation. This is shown in excerpt 2.4 of chapter 4 (p. 146) when specific definitions for “effort force” and “effort distance” were explicitly sought and provided by group members.

Finding 3 answered both questions by showing how the analogical-mapping-based comparison tasks generated a need to deal with ambiguity and how associated instruction and continued argumentation around the tasks led to improvement in students’ ability to deal with ambiguity over the course of the tasks. Early frustration in interactions was made evident by lack of consensus around a given analogical correspondence, which either did not exist or had no clear analogue on another machine. An example was shown in excerpt 3.1 (p. 157, Chapter 4), when group members spent time arguing about what would correspond to a fulcrum on an inclined plane. After doing more such tasks and receiving associated instruction, students began to explicitly ask if a correspondence could be made for a given simple machine element rather than asking to what a correspondence could be made. For example, in excerpt 3.5 (p.
171, Chapter 4) a group member ended argumentation quickly on a potentially ambiguous correspondence by simply stating that no correspondence exists for a lever’s fulcrum on the inclined plane.

Finally, finding 4 shows how small groups are scaffolded in making reflections in their argumentation. Excerpt 4.2 (p. 180, chapter 4), for example, shows a group reflecting across multiple prior correspondences between the wheel and axle and the lever in order to generate an argument in favor of these two machines being most alike.

In summary, all four findings answer the research questions with the descriptions they provide. The analogical-mapping-based comparison tasks scaffold students’ small-group argumentation by providing a process that helps them make correspondences to and within new content, in this case simple machines (finding 1); and the tasks provide students a process that scaffolds them in reflecting across previously made correspondences (finding 4). Furthermore, the tasks generate a need for discernment (finding 2) and dealing with ambiguity (finding 3), for which students can be scaffolded by related instruction and repeated engagement with new analogical-mapping-based comparison tasks.

Building on Argumentation and Related Scaffolding Research in Science Education

The present research offers two contributions to argumentation research. First, the analogical-mapping-based activities themselves are a new scaffold type and thus a contribution. Second, the findings, which provide a description of the processes that occur among students working in small-group argumentation contexts, are also a contribution to the notion of argumentation quality. These two contributions are informed by and build on existing literature in important ways.

First, let us consider some science education goals and standards related to argumentation and how the present research relates to these. The National Research Council’s (2007) *Taking Science to School* states that students should be able to: “[g]enerate and
evaluate scientific evidence and explanations” and “participate productively in scientific practices and discourse.” (Duschl et al., 2007, p. 334) The present research provides students an invitation to do just that. Specifically, student small groups are asked to engage in making an argument by analogy. This, combined with the use of analogical mapping scaffolds them with a process with which to “generate” and “evaluate” an argument in favor of one simple machine (from a possible two) working most like a given other machine. This is represented in diagram 5.1. By scaffolding small-group argumentation with analogical-mapping-based comparison tasks, the probability is increased - via all four of the scaffolding types addressed in the findings - that argumentation will provide students the chance to participate productively in scientific discourse. By scaffolding students with analogical-mapping-based comparison tasks, argumentation is less likely to end in awkward silence and more likely to lead to learning.

Earlier, The National Research Council’s (1996) The National Science Education Standards asserted that students must be able to do the following in high school science related to argumentation:

- Formulate and revise scientific explanations and models using logic and evidence
- Recognize and analyze alternative explanations and models
- Communicate and defend a scientific argument  (National Research Council, 2000, pp. 175-176; National Research Council (US), 1996)

The present research addresses these standards by providing students a scaffold to help them make “scientific explanations,” use “logic and evidence,” and “analyze alternative explanations” through analogical mapping and argument by analogy.

In the present research, students are “[r]ecogniz[ing] and analyz[ing] alternative explanations” almost by definition. They are asked principally, after all, “which machine of two
works most like Machine X?” What ensues among student small groups is a process of the exploration of “alternatives” (i.e., Machine X works most like Machine A or Machine B because...). Also, in the present research, students are given a process to scaffold them to “[c]ommunicate and defend a scientific argument.”

Reflection, which is “at the core of the scientific enterprise,” must be included in argumentation if its potential to promote learning is to be maximized (Duschl et al., 2007, p. 278). Through reflection, important learning can be tied together. Without reflection, important patterns in data or evidence, contradictions, or missing parts of an argument may go unnoticed or misunderstood.

The next important contribution to the literature is made by providing a description of the processes that occur among students working in small-group argumentation on these comparative analogical tasks. The findings show an increase in quality as discussed in both Jimenez-Aleixandre’s (2008) and Sampson and Clark’s (2006) criteria (previously discussed in chapter 2; p. 15) for what good quality argumentation should include.

Jimenez-Aleixandre (2008) states that students doing argumentation should “choose among competing explanations,” “generate products or answers,” and “talk and write science” (p. 97). These criteria were all addressed by the activities in the present work. Their final arguments and related drawings constituted a “product or answer.” Throughout the entire process they “talk[ed] and [wrote] science.” And, the very nature of the task itself asked students to “choose among competing explanations.”

Although both the Jimenez-Aleixandre (2008) and the Sampson and Clark (2006) frameworks include evidence (i.e., “Back Claims with Evidence” and “Examine if a claim accounts for all available evidence” (p. 97 and pp. 658-660, respectively)), the argumentation in this research does not depend upon students marshalling data into evidence per se. Rather, the arguments made are analogical and thus rather more conceptual. Claims and justification are considered heavily in the analysis, however. Reasoning units themselves are all based
around what claims. For example, a statement such as "the fulcrum of the lever corresponds to the axis of rotation of the wheel-and-axle" is a claim. Any argumentation performed by students either in support of this claim would be considered justification; in the analysis chapter justification played out over the transcript excerpts in the idea units.

The Need for Scaffolding in Argumentation

As mentioned in the literature review, supporting students as they engage in argumentation in science education is necessary. Von Aufschnaiter et al (2008) assert that "it is inappropriate to ask students to engage in argumentation around scientific concepts and theories when they lack any background knowledge" (p. 117). Since students do not argue well about what they do not yet understand, something of a paradox emerges. Students are asked to learn content via argumentation but must first learn that content before they can perform argumentation. Students must thus be scaffolded in order to engage in argumentation that leads to content learning.

What Must a Scaffold Do for Students?

To scaffold students is to "problematize" and "structure" content for them (Reiser, 2004). To problematize is to turn content into a problem to be solved, rather than, for example, presenting it in a lecture format. To structure content means to make the problematized content doable by breaking it down into smaller ordered steps or chunks. The two are in tension, since to problematize too much can be to structure too little and vice-versa (Reiser, 2004).

If done well, the effect of problematizing and structuring content will be to "channel" and "focus" student attention in the task to lead to desired learning (Pea, 2004). Pea (2004) builds on earlier work by Wood, Bruner, and Ross (1976), which states, "a 'scaffolding' process that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts" (p. 90). Although Vygotsky initially conceived of scaffolding as
receiving assistance from an abler peer, the notion has been expanded to include expertise that has been embedded in activities. The National Research Council’s *Taking Science to School* (2007) deals with this idea of embedding scaffolding. The authors state, “Scaffolds built into instruction, including computer simulations, can highlight [relationships] for students” (Duschl et al., 2007, p. 277).

Various embedded argumentation scaffolds have already been considered. Many of these have been software-based scaffolds (e.g., BGUILE, Belvedere) (Clark, Stegmann, Weinberger, Menekse, & Erkens, 2008; Quintana et al., 2004; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2003). Argumentation scaffolding has usually been accomplished in one of two ways. First, students can be made aware of the elements of argumentation (e.g., Toulmin’s claims, evidence, backing, etc). They may, for example, be instructed to fill out a concept map that requires evidence to be placed in one place and claims in another. This can impart order to students’ thinking process. Also, given ratios may be imparted. For example, two pieces of evidence may be necessary for a given claim. Second, content itself can be organized for students to scaffold argumentation. For example, claim-making in argumentation can be scaffolded by organizing data or questioning students in a way that highlights the logic of a given claim. Automatic data selection and graphing can be provided. Or, perhaps a series of questions asked to students in a particular order can direct student attention to two facts that, taken together, make a certain claim logical. These are all embedded-expertise-type scaffolds, since the expert assistance was built into the tasks that students perform.
How Does the Present Research Build Upon the Idea of Scaffolding Argumentation?

In the present research analogical mapping is *embedded* into the activities as a scaffold. Consider an example in figure 5.1. Through the careful choice of possible analogues for the wheel and axle, an analogically aligned lever and a superficially aligned pulley, and by providing prior analogical mapping training, the invitation to use it, and the guiding question (which simple machine is most like the…?), expertise is embedded. This embedded expertise scaffolds students by making pertinent information germane to their argumentation tasks. As they systematically evaluate the machines with analogical mapping, they are considering important simple machine elements and the relationships between them. This systematicity reduces the possibility that students will leave important information unconsidered. In these ways, embedded scaffolding makes for an argumentation activity that is likely to lead to learning.

As an example, a group described in the results chapter of the present research (p. 68; chapter 4) considers the activity shown above in figure 5.1. The group argues about whether the pulley wheels can be deemed to have a fulcrum-like axis-of-rotation. The group is simultaneously being scaffolded in discernment (finding 2) and in dealing with ambiguity (finding 3). They are discerning exactly what an axis of rotation is, how it relates to a fulcrum, and how – if at all – it is present on a pulley. At the same time they are wrestling with superficial appearances that suggest that the pulley does indeed have axes of rotation. The activities generate the need for productive discourse. They also provide a rich context with lots to point to
and many relationships (i.e., correspondences) made salient that scaffold this process. And, of course, relevant instruction also scaffolds students in understanding the need for discernment and identifying ambiguity.

How Do Analogical-Mapping-Based Comparison Activities Scaffold Argumentation?

The present research’s findings show that students are scaffolded in their small-group argumentation in four important ways. As will be shown, these all make new science concepts easier to argue about increasing the probability that argumentation is productive or leads to learning.

Finding 1

In building on prior correspondences, students find new correspondences scaffolded as they are contextualized and made more logical. This type of scaffolding increases the chance that argumentation leads to learning, since students’ attention is channeled and focused systematically as they make one correspondence on the heels of another. Not only is student attention channeled and focused, but students are also scaffolded in making connections between content along the channel. This means that when one correspondence scaffolds another, the relationship between the prior and newer correspondence is also more likely to be understood. Over multiple correspondences the “channel” of student attention can become like a well worn path that can serve as a well understood reference for other yet to be understood simple machine elements.

Finding 2

The present research “problematized” and “structured” content in part by generating a need for discernment. Students were invited to discern definitions and descriptions by the activities themselves and the instruction around the activities. This helped students be very specific about what they wanted to communicate. They were thus better able to share meanings to more effectively communicate. Scaffolding by generating the need for discernment
and addressing it with instruction reduces the likelihood that argumentation might lead to confusion or silence due to miscommunications.

Finding 3

Students in the present research needed to identify and deal with ambiguity to accomplish argumentation that lead to learning. A potential analogical mapping correspondence may be appealing based on appearances but, in fact, have little structural or functional in common (e.g., a correspondence between the axis of rotation on a wheel-and-axle and the various axes of rotation on pulley wheels). This is referred to as an ambiguous correspondence. By inviting student small groups to consider these, a need is generated for identification of such ambiguous correspondences as a type, since they will no doubt be encountered again. The intervention type along with related instruction can help students learn to better disregard information that is not likely to help their argumentation. This is important if argumentation discourse is to lead to learning and not awkward silence due to irresolvable argumentation around such as ambiguous correspondences.

Finding 4

Finally, students are scaffolded by the interventions used in this research in making reflections. By making an argument by analogy that explicitly relies upon the analogical mapping process (i.e., prior correspondences between two pairs of simple machines) that scaffolded earlier argumentation, student small groups were scaffolded to make reflections. Whereas earlier the focus had been on one correspondence at a time, at the end students must reflect on these correspondences and their respective importance in service of the main overall argument (i.e., machine X works most like machine A because...). By having the main argument take place at the end, after analogical mapping, students’ argumentation was put into the rich context of all the prior related correspondences (smaller arguments). This rich context and the reflection students must make in service of their main argument scaffolds student
argumentation, since they are more likely to understand what they are arguing about, which increases the likelihood that argumentation will lead to learning.

**Building on Analogy Research**

The present work attempts to build on prior analogy research with an eye toward bridging the gap between theory and practice. To explain this, first, an overview of some past studies will be provided. Next, the gap between research and practice will be described. Finally in this section, the contribution that the present research makes in bridging this gap will be discussed.

Three general findings will briefly be overviewed: analogy is used naturally by people; learning in individuals result from analogical mapping; and analogy best promotes learning when it is part of an active process.

Dunbar (2001) found that normal people use analogy easily and well in everyday communication. When he invited people to offer analogies for various government policies of the moment, they generally could without problem. They understood the government policies; and they knew how to choose an appropriate analogy. Similarly, Clement (1981; 1988) found that experts in physics reasoned with analogies spontaneously when provided complex thinking questions. If a new scenario was not sufficiently understood that the experts in physics could answer the question directly, Clement found they would often generate a sort of half-way scenario that was deemed sufficiently similar to the new scenario and a scenario that the experts had worked with or understood well. From these, the experts could bridge the gap and reason correctly. Clement called these “bridging analogies” (Clement, 1981, 1993; Clement & Brown, 2008). Dunbar and Clement both found that analogies are powerful tools for thinking and communicating.

Also, various quantitative studies have found that individuals can learn by using analogical mapping to compare new concepts (Gentner, Loewenstein, & Thompson, 2003; Gick
& Holyoak, 1980; Kurtz & Lowenstein, 2007; Kurtz, Miao, & Gentner, 2001). Specifically, these studies have shown statistical significance for analogical transfer, or evidence that what was learned in one scenario could be applied to an analogue. This research provides valuable evidence in support of analogical reasoning as a process that can lead to learning in individuals. In collaborative settings, however, the use of analogy has been studied very little, (Gadgil & Nokes, 2009).

Much work has shown the importance of making analogy an active process for students. Glynn (1991) states, “an analogy is a process: it is a process of identifying similarities between different concepts” (p. 223, emphasis added). Similarly, Gentner (1983) states, “[a]n analogy is a comparison in which relational predicates, but few or no object attributes, can be mapped from base to target.” (p. 160, emphasis added) By using the word “mapped”, Gentner is emphasizing process. And, Else, Clement, Ramirez (2003) state about their research findings, “[a] considerable portion of the understanding students gained thus came from exploring the [analogy] through reasoning and dialogue …” (p. 10, emphasis added). And, Clement (1993) suggests, “much more effort than is usually allocated should be focused on helping students to make sense of an analogy” (p. 1241).

In summary, analogy is naturally used by everyday people and experts in thinking and communicating. Analogical mapping promotes learning in individuals. Analogy best promotes learning when used in an active process.

The Gap Between Analogy Research and Practice

In spite of the important findings just discussed, various questions remain. Many of these questions, if answered, have the potential to provide for better practice. For example, what about using analogy in collaborative settings? What, beyond the quantitative studies, does learning with analogies look like? Why is analogy most effective when it is an active process?
And finally, the gap between research and practice remains, because important as these findings are, they can be made more actionable in an efficient way for an average classroom.

The present research notes these findings and remaining questions and takes the next step in order to help bridge the gap between theory and practice. Specifically, the present work shares some findings and principles in the literature (i.e., explicit analogical mapping can be of benefit to learning) with students directly and asks them to be informed by the research in service of their own argumentation. The present research also helps to bridge the gap by being done in a small-group collaborative setting; research on this had been lacking. The analogical-mapping-based comparison tasks developed for this research incorporate the findings of previous research into an efficient and actionable instructional model. And with its findings it produces qualitative descriptions of what such an intervention – analogical mapping and an invitation to map in service of argumentation – looks like when offered to small groups as a communicative and argumentation scaffold.

The findings clearly show that the very same analogical mapping process found to promote learning in individuals also has benefit for small group argumentation. By scaffolding students in small groups to make correspondences together, discern, recognize and deal with ambiguity, and make reflections student communication and argumentation is less likely to lead to a frustrating end and more likely to lead to learning.

These qualitative findings and the intervention type put forth in the present research are both contributions to analogy research in science education. Their continued investigation will inform later work on individuals or perhaps be evaluated in related quantitative research. The findings provided by the present research can even inform research into cognitive processes. Also, the intervention type could be modified in numerous ways, some of which will be described in the Directions for Future Research section of this chapter.
Contribution to Teaching and Curriculum Design

The contribution to teaching and curriculum design this study makes is two-fold. The present study provides an actionable intervention model and paints a detailed picture of the process as it pertains to scaffolding students’ argumentation. First, the intervention type, in which content is problematized (even content that is not usually thought of as analogical, such as simple machines can be used) is provided. Second, the findings can inform related instruction. Instructional practices may be informed by showing how student small groups are scaffolded in: making further correspondences in light of prior ones; discerning definitions for themselves; identifying and dealing with ambiguity in some correspondences; and in reflection. These two contributions will now be discussed separately.

The Intervention Type as a Contribution to Teaching and Curriculum Design

The intervention type used in this research benefits from the ubiquity of analogies and analogical models in many areas of science (Else, Clement, & Rea-Ramirez, 2008; Glynn & Takahashi, 1998). Just a few examples include: electricity as either water or a crowd of people trying to move (Gentner & Gentner, 1983), biological cells as corn kernels or houses, blood vessels as river deltas or plumbing (Else et al., 2003), and an atom as a Bohr model or line spectra model. Problematizing and structuring science content as the present research does could be commonly done. In cases in which there are two (or more) analogies or analogical models for a given real-world phenomenon - and there are many - students can be invited to argue the alignment of one over the other as in the present research.

Teachers or curriculum designers could make tasks in which two analogues (or models) are both in common use and have explanatory power; this would invite students to argue the explanatory aspects of one over the other (e.g., various atomic models). Or, one could pit a distracter with only superficial similarities, such as appearance, against a scientifically accepted analogue in order that students better understand the scientifically accepted analogue (e.g.,
pulley vs. wheel and axle). Either way, analogies will have been problematized and turned into an active process that scaffolds student learning through argumentation. And, it is likely that many of the scaffolding benefits described in the findings will result.

Although the tasks do require some care in selecting the analogues, they require few resources to produce in most cases. Resources can usually be limited to: planning, offering class time, analogical mapping training, and either diagrams or representations of a model or analogue and/or actual physical models of them.

The Findings as a Contribution to Teaching and Curriculum Design

Of course, the interventions themselves are but part of the equation. They merely generate the needs for discernment and dealing with ambiguity by providing a context. They do not, of course, teach students how to accomplish these. Teaching must be tailored to the intervention and the students. As with any intervention in science education, good teachers are indispensable.

The findings in the present research can help teachers to tailor instruction and their interventions. For example, students can potentially save themselves much frustration in being taught to expect that all analogies break down eventually. They all have potential correspondences that are ambiguous or unclear. It is the job of the instructor to identify and discuss that this will happen. In the present research, students were warned that some elements of simple machines would not have correspondences before the activities. But even more important is the act of listening to group argumentation, identifying problems with discernment, ambiguity or otherwise. Teaching groups directly that a specific simple machine (or other analogy) element will not necessarily have a correspondence can be much more effective than talking about ambiguous correspondences generally. Tailoring this instruction to the context at hand can make both the instruction and the intervention relevant to the students.
This can reduce frustration by allowing students to change their approach by first arguing about not to what a given analogy element corresponds but if it corresponds at all.

Similarly, by inviting student small groups to share their correspondences and overall arguments with the whole class at the end of the intervention, teachers can see: the language that students used, the correspondences made (or not), and the reasoning for their overall arguments and tailor instruction accordingly. For example, if students use a word such as “effort” when “effort distance” would be more appropriate, then tailored instruction can result. Students, having done the activity, can gain an understanding of the context which gives rise to or necessitates a definition. This is important, since to truly have understanding of a definition one must be able to explain its relationship to its context. More importantly, by inviting students to do future such tasks, they may also take this ability to discern forward.

Policy Implications: The Space Between the Content Standards

This research focuses on the space between elements of science content. Although national science content standards deal with important content, relatively few of these standards deal with connection making between the standards (National Research Council (US), 1996). The national science education standards do suggest less emphasis on “broad coverage of unconnected factual information.” But, they offer little in the way of guidance of how this is to be accomplished (p. 224). AAAS (2001) offers in its Atlas of Science Literacy a comprehensive way to organize content, highlighting connections between various content in science. Yet, they do not specify how to make those connections. Intended as a resource to help curriculum designers, AAAS states that their “[m]aps offer materials developers a helpful perspective on which benchmarks to target and at what level of sophistication” (AAAS, 2001).

And so, it is up to researchers, teachers, and curriculum designers to develop materials. The present research aims to do just that. And, it does so by placing deliberate emphasis on the connections between the content, in this case simple machines content. When students
make analogical correspondences, they are really making connections. They not only ask what a lever is; they ask what it is not, also. Is a lever a type of wheel and axle? A type of inclined plane? Are these good analogues?

The National Research Council’s (2007) Taking Science to School mentions a large-scale attempt underway by researchers and planners to organize content. This is called “Learning Progressions.” The authors state, “Learning progressions are a promising direction for organizing science instruction and curricula across grades K-8” (p. 213). Learning progressions “makes use of the current research base” and deals with “organization of conceptual knowledge around core ideas” (p. 221).

It is too early to tell if this research might inform learning progressions research. Learning progressions focuses on organizing much larger areas of content than the present research has. Nonetheless, the two might inform each other someday. For example, scientific models can become more sophisticated over years of schooling. This may be a place for active analogical mapping over a longer time scale between various models or offered analogies. Time will tell.

As mentioned in the results section of the present research, when students are making correspondences they are learning to understand relationships and connections, in this case, connections between various types of simple machines and simple machine elements. Somewhat paradoxically, by focusing student attention on the space between the content – the analogical correspondences that represent relationships – in this case various simple machines, students can become better able to understand the machines themselves itself. They not only argue about what a given machine (or element of a machine) is, but also what it is not.

**Study Limitations**

There were various limitations to the study. The population of fifty-four preservice elementary teachers at a large research university is not representative of all science learners.
The study was necessarily limited in time; more long term studies could be done. And, as analogical mapping was new to all students, the whole seven-week intervention was something of a training session, with improvement continuing until the end. The focus of analysis with analogy may have resulted in less emphasis than would be warranted on other areas of performance and factors affecting performance. Each of these limitations will be discussed below.

For the preservice elementary teachers, the class in which the research was done takes the place of a more traditional science class such as general chemistry or biology. This makes them different than other freshman in different majors at the same university. Although all participants reported studying simple machines prior to the class, pre-test results showed that only 2 students of 54 were able to calculate any aspects of simple machines (e.g., IMA) prior to instruction. Although there is no comparison data to other populations, this is low. And, it is possible that the students who chose not to participate would have performed differently on the interventions than most students. Also, student groups did not change for logistical reasons (i.e., preserving anonymity of nonparticipants). Thus, it is not known what effect group dynamics played in argumentation. Future studies might take place in other contexts and involve changing groups.

The seven-week time span of the study found student groups continuing to improve in their abilities to deal with ambiguity and be discerning in their descriptions and definitions. This might have continued for some time more, or students may have reached a plateau. A longer study could address this limitation. Also, a follow-up activity or interview weeks or months later could have been done. These could provide insight into long term retention of analogical mapping skills.

Finally, a wider analytical focus may have shed light on important factors in student performance such as affect and group dynamics. Frustration and other affective issues may have hindered individual student or even group performance on the tasks. And, although all
groups improved, it is possible that some groups performed less well than others due to interpersonal problems between group members. Reviewing the data with a wider analytical lens might address some of these limitations.

**Directions for Future Research**

Various directions for further research present themselves. The present research generated data that could be mined to investigate other research questions. This could include students’ (preservice elementary teachers’) interactions around ambiguity and the effect this may have on pre-service teacher’s beliefs about teaching and later teaching practices. For example, 6 students of 54 (11% of total) were found to have extremely negative views of the intervention type. This was coded for by the presence of words such as “hate,” “unfair,” and similar words in student comments about the activities, in their interview responses, or in their written survey responses. The most frequent complaint was about ambiguous correspondences. Students who felt the activities were unfair usually stated that they believed it was inappropriate to be asked to consider or make correspondences that did not necessarily exist (e.g., fulcrum on an inclined plane). Six students were also found to have strongly favorable opinions about the activities as coded by their words (e.g., freeing, valuable, great, love) in the same data sets. These students seemed to like the importance of interpretation and argument and their own sense of agency in the activities. The rest of the students had a neutral opinion of the activities. Interestingly, how individual students felt about the activity did not necessarily determine how they performed. Many of the students who expressed strong dislike for the activities were actually quite effective at them.

It might be interesting to look for relationships between preservice opinions of the activities, how they performed the activities, their beliefs about teaching, and their actual teaching practice. Any research involving teaching practices would have to be done in a new study for logistical reasons.
A related but different study might investigate what role analogical mapping might play in encouraging students to write procedures for their own lab experiments based on prior analogues. For example, it seems likely that students, having been given a detailed procedure for determining the effect of changing the weight of the bob on a pendulum, could write a (analogically mapped) procedure and carry out an experiment which determines the effect of string length or displacement. These are close analogues, of course, so the task would likely be not too difficult. However, investigating how dissimilar or far apart analogues could be when the task is made explicitly analogical holds potential as an interesting avenue for research.

A similar type of study might specifically invite students to use analogical mapping to generate hypotheses for experiments they have yet to do based on analogues they have done. This relates to Pierce’s abductive reasoning or hypothesis by analogy (Kwon, Jeong, & Park, 2006; Lawson, 2010). For example, by trying an experiment students might learn that a given solid substance cannot be heated above 55 C (its melting point) until it melts completely. And they could be given access to its density, molecular mass, polarity, and/or other features an instructor might wish to make salient. Next, they could be instructed to make predictions about a similar but different substance based upon similar data made available. A teacher could do the activity with a series of alkanes, which are strong analogues across the board, as all features such as those mentioned (including melting point) co-vary fairly linearly. Analogical mapping would have the power to make patterns of change that co-occur together evident for students. Later addition of exceptional substances (such as water or alcohols with their hydrogen bonding) could be better understood, as analogical mapping might scaffold understanding by highlighting important differences giving rise to an unexpected melting point, for example. A series of interventions that teaches students to hypothesize through the use of analogy and analogical mapping might be a very interesting line of research indeed.

Model-based-instruction can also be informed by this research. As mentioned in the Contribution to Teaching and Curriculum Design section of this chapter, often in science there
are multiple analogical models for a given phenomenon. Again, these include: electricity as either water or a crowd of people trying to move (Gentner & Gentner, 1983), biological cells as corn kernels or houses, blood vessels as river deltas or plumbing (Else et al., 2003), and an atom as a Bohr model or line spectra model. By tapping into the legitimacy already afforded these multiple analogical models and then inviting students to use analogical mapping to analyze them or make arguments about them, the abilities of the various models to represent different features or aspects of the phenomenon or concept can be problematized to become salient.

Similarly, analogical mapping could be incorporated into technology. Currently, multiple representations are commonly used at educational websites such as www.explorelarning.com of the University of Virginia and other types of educational software. Often implicit in the various slider controls, graphs, animations and other models is the analogy. A potentially interesting line of research centers on investigating what effect making analogical mapping explicit rather than implicit in educational software might have. How many or few analogy elements would be ideal for students to learn via the software? What features might make analogy more salient? How is student attention best channeled and focused using software-based-analogical-mapping? How might science concepts best be problematized and structured with analogical mapping software? How is this different than with other forms? How can small group and individual written argumentation be scaffolded with analogical-mapping-based software?

The possibilities for analogical mapping to inform future research are manifold. This work is but an important first step.
Works Cited


Gentner, D., Loewenstein, J., & Thompson, L. (2003). Learning and Transfer: A General Role for Analogue Encoding Journal of Educational Psychology, 95(2), 393-408.


Appendix A

Analogical-Mapping-Based Comparison Tasks
List the Correspondences between the Top and Bottom Scenarios in the Table Below

<table>
<thead>
<tr>
<th>Top</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person</td>
<td></td>
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</tbody>
</table>
For each of the components of situation B write a corresponding component for situation A. You may write more, if you would like.

<table>
<thead>
<tr>
<th>Situation A</th>
<th>Situation B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pancakes being cooked on a pan on a gas stove.</td>
<td>Hot coffee that has a metal bar in it that has an ice cube at the end.</td>
</tr>
<tr>
<td>Ice Cube</td>
<td>Coffee</td>
</tr>
<tr>
<td>Metal Bar</td>
<td>Drops of Water</td>
</tr>
</tbody>
</table>
Instructions: Using the correspondence mapping technique we learned in class your goal is to answer the question “How is a screw like an inclined plane?” List the correspondences in the table below.

<table>
<thead>
<tr>
<th>Screw</th>
<th>Inclined Plane</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>
Task 4

Instructions: Answer the question below using analogical mapping as learned in class. List the correspondences in the table below.

Which simple machine is most like the lever in the way it works? Why? The Wheel-and-Axle or The Inclined Plane?

<table>
<thead>
<tr>
<th>Lever</th>
<th>Inclined Plane</th>
<th>Lever</th>
<th>Wheel-and-Axle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance Arm Length</td>
<td>Resistance Distance</td>
<td></td>
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</tbody>
</table>
1. Which simple machine is most like the **lever** in the way it works?

2. Why?

3. On the Poster Paper:
   a. Write a statement (sentence or so) on the poster paper given to you explaining *why you chose the simple machine pair* you did.
   b. The poster paper should include (a) **picture(s)** to help you explain (you may draw pictures similar to those given, but please add new information – e.g., labels, arrows, emphases, etc)
   c. Include the tables of correspondences you made for both pairs.
      i. Next to each correspondence make a column which explains *why you made the correspondences* you did. (example below)

<table>
<thead>
<tr>
<th>Lever</th>
<th>Inclined Plane</th>
<th><strong>Explanation</strong></th>
<th>Lever</th>
<th>Wheel &amp; Axle</th>
<th><strong>Explanation</strong></th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>
Task 5

Instructions: Using the pictures answer the questions at the bottom of the page.

1. Using analogical mapping, list the correspondences between the couch movers and the pulley in the table below.

<table>
<thead>
<tr>
<th>Couch Movers</th>
<th>Pulley</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

2. List any structural difference(s) between the couch and the pulley system.

3. Draw the couch scenario that would have the most correspondences to the pulley diagram below on the right. Explain how the pulley system aligns to your picture.
Task 6
Name____________________

Instructions: Answer the question below, “Using analogical mapping as learned in class. List the correspondences in the table below.

Which simple machine is most like the wheel-and-axle in the way it works? **the pulley or the lever**?

<table>
<thead>
<tr>
<th>Wheel &amp; Axle</th>
<th>Pulley</th>
<th>Wheel &amp; Axle</th>
<th>Lever</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>
**Task 7**

**Name:** ______________________

**Instructions:** Your goal is to answer the question: List the correspondences in the tables below.

Which simple machine is the jack (on top) most like? – The **inclined plane** or the **wheel-and-axle**? **Or Both?** Explain your reasoning on the back side in sentence form.

<table>
<thead>
<tr>
<th>Jack</th>
<th>Inclined Plane</th>
<th>Jack</th>
<th>Wheel-and-Axle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Which simple machine is the jack (on top) most like? – The **inclined plane** or the **wheel-and-axle**? **Or Both?** Explain your reasoning on the back side in sentence form.
Appendix B

Simple Machine Guided Inquiry Sample Activity
Activity 4- Levers I
Group Name ________________________  Name: ___________________________

Materials:
1 axle (4 studs long)
1 axle (6 studs long)
8 1X2 Beams
1 Base Plate
2 Weighted Bricks
3 1X16 Beams
2 Bushings
4 1X6 Plates
1 2X6 Plate
String
Spring Balance
2 milimetric papers

Key Questions:
• How can you balance a lever without using trial and error?
• Where should you place the fulcrum to make it easiest to lift a heavy object?

Procedure: Part I ...
• Use your Lego pieces to build the lever on the page number 5.
• Place one 1X2 beam twenty holes from the fulcrum on the left side.
• Predict four possible ways to balance this lever using the rest of your 1X2 beams.
• Test your predictions. Note: For best results, hold the lever in the balanced position and then gently release.
• If your predictions were accurate, place them in the Part I Data Table.

Data Table - Part I

<table>
<thead>
<tr>
<th>Left</th>
<th>Side</th>
<th>Right</th>
<th>Side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holes From Fulcrum</td>
<td># of 1X2 Beams</td>
<td>Holes from Fulcrum</td>
<td># of 1X2 Beams</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1</td>
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<tr>
<td>20</td>
<td>1</td>
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</tbody>
</table>
Part II:

- Clear your lever and place 2 beams 4 holes from the fulcrum on the left side. On the same side of the lever place 3 beams 2 holes from the fulcrum.
- Predict where your remaining beam would need to be placed to balance the lever.
- Test your prediction.
- If your prediction was correct, enter the appropriate information into Data Table - Part II. If not, keep trying!

**Data Table - Part II**

<table>
<thead>
<tr>
<th>Left Side</th>
<th>Right Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holes From Fulcrum</td>
<td># of 1X2 Beams</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Explain below what you have learned about balancing levers. You are welcome to illustrate them algebraically (i.e. showing the mathematical relationships among the Effort Force, Load, Effort Distance, and Load Distance).
Part III:

1. Construct the lever shown on the page number 6.
2. Determine the weight of the weighted brick using a digital scale.
3. With the weighted brick on the very end of the lever, place the lever on the fulcrum such that the weighted brick is 4 holes away from the fulcrum.
4. Predict the number of force units (in grams) necessary to move the weighted brick when it is 4 holes away from the fulcrum. Assume that the effort force will be applied at the very end of the other side of the lever (in this first situation effort force has 10 holes from the fulcrum when weighted brick is 4 holes away from the fulcrum).
5. Test your prediction by pulling down (slowly) on the other end of the lever with the spring balance until the lever is parallel to the support base. **Note:** The spring balance will probably register a reading even if you are not pulling down. This reading is the weight of the spring balance itself. Since this reading will be part of all of our measurements it will not be problematic. **Also,** you will notice that the spring balance reading will change as you pull it down. The Effort Force reading that we are interested in is the reading shown when the lever is held parallel to the support base.
6. Enter your prediction and your actual result in Data Table - Part III.
7. Repeat the same procedure through the steps 4 to 6 for the other fulcrum positions (configure 4-10 holes from the weighted end to fulcrum where the effort force is always at the very end of the other side of the lever).

### Data Table - Part III

<table>
<thead>
<tr>
<th>Position: # of holes from weighted end to fulcrum</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prediction:</strong> How many force units will it take to move the lever?</td>
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<tr>
<td><strong>Actual:</strong> How many force units did it take to move the lever?</td>
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</table>

- Plot a graph of Effort Force vs. Load Distance (from weighted bricks to fulcrum) on a milimetric paper. Plot your Effort Force data along the vertical axis.

Explain below the relationship between the Effort Force needed to lift the weighted bricks and the distance between the weighted bricks and the fulcrum.
Part IV:

• Using previous measurements, fill in Data Table - Part IV below.
  \[F(N)=W(g) \times 0.001(kg/g) \times 10(N/kg)\]

Data Table - Part IV

<table>
<thead>
<tr>
<th>Resistance Force (Force Units)</th>
<th>Effort Force (Force Units)</th>
<th>Actual Mechanical Advantage</th>
<th>Resistance Distance (holes)</th>
<th>Effort Distance (holes)</th>
<th>Ideal Mechanical Advantage</th>
</tr>
</thead>
<tbody>
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Do your AMA values and IMA values differ? If so, explain how you think the differences arise.

• Plot a graph of AMA vs. Distance (from weighted bricks to fulcrum) on a milimetric paper. Plot your AMA data along the vertical axis. Don’t forget to name your graphs.

Explain below the relationship between the AMA and the distance between the weighted bricks and the fulcrum.
Beams Over Board

1

2

3

Parts Inventory

2x

2x

2x

1x

12x

3x

1x
Fiddling with Fullecrums

Parts Inventory

1x, 6x, 1x, 1x, 1x
Appendix C

Pre-Test
Pre-Instruction Knowledge Inventory

Simple Machines

1. Which inclined plane would be the easiest to push something up? (Circle one)

2. What are simple machines used for?

3. How does an inclined plane work?

4. How is a screw like an inclined plane?

5. How do the gears on a ten speed bicycle work?

6. Pictured to the right is an old time hand-powered mixer. Note that gear attached to the handle (vertical) is larger than the smaller gear attached to the mixer part (not shown). Why is the larger gear on the handle and not the other way around?

7. What do all simple machines have in common?

(over for last question)
8. Which pulley system below would be easiest to pull (A or B)? Why?

9. What is the Ideal Mechanical Advantage of the pulley system above?
Appendix D

Unit Test

(Task 7 on page 218 was also given as part of this unit exam)
1. Assuming there is no friction, if I applied effort over 10 meters to move a 100kg crate of LEGOS, using a simple machine with an Ideal Mechanical Advantage of 5, what is the resistance distance and how much force did I need to move the crate of LEGOS? In reality, when there is friction, which value would you expect to change, would this value be higher or lower than what you calculated?
2. Calculate the IMA and AMA of the following inclined plane. The box has a mass of 140 kilograms.

3. You overhear your friend making the statement, “Simple machines make work easier.” Do you agree with her? Why or why not?
4. In class, we spoke of the differences between scissors used to cut paper and bolt cutters used to cut metal. Considering what you know about levers, please explain. A drawing may be helpful.

5. Both levers in the figure below are used to lift an identical load. Which lever requires a greater effort force? Explain.

![Diagram of two levers](image)
6. Draw an example of each type of lever: class I (effort-fulcrum-load), class II (effort-load-fulcrum), and class III (load-effort-fulcrum), with an Ideal Mechanical Advantage (IMA) greater than 1. If you are unable to do so, explain why.

7. If you want to raise the load 2 meters with the following pulley system, what length of rope will you have to pull (effort distance)? Explain.
8. Calculate the AMA one way and the IMA two ways for the following pulley system. The effort force is 20N and the effort force rope moves 0.75 meters when pulled. Show your work or explain.

![Diagram of a pulley system with an effort force of 20N and a load of 50N.]

9. Given the following driver gear, sketch a gear train with an IMA of 5 whose output (driven) gear rotates clockwise. Be sure to label the number of teeth in all gears.

![Diagram of a gear with 10 teeth rotating clockwise.]

10 teeth, clockwise rotation
10. What is the IMA of the following gear train? Would the AMA be less than or greater than the IMA? Explain.

![Diagram of gear train with labels: Driver, 64 teeth; Driven, 8 teeth.]

11. Why might someone want to use the gear train shown in question 11? Give a real world example.

12. Since Actual Mechanical Advantage (AMA) is Resistance Force (Load) ÷ Effort Force, why doesn’t increasing the Resistance Force (Load) necessarily increase the AMA?
13. Name two reasons why a mechanical advantage less than one can be desirable and give two real world examples (one for each reason) using two distinct types of simple machines. The simple machine types are inclined planes, levers, wheel and axles, gears, and pulleys.

14. In your car, the axle (input) drives the wheel (output). What is a reasonable IMA for this situation? Why is this useful for a car?
15. In the following 2\textsuperscript{nd} class lever, the load distance is 0.3 meters and the effort distance is 0.9 meters. The effort force to lift the load is 15N.

a. What is the IMA of this lever?

b. What is the load force (N), ignoring friction?
Seeking to advance science education by supporting learning through argumentation that invites students to make connections with science concepts.

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- *Learning to Manage Ambiguity and Frustration in Science Argumentation* (accepted), Presenter, European Science Education Research Association, Sept 2011, Lyon, France
- *How Does the Use of Analogical Mapping as a Scaffold for Science Learners’ Argumentation Support Their Learning and Talking About Science?*, Presenter, International Conference on the Learning Sciences, June 2010, Chicago, IL
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