

USING A NEW DESIGN RULES PRACTICE AND SCIENCE TALK
DEVELOPMENT TO ENHANCE CONCEPTUAL UNDERSTANDING,
SCIENTIFIC REASONING, AND TRANSFER IN LEARNING BY DESIGN™
CLASSROOMS

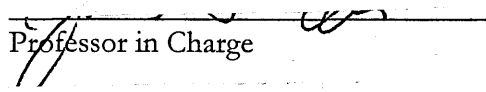
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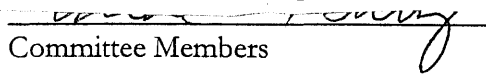
Submitted to the Department of Teaching and Leadership and
the Faculty of the Graduate School of the University of Kansas in
partial fulfillment of the requirements for the degree of Master of
Science in Education.

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ABSTRACT

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With foundations in scientific argumentation/discourse literature and transfer literature, this study describes the potential of a new ritualized classroom activity (*Design Rules Practice*) in developing the conceptual understanding, scientific reasoning, and transfer ability of eighth grade physical science students in Learning by Design™ classrooms. Teachers employ an experimental Design Rules treatment to develop student *science talk* (defined as the skill or act of communicating and explaining, both in written and/or verbal form, the science concepts and principles within a context in an abstract, generalized form) using scaffolded, iterative instructional practices. Comparison and experimental classrooms completed two post-treatment writing assessments, which were coded and analyzed. This paper presents the results of that analysis and reports that the new Design Rules practice (i.e., the experimental treatment) may have an effect in developing conceptual understanding, scientific reasoning, and transfer ability and that teacher implementation of the Design Rules practice may affect student outcomes.

Acknowledgements

There are a number of people whose time, effort, and support made this endeavor possible and educational for me. I will forever remember their assistance and concern, and I will always strive to support my students with the same level of commitment.

A great deal of appreciation is owed to the participating teachers and students of this study. The experimental teachers were brave enough to believe in and try something new and unproven, and the control teachers were brave enough to be compared to it. These four people are of the most generous in our profession. I thank you all from the bottom of my heart for letting my work in your classrooms, to grow as an educator and as a person. To the students, who “felt like the world’s most talkative guinea pigs”, I certainly would have gone nowhere without all that talking. Thanks!

I would like to thank Dr. Jennifer Holbrook for helping me get over the first hill in this study. You kept saying, “You have what it takes to do good work, and you are doing it.” I don’t think you know how good of a teacher you really are. Dr. Jackie Gray helped me understand how to develop a coding scheme and tell a story with a thesis. Jackie, I promise that I will return your APA stylebook...as soon as I am done with it, ☺. Thanks for your time and your thoughtful critiques.

Dr. Barbara Fasse deserves huge thanks for being my own personal thesis cheerleader. Your insights and pep talks kept me going and made me realize that I wasn’t actually going to die from this. To everyone else working at Learning by Design, thank you for your enthusiastic support of this research. You have no idea how so many of our conversations and debates influenced my work. I look forward to continuing them.

I would like to give special thanks to Dr. Janet Kolodner. You were unbelievably supportive of this research idea and method. Your involvement from the beginning helped me understand the purpose and importance for teachers, like me, to engage in

such a practice. You were generous with your time, and unrelenting in the belief that this was important for me to do, not only professionally, but personally. You were right.

I would also like to give very special thanks to my committee members at the University of Kansas: Dr. Arlene Barry, Dr. Doug Huffman, and my advisor, Dr. Jim Ellis.

Although our time and work together was brief, I will always remember your effort and commitment. Jim, I would especially like to thank you for your advisement. Working together at such a great distance provided many challenges, but your effort, comments, and availability never made me feel at a disadvantage. Thanks for everything you did to help me produce this thesis.

Finally, I would like to thank the one person without whom I probably would not have ever completed my graduate degree. My wife, Allison, stood behind me and encouraged me to take on this challenge because *she knew* that I could do it before I knew it. Thank you for giving up so many weekends and weeknights together so that I could go to the library, go to my office, or sit in front of my computer to finish this work. You never once complained and you listened intently as I thought-out-loud many a night during dinner. You are the best (and cutest) proofreader I have ever had, and you know more about the proper use of commas and semicolons than I would learn in eight lifetimes. While, in reality, you are at the center of my universe, you always make me feel that I am at the center of yours. I love you so much that it truly is beyond words...thank you, Pea.

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Chapter 1

Introduction

During the past two decades, United States K-12 science literacy problems have been identified and illuminated. The TIMMS Report details that U.S. achievement in science literacy is, in most cases, below the levels of our international economic peers (Schmidt, et.al., 1997). Research and reform efforts have led to the creation of standards to address this failing. The goals of the National Science Education Standards (NSES) are meant to create students who:

- experience the richness and excitement of knowing about and understanding the natural world;
- use appropriate scientific processes and principles in making personal decisions;
- engage intelligently in public discourse and debate about matters of scientific and technological concern; and
- increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers.

(NRC, 1996, p. 13)

The desired outcome is an individual's life-long exercise of concepts, principles, and benefits of science in meeting the challenges of life. The standards address an array of issues associated with educating our students and serve to guide educators, parents and students toward science literacy. Achieving desired levels of science literacy involves, in part, building sound conceptual understanding, developing scientific reasoning, and enhancing transfer in learners. (NRC, 1996)

Researchers and educators in the science education community have researched and developed curricula, methods, and practices to improve science literacy, focusing on conceptual understanding, scientific reasoning, and transfer. Learning by Design™ (LBD™), a National Science Foundation funded research group at the Georgia Institute of Technology (Georgia Tech), is developing a curriculum to improve performance in science literacy at the middle school level. LBD employs the well-researched aspects and benefits of inquiry learning, problem-based learning, and case-based reasoning to inform and shape its curriculum and methods (Kolodner, 1998). Another major component of LBD is the inclusion of design processes and activities to help structure classroom events and culture. The curricula, methods, and practices have evolved through several years of iterative implementation and re-development. The standards remain explicit goals of LBD, and they continue to drive and shape LBD's ongoing research and products.

The LBD curriculum units present design challenges to students. In these units, student groups design and develop a *design artifact* (an actual object or model related to the challenge context) that students use to address the challenge. Central to LBD's methodology is the use of repeated activity structures, or *practices*, in which teachers and students engage to develop science content understanding, science inquiry skills, collaboration skills, and scientific reasoning (Kolodner, Gray, & Fasse, 2003). One of these practices is the *Design Rules* practice. Central to a new Design Rules practice protocol is teacher focus on scientific argumentation, science discourse, and reasoning from science principles. The Design Rules practice, known to the students as a Design Rules Session, follows a round of experiments to test various design features or aspects of the artifact. Essentially, these features or aspects serve as the variables tested in

inquiry-based experiments. Following the experiments, student groups present their experimental design, data collected, and conclusion regarding the variable's effect. Each presentation ends with the group providing to the class a recommendation for future designs, i.e. – a Design Rule. Typically, the groups share Design Rules verbally and the class keeps a record of them. During the Design Rules Session, the class discusses the merits and meanings of all the Design Rules suggested (more details about the Design Rule Session are provided later in this paper).

The purpose of this study was to examine the potential effect a new Design Rules practice might have on students' science concept understanding and scientific reasoning ability in eighth grade physical science classes. The study examined the effect this practice has on the ability of these same students to transfer content knowledge and reasoning skill to a novel task. Chapter Two provides the theoretical framework for the study based upon relevant research in scientific argumentation, use of discourse in science classrooms, and transfer. Chapter Two also includes a review of LBD's curriculum foundations and how LBD identified a need to examine a new Design Rules practice protocol.

The Need for the Study

The need for improvement in these areas (i.e. – concept understanding, scientific reasoning, and transfer) has been highlighted by various assessments of U.S. science education. One reason for developing these standards came about as a result of the failures of the science education system revealed in the early 1980s in A Nation at Risk: The Imperative for Educational Reform (NCEE, 1983). More recently, U.S. Department of Education reports suggest continued difficulties in science education

nationwide (NCES, 2001). The following data gives us a picture of the problem science education still faces. This data supports the claim that science literacy in the U.S. is lagging and that many students have not yet reached the goals of the science education the standards.

In November of 2001, the National Center for Education Statistics released *The Nation's Report Card: State Science 2000* (NCES, 2001). This report relied upon the framework for the 1996 and 2000 National Assessment of Education Progress (NAEP). Students at grade levels 4, 8 and 12 were assessed in earth, life and physical science for conceptual understanding, scientific investigation, and practical reasoning. Because this thesis study involves students in eighth grade in the State of Georgia, Georgia's performance on the NAEP assessments is also provided.

The NAEP reports achievement levels performances on a scale ranging from 0-300: the higher the number, the higher the achievement level. Three distinct scale scores were identified as thresholds in the scale and serve as the boundaries for the achievement levels. Figure 1-A details the levels for grade 8 students. The scores displayed in parentheses are the thresholds in the 300-point scale.

Achievement Level	Description
Basic (143)	Eighth-grade students performing at the <i>Basic</i> level are able to observe, measure, collect, record, and compute data from investigations. They can read simple graphs and tables and are able to make simple data comparisons. These students are able to follow directions and use basic science equipment to perform simple experiments. In addition, they have an emerging ability to design experiments. Students at this level have some awareness of causal relationships....These students can explain changes in position and motion such as the movement of a truck in relation to that of a car.
Proficient (170)	Eighth-grade students performing at the <i>Proficient</i> level are able to create, interpret, and make predictions from charts, diagrams, and graphs based on information provided to them or from their own investigations. They have the ability to design an experiment and have an emerging understanding of scientific phenomena, and can design plans to solve problems...They also know that light and sound travel at different speeds and can apply their knowledge of force, speed, and motion.
Advanced (208)	Eighth-grade students performing at the <i>Advanced</i> level are able to provide an explanation for scientific results. Students can perform and critique the design of investigations, relate scientific concepts to each other, explain their reasoning. They have a modest understanding of scale and are able to design a controlled experiment. These students have an understanding of models as representations of natural systems. They have a solid knowledge of forces and motions within the solar system and...they can infer relationships between structure and function.

Figure 1-A – NAEP Achievement Levels for Eighth Grade Science (Solomon, et.al., 2001).

The U.S. DOE report calculated average scale scores for various groupings identified from the entire sample of students involved in the assessments. Average scale scores were calculated for each grade level in each state. Table 1-1 displays the percentages of public schools attaining each of the achievement levels at eighth grade, in the nation and in Georgia, for 1996 and 2000.

Table 1-1: Percentage of Schools At or Above NAEP Achievement Levels Across the Nation and in Georgia (NCES, 2001)

		Below Basic	At or Above Basic (143)	At or Above Proficient (170)	At or Above Advanced (208)
2000	Georgia	48	52	23	2
	Nation	41	59	30	4
1996	Georgia	51	49	21	1
	Nation	40	60	27	3

What is interesting to note is that the NSES call for students, as a result of their science education experience, to display many of the characteristics described at the Proficient and Advanced levels of achievement. However, in both assessments, the national statistics show that at least 40% of the students are below the Basic level, and only 30% are at Proficient and Advanced levels, with a mere 4% at the Advanced level. Georgia eighth grade students score worse than the nation in all categories.

Other measures of Georgia science students describe the situation similarly. The Criterion-Referenced Competency Test (CRCT) is a statewide assessment given to students in all grade levels in Georgia. The CRCT measures student acquisition of skills and knowledge with the purpose of gauging individual ability and the quality of education in the State. Its content targets the Quality Core Curriculum (or curriculum objectives) identified by the Georgia Department of Education (GDOE). The GDOE characterizes the CRCT as an assessment of basic, minimum knowledge and skills in earth, life, and physical sciences, and they expect students to meet the minimum standards (GDOE, 2001). In the 2000-2001 academic year, 24 %, or nearly one in four, Georgia students in grade eight did not meet the minimum standard (GDOE, 2001).

Additionally, a review of standardized tests given in grade eight Georgia schools reveals similar performances of students in science. The Stanford 9 and Iowa Test of Basic Skills scores from 1996, 2000, and 2001 are displayed in Table 1-2. The table displays the percentile rank of Georgia's grade eight students for these assessments.

Table 1-2: Percentile Rank of Georgia Grade Eight on 1996 and 2000 Standardized Assessments (GDOE, 2001)

	ITBS Percentile Rank	Stanford 9 Percentile Rank
1996-1997	53	not available
1999-2000	56	not available
2000-2001	not available	46

This information and the results of the TIMMS report reinforce the remaining need to make changes within our science education system. Obviously, changes in one area or aspect of the system alone will not be effective in addressing the issues at hand. Each component of the system, however, is capable and empowered to look for ways to address science literacy within its immediate arena. The achievement levels described earlier in the NAEP assessment offer inspiration. The Proficient achiever demonstrates much of the knowledge of content and many of the reasoning abilities essential for understanding science. Advanced achievers demonstrate solid content knowledge and the ability to apply understanding and reason about science in practical situations. The NSES advocate similar proficiencies, and a continued focus on improving conceptual understanding and reasoning in inquiry settings seems critical to improving science literacy.

This author looked for ways to affect conceptual understanding and reasoning within the LBD physical science unit, initially as a teacher, and later, as a curriculum developer working with Learning by Design. I identified a new Design Rules protocol that targeted a skill the LBD group identified and informally named *science talk* (Gray et.al, 2001). Science talk is the skill or act of communicating and explaining (both in written and/or verbal form) the science concepts and principles within a context in an abstract, generalized form. Students often cannot use the abstract, generalized language of the science domains easily to discuss, explain, justify, or reason real and hypothetical events (Roth, 1997) The new Design Rules protocol is designed to promote science talk faculty and depth of conceptual understanding. The new protocol was anchored in

research in scientific argumentation, scientific discourse, and transfer. What follows, here, is a brief description of that research and how these findings supported the experimental treatment (the implementation of the new protocol) for this study. A larger, more in-depth discussion of the theoretical foundations is provided in Chapter Two.

Overview of Theoretical Foundations

As the standards indicate, inquiry methodology and curriculum promote quality science education (NRC, 1996). There are, however, many aspects to inquiry-based learning. One aspect is the engagement of students in scientific argumentation and scientific discourse. Argumentation, as a practice, is essential in the science communities as a way to assess and evaluate the work of scientists (Driver, et.al. 2000). Research on involving students in this type of behavior suggests very positive effects. Specifically, participation in student-centered constructive discourse and argumentation about science findings and principles improves conceptual understanding and encourages reasoning from science (Driver, et.al., 2000; Zeidler, 1997; Lemke, 1990; Sutton, 1992; Barnes & Todd, 1977). Providing proper scaffolding in the right ways and at the right times during argumentation seems to be an important factor (Jimenez-Aleixandre & Rodriguez, 2000; Driver, et.al., 2000, 1994; Herrenkohl & Guerra, 1998).

Closely related to the idea of student engagement in scientific argumentation is the lack of student experience in using science talk to communicate ideas. Students need guidance, scaffolding, practice and reflection to develop this skill (Roth, 2001; Richmond & Striley, 1996; Driver, et.al., 2000). Furthermore, written expression of science conceptual understanding poses even more challenges than verbal expressions (Bereiter & Scardamalia, 1987, 1986; Bereiter, Scardamalia, and Steinbach 1984). The next

Chapter discusses science talk challenges and highlights strategies to address issues with scientific argumentation. The research cited in Chapter Two informed the design of the new Design Rules protocol used in the experimental treatment – a protocol that focuses on enhancing science talk faculty in students.

Understanding and targeting *transfer*, the recognition and application of knowledge or skill in a new novel situation (Detterman & Sternberg, 1993), seems important to the investigation of the new Design Rules protocol. After all, the NSES clearly detail the need to educate students so that they will make connections to real life situations, will use science and science processes to “make decisions” and will “understand the natural world” (NRC, 1996, p. 1). The implication of this is that students will be able to relate classroom experiences and knowledge to situations outside of school and outside of the context in which the knowledge was obtained. Students who reason scientifically and possess sound conceptual understandings are prepared for transfer in two ways. One, they can recognize the applicability of the science concepts and principles in other, varied contexts (Detterman & Sternberg, 1993). Two, they realize that scientific reasoning could be helpful or is necessary in dealing with problems of new context (Bereiter, 1995). Regardless of the type of transfer, there is a substantial amount of research detailing the levels and classifications of transfer, the rarity of transfer (especially in educational settings), and the perceived obstacles to transfer (Bransford & Schwartz, 1998; Lave, 1988). Research and development has been done to deal with the problems associated with transfer. Chapter Two presents strategies to teach and assess for transfer along with their implications for this study (Bransford, et.al., 1999).

Finally, Chapter Two includes a review of LBD's founding principles and learning models (i.e. – inquiry learning, problem-based learning, and case-based reasoning) (Kolodner, et.al., 2003, 2002; Gertzman & Kolodner, 1996; Kolodner, 1993). LBD's findings suggest that not only is conceptual understanding affected by the LBD curriculum, but that students improve science process skills and collaborative behaviors (Kolodner, et.al., 2003). While the curriculum and methods of LBD, through its practices and activities, seemed primed to develop scientific reasoning and promote transfer, the best practices for doing so were not quite clear. The Design Rules practice was identified as a possible place to start research in this area. Thus, this research study investigates two questions:

- 1) How does the enactment of the Design Rules practice affect science students' conceptual understanding and reasoning ability?
- 2) How does the enactment of the Design Rules practice affect science students' transfer of science knowledge or skills?

Design of the Study

This section offers a brief description of the study's architecture, Chapter Three includes a more thorough explanation of the methodology. This study was a quasi-experimental, static group comparison design (Salkind, 1997). Four eighth grade teachers who were implementing the Learning by Design curriculum in metro Atlanta suburban schools participated in this study. The cohorts involved were of a similar demographic, and each teacher implemented the unit at approximately the same time of the 2000-2001 academic year.

The teachers all implemented the LBD force and motion unit, *Vehicles in Motion* (VIM), and sections of Chapters Two and Three described this unit in greater detail. I divided the four teachers into two groups, experimental and comparison. The experimental group implemented the new Design Rules protocol, while the comparison group served as the control group implementing an existing Design Rules protocol. Each of the four teachers trained in their respective protocols during a summer workshop and during the school year prior to the unit's implementation. There was no pretest given to students in either group, as there was no way to really no way to design a fair pretest. The post-treatment assessment was nearly impossible to mimic in pretest form. The limitations of this quasi-experimental design and their potential effects on the results are discussed in Chapter Five.

The experimental and comparison students each completed the *Vehicles in Motion* (VIM) unit having experienced their respective Design Rules protocols. Each of the teachers involved employed the Design Rule practice to varying degrees. Specifically, each implementation varied:

- the expectation for students to use science talk and science argumentation/reasoning;
- the opportunities for students to engage in science talk and science argumentation/reasoning, both in written and verbal formats;
- the amount of teacher-centered, versus student-centered, science talk and science argumentation/reasoning;
- the use of scaffolding tools to develop science talk and science argumentation/reasoning; and

- the amount of peer critiquing and Socratic discussion of students' science talk and science argumentation/reasoning.

The ubiquitous theme of the experimental treatment was overt scaffolding of opportunities for students to 1) develop their science talk faculty, and 2) argue and reason decisions with science concepts learned during VIM.

Near the end of VIM, students completed two important written assignments. The predicted outcome of the experimental treatment was that, in these written assignments, students would demonstrate greater proficiency in science talk, scientific reasoning, and transfer. Specifically, they would:

- use science concepts and principles learned during the unit to explain, justify, and reason design decisions, problems, and solutions at a higher rate;
- articulate these science concepts and principles in a more abstract, generalized voice or manner; demonstrating greater conceptual understanding and greater tendency to reason scientifically; and
- demonstrate transfer of content knowledge and reasoning skills at a higher rate.

These measures are supported by the NSES, which describes these behaviors and actions as quality measures of science literacy. The NSES describes effective assessments that ask students to produce “their own work to provide evidence of understanding of a scientific concept, principle, or law” and to “explain orally, in writing, or through illustration how a work sample provides evidence of understanding”. (NRC, 1996, p. 88)

The NSES advocates the assessment of student explanations,

Because explanation is central to the scientific enterprise, eliciting and analyzing explanations are useful ways of assessing science achievement. . . . thoughtfully designed assessment exercises requiring explanations provide students with the opportunity to demonstrate the full range of their scientific understanding. Exercises of this sort are not designed to learn whether a student knows a particular fact or concept, but rather to tap the depth and breadth of the student's understanding.

(p. 92)

I developed a coding scheme to assess the written assignments across the criterion above and established reliability with two independent coders using the scheme. The student assignments were coded and analyzed, and I analyzed the data between experimental and control teachers using chi-square analysis (Shavelson, 1981). Furthermore, I applied the same type of analysis between teachers *within* a treatment group.

Additionally, the teacher played a large role in the effects of the experimental treatment. I expected that teachers would not implement each of the prescribed treatments verbatim. As often is the case, I assumed teachers would alter their lessons and delivery appropriately to meet perceived needs of their classrooms and schools, and fit their own style of teaching. Therefore, I present reviews of the teacher role in, and fidelity to, the treatment.

Chapter 2

Introduction

This Chapter includes a discussion of the research relevant to this study, and in particular, the literature on scientific argumentation (or discourse) and transfer. The goal of the experimental treatment for this investigation was to develop the skill defined as *science talk*¹ to potentially affect conceptual understanding, reasoning with science, and transfer. The premises, conclusions and strategies discussed in the literature provide the rationale for the treatment's protocol and methods. Also in this Chapter, attention is paid to Learning by Design's (LBD) foundations and methodology. Up until the fall of 2002, the Instructional Materials Development Program of the National Science Foundation funded LBD. During that phase of development, the project staff assessed their materials and methods to understand the effects of their work and to inform and direct future materials development. A discussion of the preliminary findings from the instructional materials development phase and their implications on the design of this study is included in this Chapter. Finally, this Chapter concludes with a discussion of how the research discussed here relates to LBD's foundations and how it provided key motivation and momentum for this study.

¹ *science talk* – Defined by this author as the skill or act of communicating and explaining (both in written and/or verbal form) the science concepts and principles within a context in an abstract, generalized form.

Scientific Argumentation

LBD advocates inquiry learning and methodology (Kolodner, et.al., 2003). LBD units revolve around a design challenge (a problem) that students try to meet or conquer. As they progress through an LBD unit, students, in groups, iteratively design and improve a design artifact to meet the criterion of the challenge. For example, in *Vehicles in Motion* (VIM), students construct and use a model car throughout the unit. Students design experiments frequently and collect data from these experiments to inform the design choices, to improve the performance of the artifact, and to experience explicitly the science principles covered by the unit. Groups present their experimental procedures, their data, and their conclusions as a means of engaging in science inquiry, achieving the unit goals and learning physical science concepts. During these presentations, students often debate findings and conclusions, while the teacher attempts to facilitate positive discussions and focus student comments on the science concepts at hand. It is during these moments that knowledge is socially constructed through scientific argument.

The standards clearly describe the use of authentic science discourse in science education.

Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. In doing this, teachers...structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse. (NRC, 1996, p. 45-46)

Russell (1983) reports, however, that often classroom discussions are not structured to rely on evidence and reason for making claims. Rather, teachers rely on the position of their authority to support claims. This counteracts the position that science education is to encourage *students* to obtain evidence and reasons to support a claim. Furthermore, it serves to undermine a student's understanding of the nature of science, because students often perceive science as just a collection of permanent, known facts determined by experts and to be dispensed by the teacher (Driver, et.al., 2000, 1996; Lederman, 1992).

Teachers enculturate students into science through quality inquiry experiences, exposure to experts, practice within science ideas and science practices, and use of science vocabulary. When students are enculturated, they are able to portray the world in a new way. Engagement in scientific argumentation and discourse can be influential in this enculturation. Furthermore, exposure to the perspectives of others and to group argument and discourse can play a significant role in developing the argumentation skills of individuals involved (Zeidler, 1997). At a larger scale, discourse of explanations and interpretations is what builds society's confidence in the agents and outcomes of scientific endeavor. As Driver, et.al., (2000) suggest, "argument is thus the mechanism of quality control in the scientific community. Understanding argument, as used in science, is therefore central to any education *about* science" (p.301). The engagement in scientific argumentation should be a prominent feature of the science classroom (Barnes & Todd, 1977; Lemke, 1990; Kuhn, 1993; Sutton, 1992).

Additionally, argument over empirical results and theory is key in developing a true understanding of the nature of science. Teachers should establish the presence and

use of data not as a part of the scientific method; rather, data should be the evidence used by students to make scientific arguments and support claims (Driver, et.al., 2000). It is this repositioning of data's place in the science classroom that serves to develop science literacy.

There are more benefits to the inclusion of authentic argument and discourse beyond increased understanding of the nature of science. A focus on authentic science discourse and deliberation of empirical data allows students to connect their work to the concepts they are responsible for learning and potentially to deepen their understanding and reasoning. Research indicates that when students do engage in argumentation and discourse it is often inauthentic. Jimenez-Aleixandre & Rodriguez (2000) report that student discourse often takes the form of one-sided presentations to the class. The students' presentation tends to be the product of their science lessons rather than learning science. For instance, students may have a nice presentation poster where they share the hypothesis of their investigation, clearly label the data they collected in a chart, and give a conclusion to their investigation. Credit is given for the inclusion of these aspects, but there is little discussion over the content. Jimenez-Aleixandre & Rodriguez (2000) conducted research in an inquiry and problem-based, high-school genetics class where teachers created an environment in which students were encouraged to socially defend their positions with data and science concept principles. This research found that this method created students who: 1) engaged in scientific argument; 2) asked for each other to explain their arguments; and 3) developed warrants, i.e.- reasons based in principles that make the explicit connection between data and a conclusion or claim.

Argumentation and Discourse in Science Classrooms: Problems

While there seems to be clear support for the inclusion of argument and discourse in science classrooms, it is not as simple as making sure that students engage in argument. As many teachers may tell you (this author being one), open discussions, especially those debating validity or implications of evidence, can be directionless and counterproductive for various reasons. Jimenez-Alexandre's and Rodriguez's (2000) research in the high school genetics class looked at unstructured group discussions. They report that these students had difficulty collecting evidence relevant to their problem, utilizing their conceptual knowledge, and constructing arguments to support the claims they made. This suggests that perhaps teachers and students need encouragement and support to promote quality discourse in the classroom.

The literature describes pitfalls to avoid and strategies to follow to help develop sound argumentation abilities and to support discourse communities in science classrooms. Because it seems that students are rarely engaging in discourse in their classrooms, it would seem logical that their unfamiliarity would breed discomfort and devaluation of such an activity. Newton, et.al., (1999) found that scientific discourse and argument, in middle and secondary science classes, occurred during two of 34 lessons observed, with each of these two sessions lasting less than 10 minutes. With a total lack of experience students might resort to naïve, fallacious argumentation strategies. Zeidler (1997) identified five reasons for why students develop false arguments:

- 1) Students will affirm false claims if they held the claim as a premise to begin with.
- 2) Students will select evidence affirming a position even if there is data in the set that disaffirms.

- 3) Students will side with beliefs that are consistent with their own rather than ones that are inconsistent, and this can keep them from accurately assessing counter-data.
- 4) Students are willing to form conclusions on too little amount of evidence.
- 5) Students will insert additional beliefs about the context of the problem or include information that is outside the boundary of the problem at hand, rather than just the evidence presented.

Teachers can have a central role in developing students' argumentation skills, and this role seems very significant in the success of the discourse in science classrooms. Driver, et.al., (2000) propose that conceptual change requires that the arguments of individuals need to be socially constructed and iteratively developed with the guidance of the teacher. "Dialogic arguments" could be teacher-managed class discussions where he/she identifies various proposed "lines of thought" (p. 301). The teacher scaffolds student evaluation of the ideas proposed and encourages movement to an agreed upon single theory or belief. The opportunities give students practice at reasoned argumentation and practice at developing arguments on their own.

Newton, et.al., (1999) conducted interviews with teachers on this subject and revealed that teachers would welcome and value productive scientific discourse and argument in their classrooms. Teachers felt, however, these discussions would be difficult to manage and that they had no structure available to guide such an effort. Geddis (1991) found that teachers were, indeed, inexperienced and ill prepared to facilitate discussions, but that coaching teachers in these situations can redirect teacher behavior and provide confidence. It would appear that teachers need scaffolding themselves.

In summary, research cited here points to: 1) the lack of opportunities for students to engage in argument and discourse; 2) the tendency of teachers to monopolize the discussion and impose their authority over the claims; 3) the lack of scaffolding and structure for students to conduct argument/discourse sessions; and 4) the lack of knowledge in teachers to manage and utilize such sessions. The rationale for student-centered argument/discourse sessions has been made, but the obstacles cited here must be cleared before the fruits of this activity can come to bear.

Argumentation and Discourse in Science Classrooms: Solutions

First, students need to be cognizant of the purpose of argumentation and discourse activities. Norris (1997) suggests that student awareness and understanding of multiple modes of argumentation serves as a significant component to the development of science literacy. Teachers need to explicitly communicate the role such activities can play in developing their understanding of the nature of science and the science concepts directly at hand (Geddis, 1991; Jimenez-Aleixandre & Rodriguez, 2000; Kuhn, 1993). Students also make shifts in their reasoning when guided by the teacher to consider alternative sides to an argument (Geddis, 1991). Reminding students of the need to check each other across several dimensions of argument and discourse could be useful. Herrenkohl & Guerra (1998) provided students with reminders to check each other for statements of theory and prediction, clear summary of results, theories supported by evidence, and provision of alternate theories. As a result, students demonstrated greater ability to practice sound discourse, which reinforces the idea that students need practice in developing these socio-cognitive abilities.

Students also require cognitive scaffolding to assist them in developing sound arguments. When students are encouraged by teachers to debate and discuss a science issue with which they have been working in class, students rarely have the proper scaffolding to know how to discuss the issue or form an argument (Newton, et.al., 1999). Richmond & Striley (1996) completed a study with an intervention built on two premises. If students are to comprehend and utilize scientific tools and ideas when experimenting, interpreting results, and conducting discourse with other students: 1) they must have practice with the tools and see their usefulness over many problem solving instances; and 2) they must see that these tools can be used to form notions of science concepts and then have opportunities to create generalizable theories or principles. After treatment, Richmond & Striley noticed that students had a higher level of engagement in the problem and a more sophisticated level of argument. They also discussed the need to develop student understanding of the social rules required to have beneficial social discourse.

Argument, Discourse, and the Language of Science

Engaging in science discourse involves tackling another challenge: the difficulty for students to speak the language of science. The treatment in this study focused upon developing science talk – the use of abstract, generalized, science-based explanations or justifications of a context. Students need to become not only comfortable with the language of science, but they also need to value the use of it. Newton, et.al. (1999) make the case for assimilating students to the language of science.

Lemke (1991) points out ‘the mastery of academic subjects is the mastery of their specialized pattern of language use’. From this socio-linguistic

perspective, learning within a discipline requires adopting the norms of the language of that discipline. For young people learning science, this requires their participation, through talk and writing, in thinking through and making sense of the scientific events, experiments, and explanations to which they are being introduced. (p. 558)

It is necessary, therefore, to be aware of the impediments to incorporating this domain's language. Most middle school-aged students do not speak or write naturally in the tone, tempo, or style that science concepts and principles are provided or discussed in science texts and forums. For example, review this paragraph taken from an eighth-grade physical science textbook, Exploring Physical Science (Maton, et.al., 1995). The paragraph appears in a section where students are reading about air resistance. The fall of an object is explained using the concepts of Newton's First Law of Motion, acceleration, velocity and zero net force.

Any falling object meets air resistance. You can think of the object being pushed up by this opposing force of the air. As the object falls, the air resistance gradually becomes equal to the pull of gravity. The forces are then balanced. According to the first law of motion, when forces are balanced there is no acceleration. The object continues to fall, but at a constant velocity. There is no further acceleration. When a falling body no longer accelerates (but continues to fall at a constant velocity), it has reached its terminal (final) velocity. (p. 338)

Most science teachers would be thrilled if their students could provide explanations like this across multiple instances involving falling objects. It would clearly demonstrate an ability to weave abstract science language within a context and to apply the knowledge to the context. Most middle schoolers, however, do not use this style of language and level of vocabulary in everyday, casual conversation, or even in classroom discussions.

Students do not instinctively weave abstract representations of science into a contextualized explanation. Perhaps, this is related to the fact that students do not engage in this behavior, nor are they expected to do so, very often.

Roth (1997) comments on the dearth of opportunities to engage in science talk. In observing an eleventh grade physics class studying Newtonian physics, students had few opportunities to test their own understanding and to communicate using abstract language. Neither the teacher nor the students were willing to create situations where alternate explanations and discourses might be developed. When students attempted to ask questions or to raise alternate explanations, the motivation behind such was not considered by the teacher to be important. In summary, “students did not develop the competence to talk about phenomenon of interest in a way compatible with scientific canon. From the perspective of many students, there was no real need to do so.” (p. 527)

In the author’s experience as a middle-school science teacher, students rarely venture from concrete descriptions and relationships between items and events, and often they created explanations that were very closely tied to the context and that often were phenomenological. They lacked generalizability and consistency between situations. A.diSessa (1998) explains that this is common among individuals with naive

and fragile conceptions of science concepts. If we are to promote, develop, and assess science talk as a sign of concept understanding, reasoning, or transfer, then students must be able to communicate abstract concepts effectively and naturally in a contextualized explanation, i.e. – speak the language of science (science talk).

A later paper by Roth (2001) discusses the effects of establishing and utilizing *discourse communities* in developing science talk. Roth found that classrooms where multiple teacher/student and student/student discussions of varying representations and examples of phenomenon and science concepts (i.e., discourse communities) allowed for increased faculty in discussing science principles more abstractly. The testing of one's own formulations frequently, via these discourse sessions in class, helps teachers and students assess their conceptions, provides for unimpeded feedback, and gives them the opportunity to see where transfer could be important or useful (Anderson, et.al., 1996). Furthermore, deep understanding requires time and routine practice, so these discourse communities must *meet* often and at the right moments (Ericsson, et.al. 1993).

Other researchers have found benefits from scaffolding science talk during discourse to improve conceptual understanding, reasoning, and transfer. Chi, et. al. (1991) examined the effects of self-explanation, through the use of *talk-aloud protocols*, in problem solving. Talk-aloud protocols are explanations of how the science principles they identified were related to the problem before them. Chi's study drew attention to the power of self-explanation in solving a problem because it focused on explanations that students created *during* the problem solving process. There were many domains in which the technique seemed to have beneficial effects, including the ability to draw from knowledge of Newton's Laws in similar and new situations. Students who used self-

explanation during problem-solving tended to score better on transfer problems and tended to have deeper, higher-level explanations within the transfer problem.

The Design Rules sessions discussed in Chapter One and the classroom discourse sessions described here in this Chapter share similar characteristics with the talk-aloud protocol. Perhaps students engaged in the discourse sessions discussed would experience similar effects of those in Chi's study.

Research cited here claims that inclusion in discourse and argument will presumably help to develop science talk. Teachers, however, will need to encourage and support the use of science talk and make those expectations clear to students. Additionally, teachers need to provide scaffolding during argument/discourse sessions to model and support student development in the use of science's specialized language. The lesson to draw from the literature cited in this chapter is as follows: students require immersion into the language and practices of scientists to develop and demonstrate scientific literacy, but they also require the proper support to assimilate and value the language and practices of scientists.

Transfer

The previous section included a discussion of the importance of engaging students in scientific argumentation and discourse to support student's development of faculty with science talk, which might impact conceptual understanding and scientific reasoning. Improvement across these dimensions within an individual would signal a higher level of scientific literacy. However, what behavior would signify improvement? Students must display behaviors or engage in activities that would make their

advancements explicit. This requires students to engage in transfer - the recognition and application of learned knowledge or skill.

Transfer is a bit of a *holy grail* in education – sought after extensively, but seemingly rare to achieve. However, as the NSES declares, achieving it is necessary in developing science literacy (NRC, 1996). It is the belief in transfer that Bransford and Schwartz (1998) claim “lies at the heart of our educational system.” (p.61) Transfer research has been prevalent throughout the last century, yet there is evidence that little progress has been made in fostering it in our classrooms. Simply put, it is not always easy to see when, how, and why transfer occurs. Some researchers have attempted to uncover the steps that lead to transfer, and as a result of their work, some answers are available. The following section includes a review of the relevant research on transfer and provides some strategies to improving transfer.

Types of Transfer

Katona (1940) pointed out a distinction in the types of transfer that students can perform: near transfer and far transfer. Perkins and Solomon (1988) termed these as *low road* (near) and *high road* (far) transfer of knowledge. When a new situation triggers knowledge and skills (i.e., activates prior knowledge in the mind of an individual) gleaned from experience in a previous similar situation, it is *low road* transfer. *High road* transfer is when a person recalls and applies abstract principles or items from a previous experience, one that on the surface might look quite different from the new situation.

Transfer can be classified further into *specific* and *non-specific* transfer. Specific transfer occurs when the content of a learning situation is applied in a new situation with similar context. For example, if a person is shown how a mnemonic can help him or her

memorize the order of the planets in the solar system, and then he or she utilizes the strategy to later recall Saturn's position in an astronomy class, *specific* transfer has occurred. However, if that learner, based on his or her experience in learning about the planets, later devises a mnemonic to help him/her remember the first ten U.S. presidents, it is *non-specific* or *general* transfer (Detterman & Sternberg, 1993). Bereiter (1995) might refer to this as *situational transfer*. This type of transfer is important to consider for my study. If students are to develop an appreciation of, and even affinity for, reasoning from science or develop theories based on the presence of evidence, then situational transfer is critical. It would benefit students to recognize when they are in a position to carry out these skills and how these operations can help them meet their own goals. Transfer is not limited just to content knowledge. Transfer of skill or reasoning matters as well.

Detterman and Sternberg (1993) point out that cognitive psychologists have highlighted another distinction of transfer. Cognitive psychologists look at similarities and differences in the *deep* and *surface* structures of the situations. Detterman uses the example of the dashboards of cars and airplanes to illustrate the idea. All cars have dashboards that basically contain the same information (similar deep structure), but each dashboard can look different from one another (different surface structures). However, airplanes might have similar dashboard configurations, but the information provided by the dials is very different from that of a car (similar surface structures, but different deep structures). It is reasonable to declare that a large goal of any science education is to develop the ability of students to engage in *far, general* transfer of *deep structures*, rather than *near, specific* transfer of *surface structures*.

Despite our ability to classify and identify types of transfer, achieving transfer has proven to be elusive. Early research on transfer conducted by Thorndike (1901) identified a key idea. His research showed that improvement in any single mental function rarely brings about equal improvement in any other mental function. He therefore argued against the use of *formal discipline* (i.e., learning Latin) to build one's mind. Rather, he and his fellow researchers advocated the benefit of developing *mental muscle* (i.e.-the ability to think abstractly and apply knowledge to new events).

Thorndike's research also showed that while people may perform well on tests focusing on specific content, they may not transfer that knowledge to a new situation very well. Katona (1940) showed that students who learned using rote memorization tended to do well on tasks that asked for a repeat of the memorized information (performing a series of tasks or events that lead to a desired end). In fact, they did better than students who learned by *understanding*. However, the *understanders* outperformed the memorizers on transfer problems that had similar but not exact matching steps. When students learn via understanding they see that a principle or idea can be applied to many different situations or problems. A *memorizer* will learn specific pieces of information that can only be applied or used in very specific instances that require this information.

In recent research, others looked beyond aspects of learning within the individual. The context within which the knowledge is learned plays a significant role. For the Jasper Project, the Cognition and Technology Group of Vanderbilt University (CTGV) studied transfer with grade-school math students. These students learned certain math concepts within a complex case involving a boat trip. CTGV concluded that the students had very little flexibility in transferring knowledge to new situations

outside the context of the boat trip (Bransford, et. al., 1999). Lave (1988) also agreed that transfer is largely dependent on how close a new situation is to an old one.

Detterman and Sternberg's book Transfer on Trial (1993) reviewed the research on transfer dating back to the beginning of the twentieth century. They found that most, if not all, research shows that transfer is rare and unreliable. Additionally, their review of research found that the likelihood of transfer highly corresponds to the similarity between the two situations.

Why such awful results? What is it about transfer and the individuals engaged (or not engaged, as it were) in it that makes it rare. Sources of transfer difficulties have been proposed. Bransford, et. al., (1999) highlight a number of difficulties in making transfer happen:

1. Transfer relies upon existing knowledge structures to shape new knowledge structures and navigate new problems. This existing knowledge may be based upon false principles or it may not be related to the matter at hand for the student. This leads to the student using incorrect ideas to formulate solutions to a new problem, only to incubate their misaligned knowledge base.
2. Transfer can be difficult, not because of what is lacking in a student's mind, but rather, the student does not know that his/her knowledge is required. Students may have the knowledge or principle at their disposal, they just do not know to retrieve it. They do not perceive the need for it, or there is no external trigger that asks students to consider the knowledge relevant to the problem.
3. Some transfer problems are based in cultural differences between the student(s) and the teacher or learning situation. Students' life experiences and experiences at home

may not lead them to respond to certain cues or questions that they would encounter in a school, with a particular teacher, or in a new learning situation.

If *general* transfer signals an ability to work from or connect to more abstract principles, then a person must have the ability to recognize an event as one that falls under the umbrella of a certain principle. Individuals who are able to make these connections must build knowledge frameworks that allow for this recognition, as indicated above. Glaser (1984) research offers insight for how these connections might be formed. He completed a review of novice/expert studies and found that novices' knowledge tended to be organized around literal objects explicitly given in a problem statement, whereas principle and abstraction underlie the objects that organize experts' knowledge. To perform like experts and engage in general transfer, students need to learn the principles and abstractions underlying experts' organization of knowledge and use those principles to organize their experiences. Even though novices have the abilities to problem solve, if they lack those principles as a base for knowledge organization, they cannot recall or reuse experiences that vary on concrete features.

Solutions to Transfer Problems

This begs the question: How can educators help students organize and classify experiences, events, and information to promote general transfer? Furthermore, what can educators do during the experiences and events themselves (either in presentation or content) so that students are able to more easily digest them to construct transfer-promoting frameworks? Science education and cognitive science research have provided some ideas.

Glaser's (1984) work, research on case-based reasoning (Kolodner, 1993, 1997), and research from Learning by Design™ at Georgia Tech (Kolodner, et.al. 2003), strongly suggest that while context similarity is a strong influence on the ability for a student to transfer, a focus on abstracting and organizing principles from experience can promote transfer, maybe even to less similar experiences via case-based reasoning (CBR). CBR is a type of reasoning founded in the use of previous experience. The learners use their prior experiences (cases) to find solutions to new problems, to alert themselves to new problems, and to predict the effects of solutions to problems. A learner engaged in CBR incorporates new experiences with old ones in memory. They re-code old experiences using feedback from new ones to improve the applicability of their index of cases. When a learner fails to apply knowledge and experience well (either through misrecognition of the situation or through lack of specific knowledge), this learner will make adjustments to his or her knowledge structures and identify what he or she needs to learn. The case-based reasoner will build new or adapt existing cases to better reason within later situations (Kolodner, 1993; Kolodner, et.al., 2003). Hence, case-based reasoning relies on engaging in transfer very frequently.

In How People Learn (Bransford, et. al., 1999), the authors offer several premises that could serve to influence instructional materials and methods created to target transfer.

1. Initial learning is necessary for transfer, and a considerable amount is known about the kinds of learning experiences that support transfer.
2. Knowledge that is overtly contextualized can reduce transfer; abstract representations of knowledge can help promote transfer.

3. Transfer is best viewed as an active, dynamic process rather than a passive end product of a particular set of learning experiences.
4. All new learning involves transfer based on previous learning, and this fact has important implications for the design of instruction that helps students learn. (p.41)

Furthermore, Bransford, et. al. (1999), identified several strategies that research has suggested are effective in getting around transfer obstacles.

- Students should experience cases of a principle and then experience other cases that are very similar in order to increase flexibility with a principle.
- Teachers can employ “what if” questioning to change the parameters of a problem or experience to increase flexibility in transfer.
- Teachers should offer, and students should engage in, multi-faceted problems in order to create student solutions that could apply in a variety of situations. (pp.50-51)

These instructional strategies target the obstacles listed above by considering that learners engage in case-based reasoning. The rationale for the premises and strategies overlaps with the basic premises of CBR. Instructional strategies that explicitly and deliberately develop case-based reasoning should influence the rate of transfer within learners.

Assessment of Transfer

A sound assessment device and method is critical to validly and reliably understanding the transfer capability of an individual. Some research initiatives during the past 30 years have been identifying transfer via tests of what Broudy calls *replicative knowledge* and *applicative knowledge* (Broudy, 1977). These assessments may demonstrate the ability to memorize tacit facts (replicative knowledge), but they do not necessarily reveal much about what the student learned. Applicative knowledge refers to abstract-based knowledge that a person would be able to utilize in a variety of situations. Bransford & Schwartz (1998) conducted research to show the extent to which general educational experiences of fifth grade and college students influenced a novel task. The task involved creating a recovery plan to protect bald eagles within their state. Both groups of students surprisingly prescribed equally-low-quality solutions, suggesting that there is little transfer of knowledge despite years of education for the college students and little that the fifth-graders had gleaned from their recent lessons on this subject in their life science course. When Bransford & Schwartz looked at the reasoning used by the two groups of students, however, there were vast differences between the two groups. Examination of the planning notes of the college students contained questions and inquiries about the role of interdependence, ecosystems, human interaction, and other facets of biology that were not present in the notes of the fifth-graders. Obviously, the college students built upon larger ideas from previous biology classes or lessons, and tried to apply that knowledge set to the problem before them.

Regardless of how apt, or in this case inept, the college students' final plans were, there was general transfer, or as it was stated earlier, situational transfer. The original assessment tool was unable to detect it because the conditions the experimenters created

to measure transfer restricted the participants, only allowing the students to share replicative knowledge rather than applicative knowledge. Bransford and Schwartz argue that there was little room for participants to demonstrate transfer outside of knowing specific content about recovery plans.

Campione and Brown (1987) make the argument that transfer is difficult to observe during planned assessments. They argue that measuring transfer via the number of prompts necessary to witness transfer (i.e. – “graduated prompting”) is more effective and appropriate than single moment assessments. All of these findings assert that it is necessary to be careful when selecting an assessment device. Some traditional tools can offer information about transfer, but their scope is limited if their focus is on replicative knowledge.

Schools and educational researchers frequently rely upon multiple choice, and at times standardized, tests. These tools offer a variety of information regarding a student’s knowledge and learning, but there are issues to consider when using them. To begin with, these tests should be valid, that is, they should provided items that actually target the content covered during the learning period. Also, they should present items in a manner and format that is familiar to the student and easy to decipher (e.g. – multiple choice answers are labeled and listed, not written in paragraph form). Finally, distracters should be plausible options.

Salkind (1997) reviews the benefits and limits of multiple choice tests:

Advantages

- They can be used to assess almost any content domain.
- They are relatively easy to score and can be machine scored.

- Students do not have to write out elaborate answers but just select one of the provided answers.
- Poor writers are not penalized if they are unable to communicate in written answers what they know.
- Good distracters can help diagnose student misunderstandings.

Disadvantages

- Limit the student's opportunity to generate creative answers.
- There is no opportunity to practice formulating and writing an answer.
- General aversion, and sometimes anxiety, in students to partake in this type of assessment.
- Items must not be written to influence students in choosing one choice over another.

If students engaged in learning activities that focused on memorization and replicative knowledge, multiple choice items can be very useful. A student's ability to recognize which planet in the solar system is closest to the sun might be determined by this type of test. Furthermore, knowledge of common characteristics of Mercury could be assessed. What might not be revealed by these questions and answers is the knowledge of the processes and history that created the characteristics or how those processes may be working similarly in other locales. Multiple choice assessment *is* a format that allows an educator to see how a student responds to stimulus valued by the educator (the array of questions provided), but it does not always permit a view of how a student might formulate connections and apply knowledge.

This paper makes the case for the development of science talk through use of scientific argumentation. The goal of science talk development is to promote conceptual understanding and reasoning, and as a result, we would hope to see improved transfer. During classroom discourse, a teacher indeed might be able to monitor and formatively assess individual students across these dimensions. Summative assessments, however, usually are required to some degree in every classroom, and multiple choice tools may not reveal all there is to understand about a student.

Written assignments and essays (including open-ended questions and responses) can supplement or replace tests and other replicative assessment materials, and they can offer a different view of transfer and science knowledge than do multiple choice tests. Written responses afford students the opportunity to construct arguments or explanations. Teachers and researchers can analyze the content of these responses to gain an understanding of 1) what the student felt was necessary to respond to the question or assignment and 2) their conceptual understanding (Bereiter & Scardamalia, 1987). In the case of the written assignments for this study, students explain or justify design decisions, solutions and recommendations to others. What students share might reveal something about what they feel is important about their design experience and the science they learned along with it. Furthermore, it is not just the content that is important, but the structure of a written assignment also is revealing. How do students choose to craft the narratives and explanations they might be sharing? How do students organize their points and what might this reveal about conceptual understanding and scientific reasoning from a specific curriculum unit? One could argue that these written products would offer insight into an individual's transfer capabilities along these lines.

Writing about Science

If students' writing is to be reviewed for level of conceptual understanding and scientific reasoning, then it is important to understand that writing abilities, separate from their general abilities in a science domain, will vary. Students approach a written assignment with varying expertise in writing. Preparing students to display transfer and to generalize science principles in writing requires the researcher to understand differences between expert writers and novice ones. Bereiter and Scardamalia (1986) found that novice writers tend to simply tell what they know at a very surface level, revealing tacit facts. Expert writers will construct more complex versions, planning their pieces more than naive writers. Furthermore, experts tend to revisit and revise their expressions more often than naive writers during the construction of a written product. Another difference emerges when each of these types of writers gets stuck and loses direction or purpose when writing. Novices tend to re-read the assignment, looking for explicitly stated clues. Experts, on the other hand, review their goals for the assignment, their writing process thus far, and their experiences for inspiration.

In another study, Scardamalia, Bereiter, and Steinbach (1984) examined the effect of *reflection* during the writing process on students' written assignments. They employed a strategy of teachers and students *modeling thought* frequently, with follow-up discussions of the ideas expressed. They found an increase in mean performance by students when writing essays and papers. They noted how students in the experimental group showed a willingness and propensity to re-evaluate and rewrite the plan and content of their

written product. Integral to this improvement was the use of cues by the teacher to help students generate and expand new ideas and to connect with previous ones.

As the literature reviewed above indicates, an integral and early step in transfer is recognizing the need to apply knowledge or skills possessed. A sign of situational transfer, might be student recognition that a written assignment is an opportunity to apply and share knowledge and engage in scientific reasoning. Providing students the opportunities to practice transfer (via science talk moments) during discussion and in writing is a part of teaching for transfer and developing conceptual understanding and reason. Case based-reasoning supports this notion (Kolodner, 1993, 2002).

Theoretical Foundations of Learning by Design

This section includes a review of the foundations of LBD, its principles and methodology. LBD is an inquiry-based and project-based approach to science education approach founded in constructivist learning theory that aims to address the social and cognitive aspects of learning. The goal of the design of LBD is to “lay a foundation, in middle school, for students to become successful thinkers, learners, and decision-makers throughout their lives, and especially to help them begin to learn the science they need to know.” (Kolodner, et.al., 2003, p. 2)

The LBD approach incorporates the cognitive model of case-based reasoning (CBR, discussed earlier in this Chapter), where students learn from the lessons they formulate from their previous experiences. Students, working with a design artifact, attempt to solve a problem or meet a challenge. Over the course of a curriculum unit, the artifact or device is redesigned by students to meet the criterion of the design

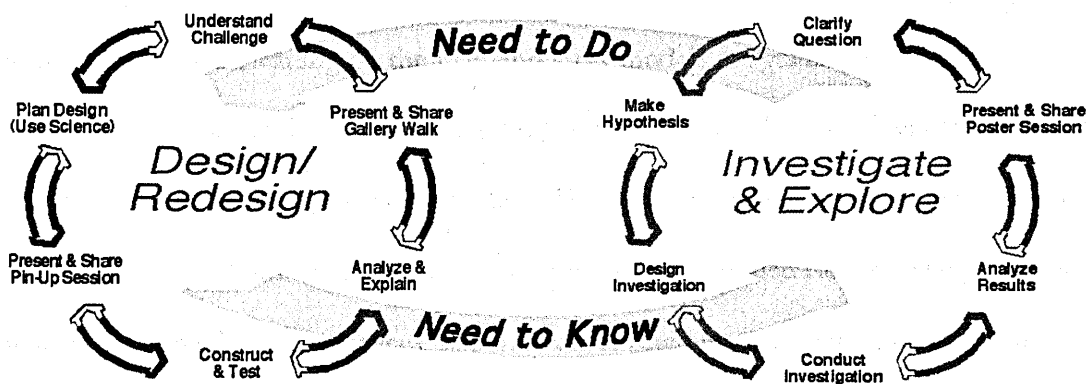
problem. They inform their design and re-design of the artifact by performing experiments to get feedback about performance and suitability. At each iteration, teachers provide scaffolds to help students construct *cases* potentially from which to draw at a later time. This use of the CBR model employs and nurtures a kind of reasoning that seems to promote science learning and transfer (Kolodner, 1993, 2002; Kolodner, et.al., 2003).

In conjunction with CBR, LBD asserts that problem-based learning (PBL) is the appropriate model to shape classroom practices (Barrows, 1986; Collins, et.al., 1989; Gertzman & Kolodner, 1996). PBL is a cognitive-apprenticeship approach that originated in medical schools. In this approach, students work collaboratively to solve problems and learn science. They identify what they know, what they need to learn more about, plan how they will learn more, conduct research, and deliberate over the findings all together in an attempt to move through and solve the problem. Working collaboratively in groups allows students to share knowledge and to build off the ideas and knowledge of others. PBL encourages and structures science argumentation and discourse reaps the rewards of such activity. Via the nature of this collaborative setting, students often are in the position where they have to engage in articulation, justification, and explanation behaviors. PBL promotes learning because of its focus on the exchange of ideas and its provision of opportunities for students to engage in these behaviors.

Additionally, the processes and practices from the field of design are central to the LBD methodology (Kolodner, et.al., 2003). Through the design of artifacts in LBD classrooms, students engage in the behaviors and activities of designers, engineers, and architects; they analyze a challenges, generate ideas to answer the challenge, research

concepts governing the challenge and its environment, build or test models, and redesign products based on feedback to better meet the challenge. Furthermore, LBD curriculum units significantly emphasize an important aspect of design – iteration. Figure 2-1 displays the LBD Cycles of Activities, illustrating the iterative engagement in design and investigation that helps students meet their design challenges.

Figure 2-1: LBD Cycles of Activities (from Kolodner, Gray, and Fasse, 2003)



Designers also work collaboratively in teams to solve problems iteratively and extend to the ideas and previous solutions of other designers and engineers. Likewise, learner behaviors and actions in the PBL and CBR models map directly onto the practices of designers, or vice-versa.

The iterative development of both the design artifact and the science skills appropriate for middle schoolers, via the practices of the CBR and PBL, allows for the simultaneous development of conceptual understanding and scientific reasoning by students. LBD explicitly provides students with science content in small doses as they experiment with the design artifact and iteratively re-design it. These small doses of content, combined with the designing, running, and evaluating of experiments, give students the ability to construct knowledge in a meaningful way. Students, motivated by

the expectations of their community of learners (classmates) and their teacher, justify their decisions with relevant content knowledge. Furthermore, they also engage in scientific discourse and argument to explain and justify claims from their experiments.

Additionally, the literature on transfer suggests that LBD's approach is congruent with teaching for transfer. Earlier, I shared some of the suggestions from Bransford, et.al. (1999) meant to impact transfer in students. LBD trains teachers in methods and practices (described in more detail later in this Chapter and in Chapter Three) proposed to develop transfer, leaning on the PBL and CBR models for guidance.

One critical and unique aspect of LBD curriculum is the use of repeated activity structures, referred to as practices or rituals (Kolodner, Gray, and Fasse, 2003). Many of these practices mimic the practices of designers as mentioned earlier. The practices foster reasoning from experiences, and they are enacted in an authentic way so that students value their happening. While the content of the practice session may change, the process and structure of the activity remain consistent. This allows the student to practice the reasoning particular to a practice and to reflect on multiple occurrences of the practice to build a fluency in their reasoning capability. What follows is a summary of the practices (rituals) of LBD embedded in Holbrook and Kolodner (1999).

Rituals that support inquiry-based learning: LBD's system of activities is designed to support a cycle of designing and testing solutions to the challenge presented in the curriculum. These rituals include messing about with challenge materials and/or artifacts. **Messing About** helps students recognize and articulate what they already know about the challenge and helps them generate relevant questions and initial

solutions. **Whiteboarding** (Barrows, 1986) is used with the whole class to develop issues for investigation and to keep track of what is learned throughout the challenge. Groups get feedback on their initial ideas from the teacher and other class members at **Pinup Sessions**. The groups iteratively build and test their designs, gathering data on the performance of each prototype and using the data to revise their designs. **Gallery Walks** with in-progress designs and finished products allow groups to offer one another constructive feedback, to share expertise, and to garner inspiration. The class also develops better understanding of the underlying science through reasoning from cases (the current class designs and existing designs in the world) and through developing **Rules of Thumb** as a class. (p.2)

Note: The term *Rules of Thumb*, cited above, is synonymous to Design Rules. “Rule of Thumb” is a phrase widely believed to have an origin in an old English Common Law that allegedly permitted a certain level of abuse of women at the hands of their husbands. While most etymology sources claim this origin as dubious and a common myth, the name of the practice and products are described in this paper as Design Rules for reasons of sensitivity.

LBD’s preliminary results of its on-going, in-development research (Kolodner, et.al., 2003) show that students in LBD perform better or as-well as non-LBD students in classroom comparisons of content knowledge measures. LBD students, however, show better performance than the non-LBD students in collaboration skills, meta-cognitive skills, negotiating solutions, and science process skills, i.e., designing fair tests, justifying with evidence, and explaining.

Summary

The literature review in this chapter provides a theoretical foundation for my study. In reasoned and proper form, LBD grounded its units in inquiry, PBL, and CBR learning models. These learning models target the development of meaningful understanding of science amongst middle-school students, and LBD curriculum units have targeted this as well. The literature, however, offers ways in which LBD curriculums could evolve and potentially could improve student understanding of science.

I propose that the inclusion of scientific discourse and argument as practices in LBD science classrooms is not only appropriate, but necessary. The potential result of engagement in student-centered, well-managed discourse is a positive effect on conceptual understanding and scientific reasoning that is socially constructed and meaningful. Additionally, student improvement in conceptual understanding and scientific reasoning is signaled by transfer. Transfer has proven elusive, historically, but suggested *teaching-for-transfer* strategies offer hope, which influenced the treatments employed in this study. In this study I consider situational transfer to be important, and I designed the assessments and coding accordingly.

While early LBD results are encouraging and validate the efforts LBD has made so far, the LBD research group continues to look for ways to improve conceptual understanding, scientific reasoning, and transfer. Inquiry, CBR, and PBL afford improvement, and the practices, in many ways, are incarnations of the practical strategies suggested by research in scientific argumentation, discourse and transfer. The LBD group continues, however, to improve upon the curriculum and methods to affect student development more specifically. This study focuses on the implementation of an

alternative version of a particular practice, the Design Rule practice. The protocol for this new practice is anchored in the research and strategies discussed in this Chapter. The next Chapter provides details of the goals, activities, and sequence for LBD, VIM physical science unit. Chapter Three also includes a discussion of the Design Rules protocols and the methodology for the study.

Chapter 3

This Chapter provides details on the context, participants, treatments and measures of the study. This chapter first provides an overview of the *Vehicles in Motion* (VIM) unit covered by teachers and students during this study, along with a more detailed description of the Design Rules practice. Also, I provide a detailed description of both the experimental and comparison treatments of the study. Throughout this Chapter, there are a number of references to items appearing in the Appendix. These items provide detailed descriptions and examples of the various artifacts used and collected during the study.

Context of the Study: Physical Science Unit - Vehicles in Motion

The VIM unit asks students to ponder the potential design of a car that scientists working in Antarctica will be able to use to perform their duties and collect information about the environment. While students never construct a real prototype of the vehicle, they do construct and work with a simple model car. The design challenge of VIM is to construct and design a vehicle that will travel as straight as possible and cover the longest distance possible within a single run. Throughout the unit, students test several engines to propel the car across a test track, complete with varying surfaces and hills. Students design, construct, test, report and share data, give recommendations, debate methods, and investigate relevant science concepts to create a better model car. The purpose of working with this model car is to inform the design recommendations for the Antarctica car. VIM has been in development and implementation for several years: In 2000-2001,

the year of this study, nine teachers in the Atlanta Metropolitan area implemented the VIM unit.

The VIM unit consists of four modules:

- *The Coaster Car* – Powered by a ramp, the students attempt to make the car roll as far and straight as possible.
- *The Balloon Car* – Powered by a balloon engine and air, the students attempt to make the car roll as far and straight as possible. Then, the students attempt to run the final design of this car over a test track made of carpet and containing hills.
- *The Rubber Band and Falling Weight Car* – Powered by engines that wind up the axle and then deliver force to move the car, the students attempt to make the car roll as far and straight as possible. Then, the students attempt to run the final design of this car over the same test track, made of carpet and containing hills.
- *Hybrid Car* – As a culminating activity, students attempt to combine the elements of the four cars into a new creation that meets the overall design challenge of conquering the test track.

Each car type has science concepts associated with it (see Table 3-1).

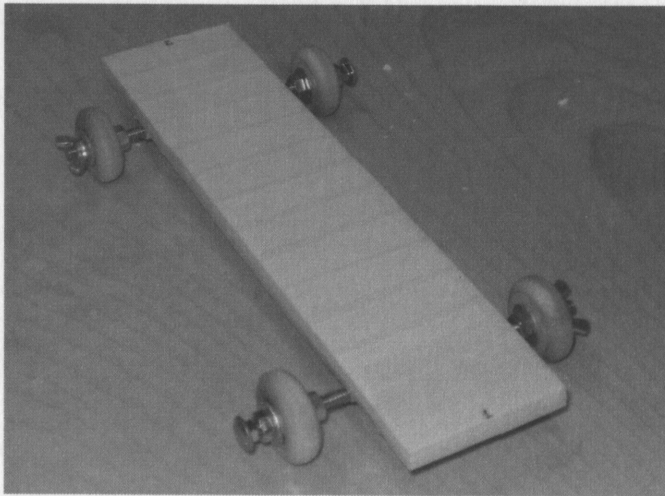
Table 3-1

Module	Science Concepts
Coaster Car	Gravity, Forces, Friction, Newton’s First Law of Motion, Velocity
Balloon Car	Acceleration, Force, and Net Force, Newton’s Second Law of Motion, Newton’s Third Law of Motion
Rubber Band Car	Newton’s Laws of Motion, Torque, Friction
Falling Weight	Newton’s Laws of Motion, Torque, Friction, Constant Force & Acceleration
Hybrid Car	All concepts listed above

In a final competition, students test their designs on the test track and across several other criteria. While students are engaged in this design challenge, they are exploring the science principles universal to forces and motion. The curriculum offers time and materials to help students link their task at hand and other outside experiences to the governing science concepts, which is one of the larger goals of LBD’s curriculum.

Design Rules in VIM

Groups in a LBD classroom simultaneously work toward a solution to their challenge, but that does not mean that all groups will be meeting the challenge in the same ways, investigating the same variable, or designing the exact same product. For example, at the beginning of Vehicles in Motion, students build a simple coaster car. The components and parts are the same across the class except for a couple of key items. Students have a choice about what type of bearings they can employ: ones made of paper, ones made of Styrofoam, or ones made of a drinking straw. Furthermore, students have the freedom to construct the car from the materials they are given in any fashion they see fit. They determine the length of the wheelbase, they choose how to tape the pieces to the chassis, they decide where the wheels will sit on the axle, etc..



Basic Coaster Car built by students in VIM

Through guidance from the teacher and their own knowledge of designing and constructing experiments (a skill focused and built upon earlier in the curriculum), students investigate the effect these differences in design (i.e.-variables) have on the

performance of the car. Because the challenge of this module is to create a coaster car that will travel down a ramp and coast as far and as straight as possible, the students soon begin to see that these variables do indeed affect the running of their vehicle.

After groups perform experiments individually, the class reconvenes to discuss the findings. Many times several groups unknowingly investigate the same variable, and their results suggest the same effect is produced when altering that variable. Furthermore, while other teams may not have investigated the variable, it could be a piece of information vital to the group's success. As a result, the class begins to see that while they may not all converge on one single design or product, there are basic design features that all groups should notice and incorporate. These are possible candidates for Design Rules. In the coaster car, the use of the straw as a bearing for the axle produces a significant increase in performance because of its low friction surface and shape. The teams that recognize the significance of employing straw bearings possess a vital piece of information that will prove to be a mainstay in the final design of the car to achieve the overall challenge.

The LBD curriculum team recognized this pattern of convergence toward a single piece of useful information. They recognized that it would be beneficial for students to record this type of information. Many times, teams would not remember to incorporate some of these very important pieces of information, and it led to a lot of frustrated and lost students muddling through the design and inquiry experience. LBD thought that if there was a poster, or similar item, on display reminding students of key issues, it might help the unit move along. Also, it would help to keep groups from

omitting a key design technique or science knowledge that would jeopardize their chances in future modules. Thus, the creation of the Design Rules as a LBD practice.

During early implementations of the Design Rules practice in the years preceding this study, the practice was ill-defined in terms of what its end product should be. These early implementations produced various types of Design Rules. Often, students were making very good observations and recommendations, but they never went any deeper than a surface/design suggestion or beyond **fabrication techniques** (i.e., use tape to secure bearings to the car because it can be removed and reapplied more easily than glue) or **feature settings** (i.e.,- keep the wheels positioned far away from the chassis so that they do not rub on the chassis). The Design Rule never was decontextualized. A variable, or car feature, may have been isolated, but it was isolated as a “vehicle variable” rather than a science variable. Students rarely explained the effects of the variable using examples from outside the context of the vehicle or science content.

This author (as an LBD teacher in 1999-2000) thought that the formulation of Design Rules might be useful in helping students closely see the underlying science concepts or principles governing the behavior of their design. To pilot the idea, I instructed students to formulate Design Rules using this template:

When (describe the action, design, or choice you are working within),
use/connect/build/employ/measure (list your suggestion or method)
because (list or supply the science principle or concept here that backs up your suggestion).

This simple template seemed to produce science-oriented Design Rules with my students. Moreover, in homework assignments and class discussions, students occasionally made these types of statements and explanations and often they would resemble the pattern, voice, and tempo of the Design Rules template that I had modeled for them. Design Rules which previously sounded something like,

Use straw bearings because they allow the car to travel farther than any of the other bearings.

began to sound more like,

When choosing a bearing for the coaster car, use the straw bearings because the straw has very low friction and will not cause the car to slow down as much as the other bearings because other bearings change the net force a lot.

A Design Rule created from this template for using the straw bearing (stated earlier) explicitly opens the door to the science of the module. The bearing itself exemplifies how low friction surfaces produce less negative acceleration in this moving body, e.g. – Newton’s First and Second Laws. This is where a teacher needs to seize the moment. Not to point out the line of logic, but to create the circumstances and to move forward so as to help students to realize and to understand the logic connecting the car to the laws governing their behavior.

Following the 1999-2000 implementation of VIM, the LBD team discussed the Design Rules idea at length with other teachers who had piloted the practice in some form or another. There were differences in the use and look of the practice, and not every teacher implemented the Design Rules as the author had. However, two prevalent uses emerged from this reflection with the teachers:

- 1) Design Rules that helped students in design techniques and craft. The Design Rules were to remind students of helpful fabrication techniques, materials use, and general design ideas with little focus on science principles governing their design success.
- 2) Design Rules that focused not only on the design technique itself, but also on the science governing the success of the technique.

As well, two ways of implementing the Design Rules practice emerged:

- 1) A one-time creation of the Design Rules during a module, usually just prior to the creation of the final design for that module.
- 2) An iterative approach of revisiting and revising Design Rules over time, within modules and across modules.

What if Design Rules became a sacred declaration? What if the class performed as a community of learners that validated suggested Design Rules? What if student teams had to support their Design Rules with science principles or concepts that related to the given event or behavior? What if we altered the Design Rules practice to focus on the strategies and principles suggested in the literature on argumentation, reasoning, and transfer? How might a new Design Rules practice develop *science talk* practice? Finally, what role would the teacher play in this new practice? These questions, ideas, and my experience motivated this study in large part.

I would like to take this opportunity to, again, review the basic design of the study. This was a quasi-experimental, static group comparison design (Salkind, 1997). This type of design lacks a pretest. A pretest was not possible for this study. It was very difficult to create pretest assessments similar to the end of unit assessments that could target the existing knowledge and abilities measured in this study. Because of constraints

on teacher-instruction time and other aspects of implementing LBD that year, the teachers were unwilling to participate in pretest activities or have students do work that was in excess of that already in the unit. Because I wanted students to complete written assignments already existing in the LBD unit (i.e. – Product History and Antarctica Car Recommendation), my options for pretest were limited.

- *Product History* – This assignment asks students to review their design experience and discuss the design decisions and features that were significant during the evolution of their car. It also asks them to explicitly identify and explain/justify those design features with science. There was no way for me to pretest for this type of behavior and task with an assignment that would be comparable to the Product History. I had no way of selecting a context familiar to all individuals, nor could I assume that these student had ever had experience designing. In fact, LBD’s experience has been that most of the students have had little or no experience with structured design of engineering in school prior to the eighth grade.
- *Antarctica Car Recommendation* – I did propose giving this assignment as a pre-test in the form of a week-long assignment, however, three of the four teachers said that they did not have time to fit it in to their schedule. The VIM unit over forces and motion is approximately 10 weeks long. The curriculum guides for the districts in which I was working provide 3-4 weeks for teachers to cover these topics. The teachers face enormous pressures from their district administration to deliver too much content with too little time, and LBD and this author are extremely sensitive to this issue. Additionally, two of the teachers voiced that it was wrong to ask kids to write a paper that they were unprepared to write.

I realize that a quasi-experimental static group comparison study is, perhaps, less powerful because it lacks a pretest. I acknowledge that this type of study is limited in understanding any effects of treatment because of possible differences in knowledge and skill present in the subjects prior to the treatments. Perhaps the results of this pilot study can serve as a tentative indicator to clarify future research questions and methods that would employ a full experimental research design.

Subjects – Teachers & Students

Four teachers initially participated in the study. Teacher 1 (T1) and Teacher 2 (T2) served as experimental teachers. Teacher 3 (T3) and Teacher 4 (T4) served as the comparison, or control, teachers. I assigned each teacher a treatment method based upon two criterion. First, this author worked with all four teachers during the LBD summer workshops prior to the initiation of this study. Based on these observations and interactions, the author was able to determine the natural teaching styles of the teachers. Therefore, T1 and T2 seemed primed to utilize the experimental Design Rules practice, while T3 and T4 seemingly would be interested in the comparison implementation. Second, when each teacher was approached about participating in the study, each indicated which implementation they would prefer to use in their classroom. Their preferences matched with the author's predictions, and thus, the experimental and comparison groups were determined.

Teacher, school, and student demographic information is below. School personnel, apart from this study, assigned students to each, and there was no way to determine or influence which students would be in the classrooms of the teachers.

T1 – Experimental Teacher

Location: Metro-Suburban Atlanta Middle School

Grade: 8th Grade, Physical Science

Years of Experience: Highly Experienced, 7+ years

LBD Experience: 1 Year

Socio-Economic Level of School: Middle Class – Professional and Working

Students in T1's Class: Classes consist of high achieving students (some designated “gifted” students); students enrolled in this class qualify because they are in above-level math; gender is evenly mixed; Caucasian 85%; African-American, Asian, Hispanic/Other, 15%, almost all students expect to attend college.

T2 – Experimental Teacher

Location: Metro-Suburban Atlanta Middle School

Grade: 8th Grade, Physical Science

Years of Experience: Highly Experienced, 7+ years

LBD Experience: 1 Year

Socio-Economic Level of School: Middle Class – Professional, Working, and Agricultural

Students in T2's Class: Classes consist of an array of capabilities from high achieving students (some designated “gifted” students) to students with learning disorders (no more than 3 in any one classroom according to the teacher); gender is evenly mixed;

Caucasian 70%; African-American 20%; Asian, Hispanic/Other, 10%; this 8th grade cohort is particularly social, and many of the students come from working class or agrarian families, students talk about attending college; grades are important to the students; students are highly competitive.

T3 – Comparison Teacher

Location: Metro-Suburban Atlanta Middle School (same school as T4)

Grade: 8th Grade, Physical Science

Years of Experience: Highly Experienced, 7+ years

LBD Experience: 2 Years

Socio-Economic Level of School: Middle Class – Professional, Working, and Agricultural

Students in T3's Class: Classes consist of an array of capabilities from high achieving students (some designated “gifted” students) to students with learning disorders (no more than 3 in any one classroom according to the teacher); gender is evenly mixed; Caucasian 90%, African-American 10%; this 8th grade cohort is particularly social, but many students have parents expecting their child to attend college, students are personable, talk about attending college; grades are important to the students.

T4 – Comparison Teacher**

Location: Metro-Suburban Atlanta Middle School (same school as T3)

Grade: 8th Grade, Physical Science

Years of Experience: 3rd year of teaching

LBD Experience: 2 Years

Socio-Economic Level of School: Middle Class – Professional, Working, and Agricultural

Students in T4's Class: Classes consist of an array of capabilities from high achieving students (some designated “gifted” students) to students with learning disorders (no more than 3 in any one classroom according to the teacher); gender is evenly mixed; Caucasian 90%, African-American 10%; this 8th grade cohort is particularly social, but many students have parents expecting their child to attend college, students are personable, talk about attending college; grades are important to the students.

**** Important Note:** T4 fell ill to a severe condition during the implementation of the study and VIM unit. This teacher was unable to teach any significant portion of the unit, and, in fact, took an extended leave of absence that lasted through the end of the 2000-2001 school year. While I am pleased and happy to report that T4 has fully recovered and has returned to teaching, this teacher's students and implementation are neither documented nor analyzed in this study. This unfortunate occurrence seemed to have no effect on the study or the ability to validly and effectively compare data from the treatment groups.

Teachers participating in the Design Rules study did not receive separate or additional compensation to the compensation received as participants in the LBD curriculum implementation for the academic year 2000-2001. LBD teachers received a stipend at the completion of a summer workshop and each time thereafter they

completed an LBD unit (Apollo 13 Launcher Unit, Vehicles in Motion, Tunneling Across Georgia, etc.) in the academic year. Participation in the Design Rules study added a minimal amount of duties, and the teachers agreed to take them on as a part of their implementation of the Vehicles in Motion unit.

I obtained consent for participation from students and their parents or guardians as a part of the consent obtained by Learning by Design at the beginning of the school year. LBD had Internal Review Board (IRB) approval, and LBD's IRB permission and research plan covered this study. See page 27 of the Appendix for a copy of the human subjects approval for LBD.

Treatments: Shared Elements

T1 and T2 employed the **experimental** treatment, and T3 employed the **comparison** (control) treatment.

Experimental Treatment

Create Design Rules that focus not only on the design technique itself, but also on the science governing the success of the technique. An emphasis is placed upon students formulating and expressing these Design Rules in this way. In addition, class Design Rules are iteratively revisited and revised as the class moves through the curriculum.

Comparison Treatment

Create Design Rules to help students in design techniques and craft. The Design Rules are to remind students of helpful fabrication techniques, materials use, and vehicle design. Teachers may inquire during discussion and formulation of Design Rules about science concepts involved, but there is no explicit emphasis or rigorous scaffolding to support Design Rules with a science principle or writing scientific explanations of a Design Rule.

All LBD classes follow an approximately 15 step sequence through each module.

The sequence is provided in Table 3-2. It is important to read and understand the

sequence to fully understand the differences between the experimental and control implementations. In the Results section of this paper, an annotated version of this sequence highlights how the actual implementations progressed and differed.

Table 3-2: Basic LBD/VIM Curriculum Sequence

Step	LBD/VIM Sequence
1.	Challenge Introduction Problems specifications, constraints, and criteria identified.
2.	Build & Mess About Build basic version of the car, or engine attached to the car, highlighted during the module. Examine and Mess-About with the basic design; students share observations.
3.	Whiteboarding Class reviews observations, constructs a Whiteboard to organize ideas and variables to test.
4.	Design Experiments Students identify specific variables to test, plan experiments.
5.	Conduct Experiments Students create and conduct experiments to test variables identified.
6.	Poster Session Students conduct a Poster Session to present their experiment(s) to the class.
7.	Design Rules Presentation Presenting group generates a Design Rule regarding their variable to help students plan future designs. Design Rules are recorded.
8.	Science Instruction Student primed for learning science related to their activities, the teacher moves into discussing science principles underlying the module. The teacher utilizes demonstrations, short investigations, mini-lectures, the textbook, and homework to focus on a specific science concept. For example, classes working with the Coaster Car will research “What is a force?”, “Friction”, and “Newton’s First Law” in their texts. They participate in a combination of activities to develop an understanding outside of the context of the Coaster Car.
9.	Conduct More Experiments Class returns to experimenting and investigating new variables and verify the results of other experiments.
10.	Poster Session II Class conducts another Poster Session; groups suggest more Design Rules. <i>Note: Teachers may repeat steps 7-10 several times to fully explore the ideas and concepts of the module.</i>
11.	Plan Final Design, Pin-Up Session Students review Design Rules, review experimental results and consult with other groups to plan final design designing the final car (or engine). Each group creates a Pin-Up (a sort of blueprint of their final design idea).
12.	Build & Test, Gallery Walks Groups build and test their design. Data is collected and Gallery Walks occur.
13.	Final Presentation Students present their final car and attempt the challenge(s).
14.	Review Challenge, Whiteboard Classes review the limitation of the car type, in general, and discuss needs to complete the challenges more successfully which leads into the next module.
15.	Assessment Students review science concepts from the module and are given an end-of-unit assessment.

The next few pages (to page 65), I describe the treatments as they were prescribed to teachers; as teachers would have learned them during our training sessions. I describe some particular aspects and activities of an LBD classroom, and then I explain the similarities and differences between the two treatments relative to those aspects. In Chapter Four, I share how each teacher actually carried out the treatment.

In both the experimental and comparison classrooms, students read and perform the science content activities in the *Vehicles in Motion* text. As groups investigate specific design choices or experiment with certain variables, the teacher uses guided discussions and other activities to help students formulate conclusions about the variables that they are testing. Teachers create a class copy of Design Rules from the Design Rules that the different groups suggest based on their experiments. Teachers help the students explore how to apply the Design Rules when designing their vehicles. Furthermore, teachers encourage the recording of Design Rules. LBD has a special worksheet, or Design Diary page, entitled *My Design Rules*, Figure 3-A (*see full page version in Appendix, pp. 1*), to help students record and develop Design Rules, and both groups use these. The use of the sheet, however, does vary in each treatment.

My Design Rules			
Source (Case or Activity)	Design Rules	Why the Rule Works	Ideas for Using the Rule
Questions and Learning Issues			

© Georgia Tech, 2000

Figure 3-A My Design Rules design diary sheet.

As groups investigate specific design choices or experiment with certain variables, the LBD teacher, in both comparison and experimental classes, guides discussions and other activities to help students formulate conclusions about the variables that they are testing.

During general LBD workshop training, teachers and LBD researchers discuss the need to support design challenges with mini-lectures, demonstrations, transfer tasks, readings, and homework that focus on pertinent science concepts. For example, all teachers using LBD have reference pages in the *Vehicles in Motion* text that discuss friction and bearings much like a traditional middle-school science classroom textbook (see Appendix, pp. 2-7, for full page copies from the VIM textbook). The teacher assigns homework that ask students to find, sketch, describe, and analyze examples of these items or concepts at home or in their everyday lives. Following these activities, the class discusses the examples found and reviews them to clear misconceptions and verify the examples. The teacher provides a mini-lecture to supplement and help explain friction and its characteristics. The discussion then returns to the design challenge with teachers

expecting that students now know that friction is playing a role somehow. Teachers also hope that students, after the last few days and experiences, have a better understanding of why and how friction plays a role.

Treatment Differences

There are two key differences between the comparison and experimental approaches:

- 1) Experimental subjects iteratively formulate Design Rules and are scaffolded to support their Design Rules with science principles constantly as a means of deepening their content knowledge. The comparison teacher relied on her other devices and strategies (some supplied by the VIM curriculum) to connect the science principles to design experiences.
- 2) The *My Design Rules* sheet in the experimental classes is a *dynamic* record of Design Rules that develop over time and with experience. Experimental students revise and reflect upon their Design Rules using this sheet. In the comparison classes, this sheet mostly serve as a one-time recording device with statements that mirror the conclusions of an experiment or design experience.

The experimental teachers follow all of the same procedures in the LBD sequence as the comparison teachers, but add several practices with regard to Design Rules. In particular, experimental teachers iteratively develop Design Rules with their students and specifically attach science principles to explain why each of the Design Rules works. As with the comparison classrooms, experimental classes investigate specific design choices or experiment with certain variables. The teacher uses guided discussions and other activities to help students formulate conclusions about the

variables that they are testing. Teachers create a class copy of Design Rules, while students record Design Rules their group, and other groups, formulate after experiments. Through class discussion and the use of data, these Design Rules suggestions are verified to a reasonable degree. It is at this point the experimental teachers initiate a process to develop Design Rules and understanding of science principles differently than the comparison classes.

Below is the LBD/VIM sequence discussed earlier, but this one (Table 3-3) is annotated to highlight where and how the experimental treatment augments the sequence.

Table 3-3: Annotated LBD/VIM Sequence for Experimental Treatment

Step	LBD/VIM Sequence	Experimental Treatment Additions
1.	<p>Challenge Introduction Problems specifications, constraints, and criteria identified.</p>	
2.	<p>Build & Mess About Build basic version of the car, or engine attached to the car, highlighted during the module. Examine and Mess-About with the basic design; students share observations.</p>	
3.	<p>Whiteboarding Class reviews observations, constructs a Whiteboard to organize ideas and variables to test.</p>	
4.	<p>Design Experiments Students identify specific variables to test, plan experiments.</p>	
5.	<p>Conduct Experiments Students create and conduct experiments to test variables identified.</p>	
6.	<p>Poster Session Students conduct a Poster Session to present their experiment(s) to the class.</p>	
7.	<p>Design Rules Presentation Presenting group generates a Design Rule regarding their variable to help students plan future designs. Design Rules are recorded.</p>	<p>Experimental class participates in Design Rules Session, where all of the Design Rules are reviewed and discussed. Students record Design Rules on the <i>My Design Rules</i> sheet, knowing that it may be edited later.</p>
8.	<p>Science Instruction Student primed for learning science related to their activities, the teacher moves into discussing science principles underlying the module. The teacher utilizes demonstrations, short investigations, mini-lectures, the textbook, and homework to focus on a specific science concept. For example, classes working with the Coaster Car will research “What is a force?”, “Friction”, and “Newton’s First Law” in their texts. They participate in a combination of activities to develop an understanding outside of the context of the Coaster Car.</p>	<p>The experimental class formulates some early Design Rules based on their experiments; the class’s attention focuses on the science issue at hand. The teacher emphasizes and models science talk: Rephrasing students answers and asking students to rephrase answers using the science vocabulary. Teacher emphasizes heavily the relationship between the abstract science principles and the examples students have generated, referring to the car often in explanations.</p>
9.	<p>Conduct More Experiments Class returns to experimenting and investigating new variables and verify the results of other experiments.</p>	<p>Before starting the next round of experiments, students review the Design Rules to identify and rewrite any misstatements or misconceptions based on their recent research. Also, students now have a better ability to fill in the column <i>Why the Rule Works</i>. Here is where they explain/justify their Design Rules with an abstract concept. Students amend the <i>My Design Rules</i> sheet and then begin the next round of experimenting.</p>

Table 3-3, Continued

<p>10.</p>	<p>Poster Session II Class conducts another Poster Session; groups suggest more Design Rules. Note: <i>Depending on the complexity of the design changes in a module, steps 7-10 maybe repeated</i></p>	<p>Experimental students once again discuss and deliberate over Design Rules as a class. This time the class is more prepared to fill in the <i>Why the Rule Works</i> column because of their exploration of the module's science concepts. Often, teachers will reword student justification or explanation (rephrasing as a question) to model the use of abstract decontextualized justification or explanation. The teacher models science talk both in discussion and when writing Design Rules. If steps 8-10 are repeated, a Design Rules Session occurs, and the <i>My Design Rules</i> sheet is edited.</p>
<p>11.</p>	<p>Plan Final Design, Pin-Up Session Students review Design Rules, review experimental results and consult with other groups to plan final design designing the final car (or engine). Each group creates a Pin-Up (a sort of blueprint of their final design idea.</p>	
<p>12.</p>	<p>Build & Test, Gallery Walks Groups build and test their design. Data is collected and Gallery Walks occur.</p>	<p>After redesign, students may verify Design Rules, or sometimes, they may discover flaws in their Design Rules. Once again, the teacher uses guided questioning and discussion (perhaps even more demos, science concept research, homework assignments) in an attempt to have students develop more valid Design Rules and better articulate science concepts within a context as evidenced by their Design Rules. This step highlights the priority and encouragement of an iterative development of science within the experimental classrooms. Again, the teacher models science talk both in discussion and when writing Design Rules.</p>
<p>13.</p>	<p>Final Presentation Students present their final car and attempt the challenge(s). Depending upon the module, the car may face anywhere from one to three challenges.</p>	
<p>14.</p>	<p>Review Challenge, Whiteboard Classes review the limitation of the car type, in general, and discuss needs to complete the challenges more successfully which leads into the next module.</p>	<p>Teacher and students review the Design Rules, identifying those that seemed to have the most influence on successful designs, i.e. – those that met the challenge.</p>
<p>15.</p>	<p>Assessment Students review science concepts from the module and are given an assessment, usually a quiz or test.</p>	

One aspect of the experimental use of the *My Design Rules* sheet stands out. On the *My Design Rules* page, students have a place to record why each Design Rule works and how they think they might apply it to their design. Realize, the students may not be able to fill in the *Why the Rule Works* section with a particular comment at the time the Design Rule is proposed. They may accept, from data and repeated testimony, that the Design Rule is true, but they may not have the abstract science concept needed to fully verify it. Furthermore, it may be the case that two different groups will create Design Rules that contradict one another. In the end, what is important is that Design Rules are generated and not initially judged in these experimental classes. The treatment dictates iterative refinement to edit or eliminate poor Design Rules.

The comparison classrooms follow the general LBD sequence listed above. The researcher expected that Design Rules in the comparison classrooms mostly originate from a design or craft perspective. That is, they do not rely heavily upon the science concept or principle behind the Design Rules. As a part of the natural LBD VIM curriculum, however, comparison teachers **do** model and discuss the connection between Design Rules and the science concept. While students and teachers in these classes may inquire during discussion and formulation of Design Rules about the science concepts involved, an explicit emphasis or rigorous scaffolding in supporting Design Rules with a science concept or principle is not expected. Teachers in these classes look to make connections to the supporting science using other methods from either LBD materials or from their own devices. Comparison classes may create a class Design Rules poster or overhead and they use the *My Design Rules* sheet to compile Design Rules, but not to analyze or revise them.

Teacher Training

This author trained all four teachers involved during the fall semester of the 2000-2001 academic year. I conducted training at each teacher's school early in the semester, and I trained each teacher individually. The VIM unit did not begin before training was complete. A follow-up meeting occurred a couple of weeks after the initial training session to address issues conceived by either the researcher or the teacher. Also, the follow-up meeting allowed for the treatment procedures to be reviewed once again.

Experimental teachers received an outline of the basic sequence for developing and revisiting the Design Rules during the VIM unit (See Design Rules Guide in the Appendix on pp. 24) during the training session. Discussion centered around the philosophy underlying the approach and how the prescribed implementation applied the philosophy. Teachers made notes on the outline and asked questions. The teachers learned during the training that they could make small adjustments to certain aspects of the procedure, but that they must try to adhere to the sequence as prescribed. We discussed the importance of having some unified experimental approach in developing Design Rules with students and how this would have an impact on the validity of the study.

At the time of the study, the comparison teacher was an experienced LBD teacher, and she had been involved in the original piloting of the Design Rules concept. The comparison treatment mimicked what this comparison teacher had used in the previous academic year. Regardless of whether this study was to be conducted, the comparison intended to employ the comparison treatment for the 2000-2001 academic year.

The use of the My Design Rules sheets, Figure 3-A (*see copy of the full sheet in the Appendix, pp. 1*), were discussed at length with both comparison and experimental teachers. Each teacher was supplied copies of the sheet during training and upon further request.

The experimental method called for the iterative use of the My Design Rules sheet, and both of these teachers were eager and ready to do so. The comparison teachers uses the sheet in any way she felt would be beneficial and productive. During training, the comparison teacher indicated she would likely use the My Design Rules sheet as a one time recording device, rather than a dynamic one.

Every teacher expressed a desire to have some latitude regarding the format of the My Design Rules sheet. T3 and T2 wanted to employ journals and wanted to include these sheets as a part of the journals. Both teachers allowed for easy inclusion of multiple sheets in the journal booklet as students worked through the unit. T1 wanted to hand out My Design Rules sheets when students needed more and asked the students to bind them in a 3-ring binder. The comparison teachers described their use of the sheets during training and during subsequent visits during implementation. The use of the sheets by all the participating teachers described in the results section.

As the students and teachers progressed through the VIM unit, I conducted in-class observations. Occasionally, during the initial weeks of the unit, the experimental teachers would have questions regarding the implementation. Very often their concerns centered around these issues: the number of iterations in writing and revising Design Rules during a module, the correcting of poorly or incorrectly worded Design Rules, and whether they, generally, were “doing it right”. A 5-10 minute discussion of the issue

usually settled any concerns, and I always reminded them of the outline and our discussions from training. These discussions ceased after the initial 2-3 weeks of the VIM unit.

Data Collection – Student Products

The researcher looked for differences in two unit-culminating written student assignments, the Product History Report and the Antarctica Car Design Recommendation. I selected these two assignments for two reasons. One, they are written assignments and, for the reasons highlighted earlier in Chapter Two, I felt that these assignments would provide good insight into student understanding and ability. Secondly, they are student-generated written assignments in which students justify and explain decisions or problems affording them the opportunity to share their conceptual understanding and their ability to transfer knowledge and skill. Each of the assignments is profiled in greater detail later in this Chapter.

Teachers collected and graded the Product History Reports and the Antarctica Design Recommendations. The investigator then collected the assignments for coding. The teachers and I discussed these assignments minimally during training so I could prevent teachers from teaching toward the assessment. The main discussion of these two assignments occurred near the very end of the unit. Later in this section I detail the nature of assignments, the training given to teachers regarding their assignment, and the format in which they were handed in to teachers. The coding of these assignments (coding scheme detailed later in this Chapter) focused on students ability to:

- use science concepts and principles learned during the unit to explain, justify, and reason design decisions, problems, and solutions at a higher rate;

- articulate these science concepts and principles in a more abstract, generalized voice or manner; demonstrating greater conceptual understanding and greater tendency to reason scientifically; and
- demonstrate transfer of content knowledge and reasoning skills more at a higher rate.

Product History

The Product History is a detailed explanation of the evolution of the students' vehicles. In the Product History paper, each student outlines the evolution of his/her car's design. The paper discusses problems encountered, design changes, experiments on design features, and explanations of design choices, both successful and unsuccessful. The VIM text provides a preliminary activity to train students how to write and develop a Product History. Then, students write a Product History for their vehicle (*copies of these pages from the VIM text are in the Appendix, pp. 19-21*). One aspect of the study was to see how students use *science-talk* to explain the evolution of their car. The assignment as it appears in the VIM text does not specifically focus on this, thus supplemental instructions were necessary. I provided each of the teachers with a Product History teacher guide (*See the Appendix, pp. 8, for a copy of the Product History Teacher Guide*). The Product History Teacher Guide provided a structure and charge for the teachers. The guide, and our discussions surrounding the assignment, centered on asking students to identify and justify/explain with science concepts the evolution of their model car.

The Product History offers a chance to understand the conceptual understanding of the concepts from VIM posed by students. As students describe the features,

problems, and aspects of their vehicle, there is a tremendous opportunity for students to relate the science they have learned, especially since the assignment explicitly asks for them to do so. Students can not only identify the concepts in play, but they can explain how and why those concepts relate or govern the feature discussed. These explanations were coded (coding scheme and criterion are detailed later) such that the richness and depth of students' understanding may be revealed. Furthermore, the Product History offers an opportunity to witness *reasoning-with-science* skills. Students have choices of how to justify or explain features, decisions, etc., and students may use scientific data or science concepts to base their explanations and decisions. This speaks to a students' ability to engage in scientific reasoning.

Finally, the Product History offers a view on transfer within the individual. Not so much transfer of knowledge, but rather, situational transfer. The Product History assignment does not direct them to consider Design Rules or other instances where they were expected to justify or explain with science. Here, students (presumably experimental treatment students) may recognize the opportunity to reason with and share their conceptual understanding to complete the requirements of the assignment.

During these discussions of the assignment, each teacher explained to me that student use of *science concepts* in the paper would be their greatest concern and their main grading criteria, also.

All teachers weighted the Product Histories as significant assignments. Also, students in all classes were given 8-10 days to work on the assignment. T3 gave the assignment as a take-home paper that would count as a portion of their final exam for

the VIM unit. T2's students wrote it as a paper/essay that would count as much as a test grade. T1 also assigned it as a paper/essay that would count as much as a test grade.

Antarctica Car Design Recommendations

The Antarctica Car Design Recommendation assignment also appears in the VIM student text. This assignment in the VIM text explicitly asks students about science issues, unlike the Product History assignment. Therefore, it needed no supplemental guide or emphasis (*copies of these pages from the VIM text are in the Appendix, pp. 22-23*). Students create and write recommendations for a team of scientists that are planning to design and build a vehicle to explore Antarctica. The assignment details the conditions the vehicle must endure and the utility of the vehicle. Students are then asked to comment on six areas of the vehicle in their recommendation: wheel and axles, bearings, propulsion, construction material, fuel, and safety.

The coding scheme used to assess the Product History assignments also is used to code this assignment. Therefore, the assignment speaks to student conceptual understandings and reasoning skills in the same way the Product History did. Some vehicle areas match very closely to the unit, like wheels and bearings, however, not all of the listed vehicle areas have VIM unit concepts immediately associated with them. This assignment does offer the opportunity for further transfer of conceptual understanding relative to the Product History assignment. Although, it is not so far removed from the context of the VIM vehicle that students would be at a loss in making connections. Students have the opportunity to consider a new situation and a new device (with similar features to their car) and to apply what they know about the content they learned during

VIM. Again, the coding scheme is detailed later in the Chapter, and the coding of these to written assignments serves to answer the research questions of this study.

As with the Product Histories, all teachers weighted the Antarctica Recommendations as significant assignments. Students in all classes had 5-7 days to work on the assignment. Some teachers, however, changed the nature of the assignment unbeknownst to the researcher until the time of data collection. T1 asked for each student group to present one written recommendation paper. The group was to form consensus, and T1 insured that the group divided the work evenly. T1 gave 20-30 minutes of class time for three days to allow the group to collaborate on the writing of the recommendation. T2 gave students three options: Option 1, write the recommendation in a paper essay, as an individual, Option 2, students could work in groups of two or three to create a PowerPoint™ presentation, and Option 3, students could film a video “pitching” their design ideas (almost like a commercial). Option 3 also required that a written script be produced so that coding would be possible. T3 had all students write the recommendations as individual essays, which was the original request of the researcher. All three teachers counted the assignment as a major grade in the class (equivalent of a lab write-up).

Data Collection – Teacher Practice

Observations of experimental and comparison classrooms occurred during key moments in the VIM sequence:

- 1) When student groups present the results of an experiment performed with a design feature (during an LBD practice named Poster Session). Typically, the student group

explains how they altered their variable, displays the data they collected, formulates a conclusion, and attempts to provide a Design Rule.

- 2) When classes discuss and review the Design Rules shared during Poster Sessions.
- 3) When students would redesign with the Design Rules as guides for their design choices.
- 4) When classes discuss the science content, explicitly, related to the module.
- 5) When students revisited Design Rules lists to either accept, edit, or refute Design Rules already created.

Each of these moments listed above occurs as part of the natural sequence of activities in all sub-units of VIM. Each of the four occasions listed, however, did not all occur with the same frequency or in the same ways for each teacher. Presumably, with the experimental method focusing on the iterative editing of Design Rules, there would be more instances to observe items (3.) and (5.) in those classes. Although, each of the four moments listed above were observed in both experimental and comparison classes at least once during each module.

The underlying theory of the experimental treatment is that students in the experimental group would be more capable of using and articulating science. Another contribution of this study, however, would be a change in the instructional practice of the teacher in developing science talk and transfer skills. As discussed earlier, teachers in both the experimental and comparison classrooms followed a basic process, but each teacher brought individual strengths and perspectives to their implementation. As these teachers progressed through the unit, I noted teacher practices employed to develop the creation and use of Design Rules in each classroom.

This attention to teacher implementation permits examination of several questions. What actions, questions, and practices did these teachers employ, and in what ways might those have affected the development and use of Design Rules? What evidence emerged to suggest there is a connection between formulating Design Rules in a certain manner and the ability to articulate science principles in context? This author looked to see which practices engaged students in negotiating Design Rules and articulating science principles. Furthermore, if differences in the data within a treatment group emerged, I reviewed any differences in teacher practices for possible correlation. This effort provides commentary on the efficacy of the approach from the teacher's perspective and important details regarding methodology for using Design Rules to increase science talk, conceptual understanding, scientific reasoning and transfer.

Data Analysis: Coding the Written Assignments

Each of the written assignments contained useful information that helped to reveal how a student chooses to justify and/or explain features, highlights, problems, and solutions from their vehicle design experience. In the case of the Product History, the students are indirectly trained (*via a preliminary activity, see Appendix pp. 17-18 for a copy*) to write the Product History chronologically. The requirements of the Antarctica Recommendation are clearly listed in the text and explained at the time the assignment was given. To help code the assignments I developed a scoring guide. This guide not only helped in developing a more sound, consistent coding method, but also afforded a training tool for reliability measures. This author served as the main coder, but two other coders were employed to assess reliability. The remainder of this section details the

coding process of individual assignments, the coding scheme, and the categories within the scheme.

Each student assignment (Product History and Antarctica Car Recommendation) is read through once, completely. Then, each reference to a design problem, feature, solution, experiment, or idea is identified. These references are titled *events*. These events are marked and numbered on the actual copy of the assignment. Then, the event is coded according to specifications and rules described in the rubric. A detailed explanation of the coding rubric, including sample events and a completed coding form appears in the Appendix (pp. 9-16). What follows here is a blank coding sheet, Figure 3-C, and brief explanations of the coding categories. After the coding categories are discussed, a sample of an actual completed coding sheet is provided, Figure 3-D. This coding scheme is applied to both the Product History and Antarctica Car Recommendation assignments.

Student Number	Event	Curriculum Target	Justification	Validity	Form	Depth

Figure 3-C: A blank coding sheet for coding a Product History Report.

Coding Categories

Event – A reference to a design problem, feature, solution, experiment, or idea. Each event is numbered.

Curriculum Target – The issue discussed is a science content issue targeted by VIM unit. Examples include Newton’s Second Law, Friction, and Acceleration. Examples of

non-targeted issues would be Impulse, Torque, and Potential energy. These non-targeted events will still be coded in the science content section of the rubric. The entry is a 1 or a 0 – 1 is for targeted issue, 0 is for a non-targeted issue.

Justification – This code reveals something about the way student choose to communicate and justify/explain the event. This category speaks directly to whether students choose to base decisions and explanations in science or not. The codes indicate whether students are citing relevant science concepts or data as an indication of conceptual understanding and scientific reasoning. This also serves as an indicator of transfer. In both assignments, codes reveal students' propensity to reason with science and explain the science in a manner similar to their Design Rules experience. With the Antarctica Car Recommendation, this category directly reveals science content transfer. Events coding at 3 or higher signal these items.

Implicit Justification

0 – No reason is given for the choice or decision.

Explicit Justifications

1 – Student chooses to justify event with a reason based in their design experience where a criterion is included.

2 – Student chooses to justify event with data collected during experience, but no science references are made.

3 – Student chooses to justify event with a reason based in a science principle. The principle can be stated in an applied, abstract, or both applied and abstract fashion.

4 – Student chooses to justify answer with a reason based in a science principle and with data they collected in their experiments.

The level of understanding and the value that a student places on science in their event is coded in these last three categories (Validity, Form, and Depth). Here, “Concept” refers to the fact that the word or *term* was used to reference the science concept, i.e. – “...because of Newton’s Second Law”. “Principle” refers to the use of an explanation or definition of a science concept, i.e. – “...because if you increase the net force, you will increase the acceleration if the mass stays the same.” These last three categories were coded only if the student has a value of 3 or higher in the “Justification” column. Justification codes other than 3 or 4 do not support the criterion of these three categories, and thus, these categories were not coded if the Justification code was 0, 1, or 2.

Validity – The science concept cited correctly or incorrectly governs the event cited.

Form – The event is categorized by the form of science justification the student chooses to justify a design choice, decision, or response: Phenomenon, Concept, Principle, or Concept/Principle. Events can cite science in many ways. When students cite science at the 3 and 4 level, they demonstrate a more robust conceptual understanding, and I contend that their level of reasoning is more advanced. In both assignments, coding for this category reveals depth of science content knowledge. The results, also, offer a glimpse at why students might demonstrate higher transfer on the Antarctica Car Recommendation in their Justification coding. If their conceptual understanding is more advanced, then perhaps their ability to transfer is higher.

Phenomenological Observation

1 – The student only states the phenomenon observed that is related to the design issue or problem. The event qualifies as a science justification because the

student uses science verbiage, but clearly does not intend the actual meaning of the concept.

-or-

The student approaches it from a design or fabrication standpoint, not really discussing science but rather engineering.

Concept

2 – The student only states the concept (*term*) related to the design issue or problem only.

Principle

3 – The student only states the principle related to the design issue or problem, without stating the concept (*term*).

Concept and Principle

4 - The student states both the concept and the principle related to the design issue or problem.

Depth – The event is categorized by the manner or style in which the student refers to the science principle involved in the design choice, decision, or response: Applied, Abstract, or Applied and Abstract. Events coded at the 2 and 3 level indicate that students are able to generalize about the concept involved, yet they are also able apply it well within the context before them. Events coded at the 0 and 1 levels may indicate that students only see the concept at a surface level. Much like the Form category, the results reveal depth of conceptual understanding, which serves as the underpinning and motivation to reason with science and to perform transfer.

No Depth

0 – Student only states the Concept (term, science word) or phenomenological observation with no discussion or supporting points about it.

Applied

1 - The student states the principle only as it applies to the design issue or problem with in context.

Abstract

2 – The student states the principle abstractly only, implying that it is related to the design issue or problem.

Applied/Abstract

3 – The student states the principle both abstractly and as it applies to the situation explicitly.

Student Number	Event	Curriculum Target	Justification	Validity	Form	Depth
62201403	1	1	3	1	2	1
	2	1	3	0	2	1
	3	1	1	-	-	-
	4	1	3	1	4	1

Figure 3-D: A completed coding sheet from a coded Product History Report.

Because the Antarctica Car assignment differs from the Product History, the coding approach is altered a bit. Students were granted the freedom to explore all kinds of ideas regarding the design of the Antarctica Car. The aim of this freedom was to see if students would transfer their science content knowledge into new design features that were not directly encountered in the VIM experience. However, the flip side of this freedom is that students will discuss design features that are important to an Antarctic explorer but do not focus on the science content from the VIM unit. For example, if an event suggested that the material of the vehicle be made of polished aluminum because it would be reflective in the sun to aid search planes rather than being lightweight, then the event would not be coded. In contrast, another student could discuss the lightweight aspect of the materials suggested, and this event would be coded. Students might discuss the need for a diesel engine because it works well in cold weather, but they may not discuss the force this type of engine provides. On the other hand, some students would discuss the force and acceleration issues of a diesel engine idea. The shift in

coding for this assignment is to focus upon events that discuss design features that **are** rooted in the science content from VIM.

Reliability

The coders (author and two independent coders) in this study achieved good reliability. Each coder, familiar with the science and premise of the study, trained with the coding scheme during three sessions. Each coder received a sample of events equaling 25% of the total number of events coded. The events making up the sample were randomly selected from each of the three teachers. For the Product History assignment, reliability between coders ranged between 76% – 100% (average reliability = 91%). For the Antarctica Car Design Recommendation assignment, reliability between coders ranged between 70% – 100% (average reliability = 85%). See Tables 3-1 and 3-2 for reliability results.

Table 3-1: Reliability of Independent Coders with Researcher for Coding Scheme Categories on the Product History Assignment

	Curriculum Target	Justification	Validity	Form	Depth
Independent Coder #1	100%	90%	100%	86%	76%
Independent Coder #2	100%	92%	100%	82%	86%

Table 3-2: Reliability of Independent Coders with Researcher for Coding Scheme Categories on the Antarctica Car Design Recommendation Assignment

	Justification	Validity	Form	Depth
Independent Coder #1	89%	97%	70%	76%
Independent Coder #2	91%	100%	77%	83%

Data Analysis Method

Once the data artifacts were completely coded, the events were first grouped by teacher. Then, the total counts (i.e.-total number of occurrences) for each classification in a coding category (i.e. – Justification as 0, 1, 2, 3, or 4) were tabulated for each teacher. Null-hypotheses were that there would be an even distribution of events in each classification of a category across teachers. That is, there was no predictable relationship between teacher treatment and category classification distributions. Because the data are non-parametric, chi-square analyses, where expected frequencies are compared to observed frequencies, was most appropriate (Shavelson, 1981). If the chi-square value of the two-way analysis (Teacher x Category Classification) for any category is higher than the critical value, then the null-hypothesis can be rejected. If the probability associated with the chi-square test value is less than 0.05, then the test would be considered statistically significant and the null can be rejected. The chi-square analysis was performed for T1 v. T3, T2 v. T3, and T1 v. T2 across each of the coding categories for both written assignments.

Chapter 4

This Chapter details the results of the study. The first portion of this Chapter details the observations of teacher implementation of the treatments in their classrooms (qualitative results). The second portion provides the data analysis of the coded written assignments (quantitative results).

Qualitative Results

These results are the summary of the observations made during the implementation of VIM in the classrooms of each of the participating teachers. I anticipated (hypothesized) that the actions and role of the teachers in each of the treatments could have an effect on the quantitative results of the written assignments. While I provided each teacher a guide for implementing his/her respective treatment, variations occurred. A record of where and how those differences manifested is provided here. Remember that each teacher participates in the sequence during each of the four modules. This reporting of qualitative results are generalizations, or summaries, of the teacher actions and roles aggregated from all four modules.

There is one interesting, unexpected aspect of these results. Despite receiving similar training and guidance, the two experimental teachers differed in their actions and roles as they progressed through the modules. Their treatments varied from each other and may have some correlation to the differences in quantitative results. Figure 4-1 summarizes teacher fidelity to the prescribed treatment mapped over the LBD Sequence. In Figure 4-1, the “---” symbol indicates where a teacher alters the experimental treatment.

While T1 and T3 implemented the treatment as prescribed, T2 either made changes or left out portions of the treatment. T2's alterations, however, did not constitute the implementation of the comparison treatment. There are steps where T2 implements the prescribed treatment in the same way that T1 does (e.g. – Steps 5, 9, and 13); however, there are steps where T2 mimics T3's treatment (e.g. - Steps 6 and 7). At other times, T2 implements an altered version of the experimental treatment that does not mimic or match either T1's or T3's (e.g. – Steps 8 and 10).

Likewise, T1 enhanced certain aspects of the treatment, not changing the content or timing of intervention, but rather the depth of discussion and scaffolding. While the experimental treatment prescribed such actions, T1 carried them out to a higher degree than anticipated. The specific steps where alterations occurred (in bold in Table 1-1) are described in greater detail in the pages following Figure 4-A. The sum of these actions may correlate to the quantitative results for each student group, and Chapter Five discusses this potential correlation and its potential meaning.

Step	LBD Sequence (Treatment)	T1 Experimental	T2 Experimental	T3 Comparison
1.	Challenge Introduction	•	•	*
2.	Build & Mess About	•	•	*
3.	Whiteboarding Session	•	•	*
4.	Design Experiments.	•	•	*
5.	Conduct Experiments	•	•	*
6.	Poster Session	•	---	*
7.	Design Rules Presentation.	•	---	*
8.	Science Instruction	• +	---	*
9.	Conduct More Experiments	•	•	*
10.	Poster Session II	•	---	*
11.	Plan Final Design, Pin-Up Session	•	---	*
12.	Build & Test, Gallery Walks	• +	---	*
13.	Final Presentation	•	•	*
14.	Review Challenge, Whiteboard	• +	--	*
15.	Assessment	•	•	*

Legend

•	Teacher implemented experimental treatment
• +	Teacher implemented and enhanced experimental treatment
---	Teacher altered experimental treatment
*	Teacher implemented comparison treatment

Figure 4-A: LBD/VIM Sequence – Teacher Implementation Fidelity

Step 6 Summaries

Step	LBD Sequence	Experimental Treatment Additions
6.	Poster Session Students conduct a Poster Session to present their experiment(s) to the class. Each group prepares a Design Rule.	

Step 6 Summary of T1 – Experimental Teacher

T1 required students to create detailed posters of their experiment(s). They were required to explain what variable they were testing, to display the data they collected, and to write a conclusion to their experiment and a Design Rule. As the unit progresses, students have a cache of knowledge from which to draw to explain aspects of the vehicle's motion and the Design Rules they create. Regardless of their level of knowledge, T1 would have students follow the template, suggested during the training, for stating their Design Rule:

When (describe the action, design, or choice you are working within),
use/connect/build/employ/measure (list your suggestion or method)
because (list or supply the science principle or concept here that backs up your suggestion).

Step 6 Summary of T2 – Experimental Teacher

T2 always required students to explain the variable they were testing, to explain how that variable was altered on the vehicle, and to display the data they collected during a Poster Session. For T2, the final requirement for the student groups was to provide a *recommendation*. This recommendation was **not** a Design Rule, but rather a design suggestion for making the car perform better. At this point in the sequence, this is more in line with the comparison treatment.

Step 6 Summary of T3 – Control Teacher

Upon the completion of the experiments, each group reported its findings to the class. As in all LBD classes, including T3's, the members of the class scrutinized the experimental methods. If the class verified that the experiment was well run and that proper steps were taken to measure outcomes and control variables well, then the group's findings were considered valid. If the group revealed errors in its experiment, then the class asked the group to repeat its experiment and obtain valid information. T3 required students to explain the variable they were testing, to explain how that variable was altered on the vehicle, and to display the data they collected.

Step 7 Summaries

Step	LBD Sequence	Experimental Treatment Additions
7.	Design Rules Presentation Presenting group generates a Design Rule regarding their variable to help students plan future designs. Design Rules is recorded.	Experimental class participates in Design Rules Session, where all of the Design Rules are reviewed and discussed. Students record Design Rules on the <i>My Design Rules</i> sheet, knowing that it may be edited later.

Step 7 Summary of T1 – Experimental Teacher

After students had completed their initial round of experiments and stated their suggested Design Rule (or no Design Rule if their experiment was inconclusive or invalid), T1 had each student record the suggested Design Rule on the *My Design Rules* sheet (see *Appendix, pp. 1*). After all the student groups finished presenting their posters and experiments, the entire class reviewed T1's overhead transparency of the *My Design Rules* sheet. Students then could review their *My Design Rules* sheets to verify that they had recorded all of the Design Rules correctly. Then, the entire class reviewed and discussed the *Why the Rule Works* column for each Design Rule recorded. T1's students

were not always equipped to explain why the rule worked, because they had not yet been exposed to the science of the unit. Figure 4-B is a recreation of a student's *My Design Rules* sheet from early in the Coaster Car module.

Source	Design Rule	Why the Rule Works	How to Use Design Rule
Coaster Car, 11/3	Axles must be parallel so the car will go straight.	Friction?? Not sure really.	
Coaster Car. 11/3.	Axles should not move excessively side-to-side within the bearing.	Bolts (axles) are threaded and act like screws so they move to the side.	Make sure there's room for the bolt to move, but not too freely.
Coaster Car. 11/3.	Tape should be secured to chassis.	Loose bearings allow axles to move.	Tape bearings securely.

Figure 4-B: T1, 6th Period Student, Coaster Car My Design Rules Sheet

Step 7 Summary of T2 – Experimental Teacher

T2 deviated from the prescribed experimental treatment at this point. T2 felt that students would not be prepared to develop Design Rules and justifications for the Design Rules having not explored the science behind them. Students would record in their journals, but not on *My Design Rules* sheets, the experimental recommendation of each group. The following are some Coaster Car examples from T2's class:

- Use the straw bearings rather than block.
- Make the bearings wider than the chassis.
- Blocks over (straw) bearings make it stronger.
- Put chassis up top, making bearings and axles on bottom.
- Make bearings as long as possible without touching hex-nuts.
- Keep wheels nice and tight.
- Make sure axle is free of tape.
- Measure (distance traveled) from front, (but) let go from back (end of car).

During every module, T2 wanted to get to the science and to have students conduct another round of experiments before the students started to generate Design Rules and attempted to justify them.

Step 7 Summary of T3 – Control Teacher

At the end of the Poster Session, the final requirement for the group was to provide a Design Rule that the other groups could follow or use when making a design decision. The following list displays actual Design Rules supplied by students from T3's class for the balloon car module.

- 3 engines push more air out increasing the distance.
- 3 balloons provide more force giving more distance.
- 3 cup tower because gets balloons off the wheels.
- 3 straw exhaust will increase acceleration
- More air in the balloon → more distance.
- Longer straw → further car will go.
- Place engine on top of the cup to keep the balloon from touching wheels and causing friction.
- 3 exhausts (straws) release more air to get initial acceleration.
- Angle of exhaust should be upwards because data showed more acceleration.

As students supplied their Design Rules, T3 would be recording the Design Rules seated at her desk. Later that evening or the next day, T3 would create a complete list of Design Rules generated during the experiments for the entire class. At no time during this process would the students record their Design Rules in a journal or design diary page. Other than having students write their own Design Rules on their presentation poster, the Design Rules were not recorded by individuals at this stage of the module. T3 would record all of the Design Rules each class generated during the presentation day(s) and would save the list for use later.

After a group stated its Design Rule, the other students were permitted to ask for clarification or further explanation. Sometimes, T3 would ask the group to explain how a particular science concept might be related to its Design Rule. Most of the

experimental variables that students investigate in the curriculum do relate to target science concepts. T3's student groups would attempt to relate their findings to a science concept. Success at this would depend upon the group's knowledge or the level of difficulty of the related science concept. At times, students would need guided questioning or help from seated classmates to find the link. Other times, no link was established. In the latter moments of a group's poster session, T3 would try to have a discussion or ask for an explanation of how a science concept was related and why the Design Rule would be helpful. The following is a transcript of students interacting with T3 during their poster session late in the VIM unit about the science concept related to their Design Rules.

T3: *(After T3 reads all the Design Rules)*, Why does more weight make the car go slower?

Student: Uhhh, because it is harder for them to push

T3: Harder for what to push?

Student: The rubber band.

T3: Push on what?

Student: The ground.

T3: The ground? The rubber band pushes on the ground?

Student: No, on the wheels....the axles! OK, so the more weight makes more pressure for the rubber to push on the axle.

T3: Ok, so what law are we talking about?

Student: Newton's.

T3: Which one? *(jokingly)* You've got a 30% chance of getting it right.

Student: *(laughing)* Alright, ahh the third one.

T3: If you increase the mass, not changing force, you decrease the...?

Student: Acceleration!

T3: Now, which law is that?

Student: Third.

T3: What is the Third Law? What does it say?

Student: Ahhhhh....um...

T3: For every force...

Student: There is an opposite and equal size force.

T3: Is that (*pointing to the Design Rules on their poster*) Third Law?

Student: No, it's Second Law.

T3: Why is it Second Law?

Student: (*Not really knowing what to say*) Because it is saying that.... (*long pause*)...um..

T3: I am just trying to get you to say in one sentence what you've told me in about ten.

Student: Okay, alright, ask the question again.

T3: Why is this (*pointing to the Design Rules on the poster*) Second Law? Why is it if you increase the mass, you'll decrease the acceleration on this car, why is that Second Law?

Student: Because the more mass that you add, the slower.

T3: I'll take that.

This exchange was typical of how students were afforded the opportunity to bridge the science to the design, but they were never actually mandated to establish really

explanations. Students were not required to write these links down on *My Design Rules* sheets, nor were they told that they would be expected to establish links in other contexts. T3 *would* discuss, at a later point, the science principles more in depth as a separate activity. Students would see and participate in a demonstration or view a video to see the concept in another context. These moments in T3's class are described in greater detail later in the Step 8 Summary. The point to be emphasized here is that students spent limited time discussing the related abstract science principle, and they never recorded these thoughts during Design Rules discussions.

T3 would not discriminate as to which Design Rules she included in her list. She felt that the students would need to decide which Design Rules were relevant and worthy of their attention, and she made this decision in the name of "inquiry teaching". T3 determined that this was one method in which students could construct their own learning experiences. Sometimes, the Design Rules were fabrication issues, mechanism setting issues, and even invalid pieces of advice. This is a list of some of the Design Rules developed in T3's class:

- Use a j-post because it is easier to use than an x-post.
- Use thin string because it does not tangle → gives the car more distance.
- Use only 2 rubber bands because if you have a lot of knots in a chain of rubber bands the knots get caught on the chassis screws.
- Block bearings work to keep out friction.
- Change engines frequently (every 3 uses) if a drop in distance is observed.
- Too many engines cause obstructions in engine itself. Use no more than 2-3 engines to provide more distance.
- Straw length did not show much difference in distance (let out the same amount of air)
- Longer straw → further car will go.
- Data showed greater distance with clear type straws.

- Use a long straw because shorter deflates balloon faster.

Step 8 Summaries

Step	LBD Sequence	Experimental Treatment Additions
8.	<p>Science Instruction Student primed for learning science related to their activities, the teacher moves into discussing science principles underlying the module. The teacher utilizes demonstrations, short investigations, mini-lectures, the textbook, and homework to focus on a specific science concept. For example, classes working with the Coaster Car will research “What is a force?”, “Friction”, and “Newton’s First Law”. They participate in a combination of activities to develop an understanding outside of the context of the Coaster Car.</p>	<p>The experimental class formulates some early Design Rules based on their experiments, the class’s attention is focuses on the science issue at hand. The teacher emphasizes and models science talk: Rephrasing students’ answers and asking students to rephrase answers using the science vocabulary. Teacher emphasizes heavily the relationship between the abstract science principles and the examples students have generated, even referring the car often in explanations.</p>

Step 8 Summary of T1 – Experimental Teacher

In the LBD sequence, after experimentation, the next step is to closely examine the science issues upon which a particular module focused. For example, the balloon car module highlights Newton’s Third Law of Motion. These engines demonstrated this principle and also allowed students to begin looking at Newton’s Second Law of Motion. During these class periods, all LBD teachers would perform demonstrations and use information from the LBD textbook, short activities and assignments from district-supplied materials, and mini-lectures to *teach* the science principles. As in most LBD classrooms, T1 would cap the day(s) by having students find, sketch and explain examples of the principle from real life situations. T1’s intention for these days was quite clear. She wanted student to see a variety of examples and applications of the science principles highlighted by the module.

One unique aspect of T1's implementation was how she used and expected science talk. During "science day(s)", T1 often explained or discussed the science principles repeating the pattern and content of the template. If T1 performed a demonstration, she would perform the demo and ask student to propose explanations for what they had just witnessed. Students, not being as well versed in explaining everyday events with abstract language, would use casual and less precise wording. These explanations could be characterized as 'getting at the right idea', however, the students did not attempt to relate the event to a more abstract idea. Often, the students could not provide (or were unaware of) a bridge between the context and the abstract. T1 patiently would guide and model this bridge for her students. Often when students added to the discussion, T1 would ask them to rephrase or explain their thoughts "using the science we've been talking about". Review the following transcript where T1 asks for an explanation that centers around the science they have been learning: T1 has the class looking over some of their design ideas after discussing friction and Newton's First Law, specifically how objects under the influence of net force will change their motion. Student Z has asked why many of the groups are using CDs for wheels. Another student attempts an answer, but it is a very surface level answer and is not rooted in science. T1 asks other students who have chosen the similar design choice to offer some explanations.

T1: Can anybody give me a bit more, scientifically, for why you might choose those wheels? Yes, (Student X), go ahead.

Student X: We chose these wheels because we learned that friction changes the motion of the car. And what we want is for the motion to be changed as little as possible so our car will keep

coasting along as far as it can go instead of being slowed by the friction between the wheels and the ground. These wheels have a smaller surface area touching the ground. Plus, if there are, um, wheels that are wider, then more wheel is touching the ground, then there's going to be more friction than when they are thin.

T1: Why?

Student X: Because of what friction is.

T1: So, what is friction?

Student X: It is the force from contact between two objects, like rubbing together, and the friction here is pushing opposite the way you want the car to go. So, if the car was rolling this way (*points to the right*) then the friction would be this way (*points to the left*).

T1: OK, good. (Student Z), does that answer your question?

Student Z: Yes.

Step 8 Summary of T2 – Experimental Teacher

T2 also would perform demonstrations and use information from the LBD textbook, short activities and assignments from district-supplied materials, and mini-lectures to *teach* the science principles. Then, she would cap the day(s) by having students find, sketch and explain examples of the principle from real life situations. T2's approach to this was different than anticipated or prescribed. In pre-study observations, T2 seem to value the understanding and communication of abstract issues in science teaching. T2 taught high school biology teacher for several years, and T2 expressed to our research team that she indeed was looking to raise the bar at the middle school level. T2 felt these students needed rigorous expectations for science content knowledge, and she wanted to change the level of discourse about these topics with the students in her classes.

Often during these days of science discussion, T2 would model science talk, but rarely asked or expected students to engage in it. As an example, students were discussing a demonstration where T2 had strung a piece of string across the classroom. Attached to the string were two straws, one at each end. The straws were different sizes, with one resting loose around the string and the other somewhat tighter. T2 applied a force (a simple “flick” of the finger...assumed to be the same amount of force delivered to each straw), and the straw would traverse down the string. The tighter straw traveled only 1/4 the distance the loose straw traveled. Review the transcript of an exchange following this demonstration in which students were permitted to answer freely and aloud.

T2: What is the difference between these two straws that might lead to this outcome?

Student: The “tighter” straw was gripping the string and this slowed it down faster.

T2: What specifically was slowing the straw down?

Many students: Friction!!

T2: What is friction? What type of thing is “friction”?

Many students: Force!

T2: What direction does this friction produce a net force in?

No answer...T2 rephrases the question

T2: What direction does the friction act on the straw as it travels forward?

Student: Backwards.

T2: Can “backwards” friction create or add to the net force also acting backwards?

Many students: Yes.

T2: How does changing net forces affect the motion?

Student: This change in net force will slow the straw down?

T2: Which of Newton's Laws explains this?

Many students (simultaneously): First Law...Second Law.

T2: Let's review the two laws...remember First law says that if you change the net force acting on an object, the object will change its motion...if you do not change the net force on an object, its motion will continue as it is. Second Law discusses how acceleration and mass are related to the net force on an object... for example, if you change the mass, the acceleration is going to change if the net force on the object stays constant. So, which Law matches what we are talking about here with the straws. Are we changing net force or are we looking at changing the mass and acceleration of the straws?

Many students: The net force!!

T2: So, which Law?

Many students: First Law.

This type of exchange and discussion took place not only during science instruction days. It occurred with most teacher-provided examples of a concept, demonstrations, students-derived examples, and of course, with the discussion of changes in car design.

During some of the modules, T2 would have students find their own examples of the principle from real-life experiences or events they had witnessed. As in many other LBD classes, the students would sketch the event and describe how the principle was related to it. The entire class would discuss the examples collected, and T2 would allow all students to add to the knowledge being created. The discussion of these

examples, however, would follow the same pattern described in the previous transcript where T2 did most of the *science talking*.

Step 8 Summary of T3 – Control Teacher

T3 closely examined the science issues upon which a particular module focused. The whole class reviewed and discussed the examples, with T3 stating how each example demonstrates the principle specifically. The typical conclusion to this discussion included T3 stressing how science knowledge and consideration of the science principles might influence their design decisions for the students' cars. Again, T3, not her students, engaged in science talk, a majority of the time during these days, and students rarely asked questions or contributed to the knowledge.

Step 10 Summaries

Step	LBD Sequence	Experimental Treatment Additions
10.	<p>Poster Session II Class conducts another Poster Session; groups suggest more Design Rules. Note: <i>Depending on the complexity of the design changes in a module, steps 7-10 maybe repeated</i></p>	<p>Experimental students once again discuss and deliberate over Design Rules as a class. This time the class is more prepared to fill in the <i>Why the Rule Works</i> column because of their exploration of the module's science concepts. Often, teachers will reword student justification or explanation (rephrasing as a question) to model the use of abstract decontextualized justification or explanation. The teacher models science talk both in discussion and when writing Design Rules. If steps 8-10 are repeated, a Design Rules Session occurs, and the <i>My Design Rules</i> sheet is edited.</p>

Step 10 Summary of T1 – Experimental Teacher

T1's students' phrasing of their Design Rules in the latter portion of the unit almost always resembled the pattern of the template. As the unit progressed, some

students autonomously dissected the Design Rule being presented during the Poster Session and recorded its elements in the appropriate columns of the *My Design Rules* sheet. Again, T1 reviewed each of the Design Rules presented during the Poster Session, and the class discussed the science at length. The following transcript exemplifies how students attempted to apply their science knowledge and debate the science amongst themselves during a Poster Session. Students were working in *Rubber Band Car*, and a group was presenting an experiment and suggesting a Design Rule from its results.

T1: So you said, using more rubber bands in a chain increases the distance the car travels? [*students nod 'yes'*], do you have any idea why?

Student R: Since it is a longer chain, you are able to (wind) the wheels back more, and since you do that, it creates more rotations in the wheels which makes it go further.

T1: Ok. So you are saying that the Rubberband is wound around the axle more times...can you talk about it more in terms of science? In science terms what does that tell you?

[*Long pause*]

Student S: That there is more force?.

T1: Does it increase the force? Winding it around more, does that increase the force?

Student U: No, it stays the same. It's the same force its just for longer.

[*Many students agree and disagree at once*]

Student T: Well, if you think about it the force just lasts longer. If you have just one rubber band it increases speed but then it stops. If you have more (rubber bands) then the speed will just keep rising.

Student R: So, it gives it more time to increase the speed?

Student T: Yeah, and it's going to reach higher speeds.

Student U: It has the same amount of force, but since (the chain) is longer, it has more time to accelerate.

T1: Ok. [*T1 records Student U's statement on the overhead in the Why the Rule Works column of the My Design Rules sheet*]

During this step, T1's classes always revisited and reviewed the Design Rules proposed previously. Armed with greater knowledge of the science concepts, students edited (actually crossed out or marked-up) the invalid or misstated Design Rules on their *My Design Rules* sheets. T1 also edited the class version of the *My Design Rules* sheet (overhead transparency). During these edits, the class and T1 discussed the science concepts and debated the best phrasing or wording of the Design Rule in question. Figure 4-C is a recreation of a *My Design Rules* sheet from a student in T1's class.

Source	Design Rule	Why the Rule Works	How to Use Design Rule
Coaster Car, 11/3	Axles must be parallel so the car will go straight.	Friction??	
Amended Coaster Car, 11/10	Axles must be parallel so the car will go straight.	<i>When axles (are nonparallel) there is an increased friction between the wheel assembly & chassis which slows car, turns the car.</i>	
Amended Coaster Car, 11/15	Axles must be parallel so the car will go straight.	When axles (are nonparallel) there is an increased friction between the wheel assembly & chassis which slows car, turns the car changes the motion of car.	
Coaster Car, 11/3	Axles should not move excessively side-to-side within the bearing.	Bolts (axles) are threaded and act like screws so they move to the side & create friction between the wheel assembly & chassis or bearings.	Make sure there's room for the bolt to move, but not too freely.
Amended Coaster Car, 11/10	Axles should not move excessively side-to-side within the bearing.	Bolts (axles) are threaded and act like screws so they move to the side & create friction between the wheel assembly & chassis or bearings.	Make sure there's room for the bolt to move, but not too freely.
Amended Coaster Car, 11/15	Axles should not move excessively side-to-side within the bearing.	Bolts (axles) are threaded and act like screws so they move to the side & create friction between the wheel assembly & chassis or bearings <i>which changes the motion of the car.</i>	Make sure there's room for the bolt to move, but not too freely.
Coaster Car. 11/3.	Tape should be secured to chassis.	Loose bearings allow axles to move.	Tape bearings securely.
Amended Coaster Car, 11/10	Tape Bearings should be secured to chassis.	Loose bearings allow axles to move & create friction between axle & bearings which causes slows rotation of axle → slows down car & reduces distance	Tape bearings securely.
Amended Coaster Car, 11/15	Tape Bearings should be secured to chassis.	Loose bearings allow axles to move & create friction between axle & bearings which causes slows rotation of axle → slows down car & reduces distance affecting the motion of the car.	Tape bearings securely.

Figure 4-C: T1, 6th Period, Coaster Car

Another note of interest, it seems that T1's classes tend to conduct at least 3 rounds of experiments in each module, which means that the students are developing their Design Rules more often than I anticipated. During a teacher interview that year,

T1 confirmed that she liked to have the students engage in the experiments often, but that she expected efficient experimentation and use of the time.

Step 10 Summary of T2 – Experimental Teacher

After the second round of experiments, the groups suggested Design Rules for the first time. After a group stated its Design Rule, the other students asked for clarification or further explanation. Once all student groups had stated and discussed their Design Rule, T2 displayed an overhead transparency of the *My Design Rules* sheet. T2 supplied each student with a journal. It was the choice of teacher T2 to have students keep all of their work in a journal for each module of VIM. In each module's journal, a student would have 3-4 blank *My Design Rules* sheets. Each member of the class would record the Design Rules on his/her *My Design Rules* sheet. T2 would take the time to discuss the science behind the Design Rule. Students would attempt to fill in the *Why the Rule Works* section of the *My Design Rules* sheet. The class would discuss the science principles behind the rule. Figure 4-D is a recreation of Design Rules from T2's 4th period class during Balloon Car.

Source	Design Rule	Why the Rule Works	How to Use Design Rule
1 cup did not go as far as 2 cups (tower).	2 cups work better than 1 cup.	Balloon cause friction with ground. Raising balloon takes away friction.	Use 2 cups.
Cups not on the back cause balloon to drag.	Put cup at the back of the chassis.	Balloon cause friction with ground decreasing (positive) net force. Raising balloon takes away friction increasing (positive) net force.	Put cup on the back.
Small straws don't make car move.	Use big (diameter) straws.	Decreases friction in the straw, increases the net force.	Use big straws.
Balloon pops	Don't over-blow balloon.		
Large balloons went slow.	Use 2 small balloon.	Rubber has more force on air, increases net force.	Use small balloons.
Car won't move	Put exhaust straight.	Puts the propulsion force in straight path.	Place engine with exhaust straight back.

Figure 4-D: T2 – 4th Period, Balloon Car Design Rules

The discussion of the “*Design Rules*” and the “*Why the Rule Works*” column followed the tempo and style of the science talk discussion described when the class explored the science content of the module (described in T2’s Step 8 Summary). Students rarely articulated, nor were they asked to articulate, complex answers utilizing abstract language. Review the following transcript from a Design Rules session during the 4th period class that developed the Design Rules featured in Figure 4-D. T2 has displayed the Design Rule a groups suggested on the overhead, and the students have their journals open to the *My Design Rules* sheets.

T2: So (the balloons when inflated) are hitting the chassis, or some people say that they are hitting the ground. [*Pointing to a Balloon Car assembled on the demo table*] So, if I were to blow (this balloon) up, what would be some of the problems?

Student K: The balloon would cause friction because it’s rubbing the ground.

T2: It's going to have friction and what's friction going to do to your net force?

Student H: It's going to slow it down.

T2: It's going to lower your net force. So, to explain this one [*walking to the overhead to record something*], what can you tell me in one sentence?

Student M: It cause friction with the ground and wheels.

Student O: It causes unwanted friction.

T2: [*reading aloud what she writes on the overhead*] Causes friction with the ground, decreasing net force. [*later adding*] Raising balloon takes away friction, increasing net force.

Here, T2 is formulating the science talk and explanation using verbal cues from her students, while the experimental treatment advocates just the opposite to occur.

Throughout the unit, T2 deviated from one particular aspect of the experimental implementation model. In the training sessions, experimental teachers were asked to use the following template to help students phrase their Design Rules:

When (describe the action, design, or choice you are working within),
use/connect/build/employ/measure (list your suggestion or method)
because (list or supply the science principle or concept here that backs up your suggestion).

Teachers were told that they could employ their preferred method of teaching the template idea to the students. Teachers even could alter the template if they determined that student needs required it. However, whatever final template was employed, attention to the abstract science principle must be a part of it. Despite this guidance, T2 was never observed employing the template. During a follow-up interview, T2 explained that she felt when her classes reviewed Design Rules and discussed the science involved with

them, the students essentially engaged in the intended process of utilizing the template. She felt that students comments and explanations followed this pattern, and that scaffolding them any further was not necessary.

Step 10 Summary of T3 – Control Teacher

The same poster session procedures described in T3's step 7 were followed. T3 recorded Design Rules established during the second round of experiments. After T3's classes reached the point where they no longer were going to complete additional rounds of experiments (usually 2-3 rounds per module), T3 would compile and prepare a list of all the Design Rules created during the module.

Step 11 Summaries

Step	LBD Sequence	Experimental Treatment Additions
11.	Plan Final Design, Pin-Up Session Students review Design Rules, review experimental results and consult with other groups to plan final design designing the final car (or engine). Each group creates a Pin-Up (a sort of Blueprint of their final design idea.	None

Step 11 Summary of T1 – Experimental Teacher

T1 had students create Pin-Ups where the design idea was sketched/drawn very large. Students were expected to justify and explain their design choices using science concepts. Each unique, or significant, design feature would have a caption (2-3 sentences) describing the feature and how a science principle would predict successful performance. T1 asked students explicitly to use Design Rules to influence these justifications and explanations.

Step 11 Summary of T2 – Experimental Teacher

T2's students rarely returned to edit their Design Rules after discussing the science for the module. They would return to experimenting and designing with their cars. Students would rework poor experiments (revealed during the Poster Session), verify the experiments of others by investigating those variables themselves, and test the effects of new variables that had gone untested in the first round. The class reconvened to discuss the findings of its latest experiments and to revisit the Design Rules. Only toward the very end of the module, here in step 11, would T2 have her students review their previous Design Rules to edit the "*Design Rule*" and "*Why the Rule Works*" columns. The students also would continue to record new Design Rules in their journals.

Two interesting aspects of T2's implementation stand out. Toward the end of a module, many of the variables tested and described by a Design Rule have roots in the science of the module. At this point, T2 would convene the class to prepare for their final design. T2 would ask students to supply final, or edit prior, Design Rules, and the discussion pattern described earlier (in Steps 8 and 10) prevailed. T2 would model science talk but students did not supply it. While the discussion of "*Why the Rule Works*" was very rich, T2 *rarely* guided students to formulate the justification or explanation of something using abstract language. T2's approach was to have students attempt to do this, but she usually supplemented the statement(s) with the more abstract language. Furthermore, when students filled in the "*Why the Rule Works*" column, their statements were vague and/or very surface-oriented. For example, they would justify using multiple engines by citing that "more force means more acceleration", or they would just say,

“Newton’s Second Law”. These responses satisfied T2, and she too recorded them on the class copy of the *My Design Rules* sheet. The classes were citing science, but never at a deep level. Figure 4-E is a recreation of an amended version of the Design Rules described earlier in step 10. The italicized print indicates where students edited a previous/existing Design Rule.

Source	Design Rule	Why the Rule Works	How to Use Design Rule
1 cup did not go as far as 2 cups (tower).	2 cups work better than 1 cup.	Balloon cause friction with ground decreasing (positive) net force. Raising balloon takes away friction increasing (positive) net force.	Use 2 cups.
Double-balloon Test	Use double or triple balloon engines.	This increases the force acting on the car, <i>Newton’s Second Law</i> .	Double balloon the engines.
Cups not on the back cause balloon to drag.	Put cup at the back of the chassis.	Balloon cause friction with ground decreasing (positive) net force. Raising balloon takes away friction increasing (positive) net force.	Put cup on the back.
Small straws don’t make car move.	Use big (diameter) straws.	Decreases friction in the straw, increases the net force.	Use big straws.
Balloon pops	Don’t over-blow balloon.		
Large balloons went slow.	Use 2 small balloon.	Rubber has more force on air, increases net force.	Use small balloons.
Car won’t move	Put exhaust straight.	Puts the propulsion force in straight path, <i>Third Law</i> .	Place engine with exhaust straight back.

Figure 4-E: T2 – 4th Period, Balloon Car Design Rules

Step 11 Summary of T3 – Control Teacher

To prepare for the creation of their final car design within each module, T3 would create signs that each listed an experimental variable category. For example, the following are some categories from the Balloon Car module: Number of Engines, Number of Balloons per Engine, Number of Straws, Angle of Exhaust, Height of Tower, and Length of Straws. T3 would place these signs all around the classroom.

Every poster, detailing the experiments in all of her classes, were taped on the wall under the appropriate category. On another wall, the Design Rules lists generated by each class during the module were recorded on large posters (by T3) and were displayed.

Students opened to the *My Design Rules* page in their journals. Each student group would roam around the room reviewing the Design Rules and the experimental results. The students would then convene in their groups to decide which Design Rules were indeed going to be incorporated into their group's final design. T3's intention was to have students debate within their groups the Design Rules to eliminate weak Design Rules and to focus only on the most crucial ones. As the group created their final list, the students in a group were to fill in the *Why the Rule Works* column together.

T3 would stress the importance of this act to students with, "it is the reason why we are working with these cars in the first place...it's the science that's the most important for you to take away from this experience". Despite comments like this, at no time did T3 review Design Rules to discuss the *Why the Rule Works* connection to science principles. In their journals, students would record the Design Rules they wanted to incorporate into the design of their car. Figure 4-F is a recreation of a *My Design Rules* sheet from one student's journal.

Source	Design Rule	Why the Rule Works	How to Use Design Rule
4 th Period	(<i>Wide</i>) straws	Lets air out faster	(<i>Wide</i>) straws for the engine
6 th Period	Shorter straws	Gives more force	Cut 5 cm off straw
6 th Period	2 engines	To add more force and acceleration	Side by side 2 cm apart
5 th & 6 th Period	2 balloons per engines	Pushes air out faster	2 balloons inside one another
3 rd Period	90 cm. (<i>circumference of inflated balloon</i>)	More force	90 cm. of air bin balloon.
Our group	Change balloons every 5 times	Keeps the balloon tighter.	Change balloon every 5 times.
3 rd & 5 th Period	McD's straw	Lets air out good but not too much	Use McD's straws
6 th Period	2 cup tower	Not a lot of weight	Two cup tower
3, 4, 5, and 6 Periods	Engine on top	Farther away from wheels.	Put engine on top (<i>of tower</i>).
5 th Period	Angle of exhaust straight	Made car go farther	Put engine straight

Figure 4-F: T3 – 3rd Period Student – My Design Rules Sheet for Final Balloon Car

These students did see the opportunity and need to refer to science, but their use of the terms or concepts seems very superficial. In the above sample, the student refers to science in only 4 of the 10 opportunities. Furthermore, only the third *Design Rule* in the list attempts to justify a design decision in a generalizable manner.

During the Pin-Up phase, T3 would have each group highlight two items of note on its Pin-Up. One, a list all of the Design Rules the group planned to incorporate in its design. Two, an explanation of how the science the group had learned during the module was playing a role or was exemplified by its final design. The Pin-Ups' language resembled the language used in figure 5-6.

At no time during the development or review of Design Rules during each module did the class edit or rephrase the Design Rules created. T3 felt that students would be able to verify or refute Design Rules through their experience. She felt that

their final designs should reflect good or valid Design Rules and that poor or invalid Design Rules would fall victim to natural selection.

Step 12 Summary

Step	LBD Sequence	Experimental Treatment Additions
12.	Build & Test, Gallery Walks Groups build and test their design. Data is collected and Gallery Walks occur.	After redesign, students may verify Design Rules, or sometimes, they may discover flaws in their Design Rules. Once again, the teacher uses guided questioning and discussion (perhaps even more demos, science concept research, homework assignments) in an attempt to have students develop more valid Design Rules and better articulate science concepts within a context as evidenced by their Design Rules. This step highlights the priority and encouragement of an iterative development of science within the experimental classrooms. Also, again the teacher models science talk both in discussion and when writing Design Rules.

Step 12 Summary of T1 – Experimental Teacher

A glaringly apparent and unique aspect of T1’s classroom was the frequent engagement in science talk when discussing ideas or problems during the challenge. Repetition of the practice was not limited to “science” and “Design Rules” days only. During Gallery Walks (LBD practice where groups share information and ideas), T1 asked students to rephrase and expand upon answers and explanations to include abstract references. During pin-up sessions and build-and-test days, T1 structured the conversations in the classroom would be structured to include abstract principle referencing. As the unit wore on, there were instances where students would justify naturally, almost involuntarily, design changes and proposals citing science in a deep way. This format of justification was very common place in T1’s classroom, more than the researcher had been anticipated with the experimental implementation.

Step 12 Summary of T2 – Experimental Teacher

No points worth illuminating.

Step 12 Summary of T3 – Control Teacher

Once students identified their final set of Design Rules, they began designing and testing. They would continue to collect data on the performance of the design, but only as a measure of design choices, not for experimental purposes. If a group found that a design choice (rooted in a Design Rule) was poor in performance, they would no longer include that Design Rule in their design. Students would share design successes and flaws during Gallery Walks as they built and tested their designs, but there was never a formal amending of the Design Rules. In fact, the Design Rules were never visited again. This included Design Rules recorded in their journals. If the students found a Design Rule to be invalid or of no consequence, they did not amend it or discuss it. There would be science discussions on new topics and design features, but rarely was there a return to a Design Rule that would have an effect on the design challenge of the current module.

Summary of Qualitative Results

- 1) T1 (Experimental) implemented the experimental treatment with high fidelity. In fact, her engagement in the methods and strategies was at such a high level, it exceeded the expectations of the researcher. She frequently modeled science talk, engaged students in speaking and writing science talk, and had student edit their science talk during peer-feedback situations. T1 also expected students to engage in

science talk during moments of the sequence that were not dictated by the prescribed treatment.

- 2) T2 (Experimental) implemented what might best be described as a quasi-experimental treatment. T2 waited until late in each module to engage students in science talk, and it was usually teacher-centered. Students had discussions about the science, trying to link their Design Rules to the science; however, they never recorded these justifications and explanations in a deep manner. Furthermore, T2 did not employ the strategies and methods during each of the points in the sequence as instructed during training.
- 3) T3 (Comparison) implemented the comparison treatment as anticipated. There was no significant reliance on Design Rules to make connections to the science. Even when students afforded her the opportunity (see the transcript on pp.88-89), T3 did not provide the scaffolding and iterative development of the connections that the research literature suggests in necessary.

Quantitative Results

These quantitative results provide a summary of the coded results for the Product History Report and the Antarctica Car Design Recommendation for all three participating teachers. Recall that one of the teachers, T4, dropped out of the study during the first third of the curriculum due to severe illness. The results of coding the Product History Reports are first, followed by the Antarctica Car Recommendations. The reporting of results for each assignment is divided into two smaller sections, as the coding was completed in two stages. The first section reports the results from coding the Events, Curriculum Target, and Justification categories. Then, the second section reports results from coding only the events that scored a “3” in the Justification category. The results for Validity, Form, and Depth comprise the second section. The purpose of the coding categories was to classify and categorize the events and their characteristics presented in the assignments collected from each teacher. Included in some of the presentations of these categories are the rates of occurrence for each teacher. This percentage of occurrence helps to reveal how frequently experimental and comparison students discussed in their written assignments:

- Design features that reference or cite science.
- Form of the science references. Did the student only use the science term (*e.g.- friction*) or did they provide a deeper explanation of the term within the reference?
- Level of abstraction or generalization in the references to the science concepts. Did the student justify or explain design features via the science concept in an applied manner or more abstractly?
- Transfer of science content knowledge and reasoning skill into new, novel situations.

Brief descriptions of each coding category are, once again, provided, however, Chapter Three provides greater detail about each coding category and its assignment criterion.

In a limited number of teacher comparisons in some of the categories, the category classification results yield expected frequencies lower than 10, with $df = 1$ or less than 5 with $df \geq 2$. One accepted practice is to collapse classifications of a category (i.e.- collapse classifications 'Events coded as 1' and 'Events coded as 2'). As a result, the researcher combined expected frequencies of different classifications are combined, and this raised the expected frequency of the newly formed classification ('Events coded as 1 or 2'). Of course, this option is only appropriate and available if the collapsing of the classifications can be justified and reasonable. In these results, where collapsing occurred, justifications are provided.

For some teacher comparisons, in a limited number of categories, expected frequencies were too low and collapsing was not an option. Thus, one assumption of the chi-square test is violated. Fortunately, where this occurred, there are little differences between the measured outcomes for the two teachers in that specific category. Therefore, it is not necessary to weigh the importance of differences, via a chi-square analysis, that **do not** exist.

Finally, in the Form category, events coded as '1 – Phenomenological' were eliminated from the analysis. According to the protocol of the coding rubric, it would initially appear that students used 'science' to explain or justify these type of events. Upon a deeper consideration of the event (coding for Form and Depth), the literal scientific meaning of the term was not intended. However, there is no way to tell if the

student actually believed they were explaining or justifying the event with science in this manner. Thus, by default, one must assume that they were 'using science'. Therefore, these few events are being counted as '3' events in the Justification coding, but they were eliminated from the data reporting and analyses in the Form and Depth categories.

Product History – Category: Event

An Event is a student-supplied description of a design idea, design application, problem, or solution that provided an opportunity for a student to justify or explain the issue further. The events-to-assignment ratio is calculated to see differences between students with regards to the number of events, on average, students chose to discuss in the assignment. T1 students provided more than twice as many events per assignment than T2 and T3 students did. Table 4-1 displays the ratio for each teacher.

Table 4-1: Product History, Event Coding

Product History Assignment	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Total Assignments Collected	78	50	67	195
Aggregate Events in Assignments	804	224	305	1334
Events/Assignment	10.31	4.48	4.55	
Standard Deviation	2.52	2.13	1.58	

Product History – Category: Curriculum Target

This category determines whether the coded event centers on a science content issue targeted by the VIM unit. Examples include Newton’s Second Law, Friction, and acceleration. Some examples of non-targeted issues would be impulse, torque, and potential energy. During implementation, some non-targeted issues were discussed in each of the classes during the VIM unit, at the teacher’s discretion. The purpose of coding this was to show that the students in all three classes were citing events that related to the unit of study. If the events focused on widely differing science concepts, it would have been improper to compare the events between T1, T2, and T3.

The results in Table 4-2 show that students provided events targeted by VIM 95.8% (770 ÷ 804) of the time in T1's classes, 98.7% (221 ÷ 224) of the time in T2's classes, and 98.4% (301 ÷ 305) of the time in T3's classes.

Table 4-2: Product History, Curriculum Target Coding

Curriculum Target	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Non-Target – 0	34	3	4	43
Target – 1	770	221	301	1291
Total	804	224	305	1334

Product History – Category: Justification

The assigned code categorizes the way students choose to communicate and justify/explain the event. Table 4-3 displays the totals for this category.

- 0 – Justification/Explanation is implicit.
- 1 – Justification/Explanation rooted in opinion or design experience.
- 2 – Justification/Explanation rooted in data collected by student.
- 3 – Justification/Explanation rooted in science concept or principle.
- 4 – Justification/Explanation rooted in both science concept or principle and data collected by the student.

Table 4-3: Product History, Justification Coding

Justification	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 0	56	51	139	246
Events coded as 1	95	66	89	250
Events coded as 2	12	3	4	19
Events coded as 3	641	104	73	817
Events coded as 4*	0	0	0	0
Total	804	224	305	1332

*Since zero events were coded as “4”, the category was not included in the results reporting or the chi-square analysis.

Table 4-4 displays the occurrence rate of each **Justification** classification for each teacher. For example, T1 had 56 out of 804 total events coded as “0”. This translates into 7% of all T1 events qualifying as “0 – Justification/Explanation is implicit”.

Table 4-4: Product History, Justification, Occurrence Rates

Justification	T1 (experimental)	T2 (experimental)	T3 (comparison)
Percentage of events coded as 0	7%	23%	46%
Percentage of events coded as 1	12%	30%	29%
Percentage of events coded as 2	1%	1%	1%
Percentage of events coded as 3	80%	46%	24%

Because the expected frequency of “Events coded as 2” is less than 5 with $df \geq 2$, classifications ‘0’, ‘1’, and ‘2’ were collapsed. These codes represent students explaining or justifying events with something other than science, where as ‘3’ signals the use of science. Table 4-5 displays the post-collapse results.

Table 4-5: Product History, Justification, post-collapse

Justification	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 0 - 2	163	120	232	246
Events coded as 3	641	104	73	817
Total	804	224	305	1332

The chi-square analysis does support the rejection of the null-hypothesis for:

- 6) T1 v. T3, with $\chi^2(1, N = 1332) = 300.1, p < 0.001$
- 7) T2 v. T3, with $\chi^2(1, N = 1332) = 29.4, p < 0.001$
- 8) T1 v. T2, with $\chi^2(1, N = 1332) = 97.4, p < 0.001$

Section 2

The level of understanding and the value that a student places on his/her reference to science is coded by the next three categories: **Validity, Form, and Depth**. These three categories were coded only if the event was coded as a “3” in the **Justification** category. Also, for this study, the word “Concept” refers to the use of the *word or term* to reference the science concept, i.e. – “...because of Newton’s Second Law”. “Principle” refers to the use of an explanation or definition to reference a science concept, i.e. – “...if you increase the net force on the car, you will increase the acceleration if the mass stays the same.”

Product History – Category: Validity

This category determines whether the science concept cited in the event correctly or incorrectly governs the event. I completed this code to insure that I was not comparing a majority of events from one teacher where the science cited was mostly incorrect with events from another teacher where the science cited was mostly correct. This code only looks at the science citation at the surface level, that is, was the science concept cited actually related to the feature or problem? In almost every case, regardless of the teacher or treatment, the students cites the correct concept. The citation may not have been deep, demonstrating equal conceptual understanding, but it usually was the correct concept. This is supported by the fact that very few events were coded as 0-Phenomenological in the Form category. Because the percentage correct is so high for all teachers, a chi-square analysis was not needed.

The category is coded as 0 for incorrect and 1 for correct. The results in Table 4-6 show that students were connecting the correct science principle to the event cited 93% (or 592 ÷ 641) of the time in T1's classes, 87% (or 90 ÷ 104) of the time in T2's classes, and 92% (or 67 ÷ 73) of the time in T3's classes.

Table 4-6: Product History, Validity Coding

Validity	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Incorrect – 0	48	14	6	68
Correct – 1	593	90	67	749
Total Events	641	104	73	817
% Correct	93%	87%	92%	92%

Product History – Category: Form

The event is categorized by the form of science justification the student chooses to justify or explain the event. This coding was completed because not all science-cited events were justified or explained in the same format. Students referenced science concepts in the manners listed. Table 4-7 displays the totals for this category.

- 1 – Phenomenological explanation or interpretation of event.
- 2 – Concept, only, was stated.
- 3 – Principle, only, was stated
- 4 – Concept and Principle were both stated.

Table 4-7: Product History, Form Coding

Form	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 1	24	16	9	49
Events coded as 2	365	67	53	485
Events coded as 3	118	16	8	142
Events coded as 4	134	5	3	142
Total Events	641	104	73	818

Table 4-8 displays the occurrence rate of each **Form** classification for each teacher. For example, T2 had 16 events coded as “3” out of total of 104 events. This translates into 15% of all T2 Events were coded as “3”, or “Principle, only, was stated.”

Table 4-8: Product History, Occurrence Rates

Form	T1 (experimental)	T2 (experimental)	T3 (comparison)
Percentage of events coded as 1	4%	15%	12%
Percentage of events coded as 2	57%	65%	73%
Percentage of events coded as 3	18%	15%	11%
Percentage of events coded as 4	21%	5%	4%

Remember, events coded as ‘1 – Phenomenological’ were eliminated from the analysis in this category. Because the expected frequencies of events coded as 3 and 4 each were less than 5 with $df \geq 2$, classifications ‘3’ and ‘4’ were collapsed. These codes both represent students explaining or justifying events with ‘science’ using the principle, not just the concept name or term. Table 4-9 displays the post-collapse results.

Table 4-9: Product History, Form, post-collapse

Form	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 2	365	67	53	485
Events coded as 3 - 4	252	21	11	284
Total	617	88	64	769

- The chi-square analysis does support the rejection of the null-hypothesis for:
- T1 v. T3, with $\chi^2(1, N = 769) = 13.7, p < 0.001$
- T1 v. T2, with $\chi^2(1, N = 769) = 9.4, p < 0.005$

The chi-square analysis does **not** support the rejection of the null-hypothesis for:

- T2 v. T3, with $\chi^2(1, N = 769) = 0.9$

Product History – Category: Depth

This category codes the level at which the student generalizes the science concept involved in the event. Table 4-10 displays the totals for this category.

- 0 – No depth to the use of science.
- 1 – Applied use of science.
- 2 – Abstract use of science.
- 3 – Applied and Abstract use of science.

Table 4-10: Product History, Depth Coding

Depth	T1 (experimental)	T2 (experimental)	T3 (control)	Total
Events coded as 0	82	21	26	129
Events coded as 1	422	65	34	521
Events coded as 2	18	1	1	20
Events coded as 3	95	1	3	99
Total Events	617	88	64	769

Table 4-11 displays the occurrence rate of each **Depth** classification for each teacher. For example, T3 had 34 events coded as “1” out of 63 total events. This translates into 53% of all T3 events qualifying as “1 – Applied use of science.”

Table 4-11: Product History, Depth, Occurrence Rates

Depth	T1 (experimental)	T2 (experimental)	T3 (comparison)
Percentage of events coded as 0	13%	22%	41%
Percentage of events coded as 1	69%	76%	53%
Percentage of events coded as 2	3%	1%	1%
Percentage of events coded as 3	15%	1%	4%

Remember, Events coded as '1 – Phenomenological' were eliminated from the analysis in this category. Because the expected frequencies of events coded as 2 and 3 each were less than 5 with $df \geq 2$, classifications '2' and '3' were collapsed. Both of these codes signal explaining or justifying events with science at an abstract level. Table 4-12 displays the post-collapse results.

Table 4-12: Product History, Depth, post-collapse

Depth	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 0	82	21	26	129
Events coded as 1	422	65	34	521
Events coded as 2 - 3	113	2	4	119
Total	617	88	64	769

The chi-square analysis does support the rejection of the null-hypothesis for:

- T1 v. T3, with $\chi^2(2, N = 769) = 34.3, p < 0.001$
- T1 v. T2, with $\chi^2(2, N = 769) = 18.4, p < 0.001$

The chi-square analysis cannot be completed for T2 v. T3 because the expected frequency for this comparison is less than 5 with $df > 2$.

Antarctica Car Design Recommendations – Section 1

Antarctica Car – Category: Event

An Event is a student-supplied description of a design idea, design application, problem, or solution that provided an opportunity for a student to justify or explain the issue further. The events-to-assignment ratio was calculated to see differences between students with regard to the number of events, on average, students chose to discuss in the assignment. T1 students provided more than twice as many events per assignment than T2 and T3 students did. Table 4-13 displays the ratio for each teacher.

Table 4-13: Antarctica Car, Event Coding

Antarctica Car Assignment	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Total Assignments Collected	21	14	61	96
Aggregate Events in Assignments	98	39	96	233
Events/Assignment	4.67	2.79	1.57	
Standard Deviations	2.09	2.08	1.09	

Antarctica Car – Category: Justification

The assigned code categorizes the way students choose to communicate and justify/explain the event. Table 4-14 displays the totals for this category.

- 0 – Justification/Explanation is implicit.
- 1 – Justification/Explanation rooted in opinion or design experience.
- 2 – Justification/Explanation rooted in data collected by student.
- 3 – Justification/Explanation rooted in science concept or principle.
- 4 – Justification/Explanation rooted in both science concept or principle and data collected by the student.

Table 4-14: Antarctica Car, Justification Coding

Justification	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 0	1	1	12	14
Events coded as 1	3	2	36	41
Events coded as 2	0	0	0	0
Events coded as 3	94	36	48	178
Events coded as 4*	0	0	0	0
Total	98	39	96	233

*Since zero events were coded as “4”, the category was not included in the results reporting or the chi-square analysis.

Table 4-15 displays the occurrence rate of each **Justification** classification for each teacher. For example, T1 had 94 out of 98 total events coded as “3”. This translates into 96% of all T1 events qualifying as “3 – Justification/Explanation rooted in science concept or principle”.

Table 4-15: Antarctica Car, Justification, Occurrence Rates

Justification	T1 (experimental)	T2 (experimental)	T3 (comparison)
Percentage of events coded as 0	1%	3%	12%
Percentage of events coded as 1	3%	5%	38%
Percentage of events coded as 2	0%	0%	0%
Percentage of events coded as 3	96%	93%	50%

Because the expected frequency of “Events coded as 2” is less than 5 with $df \geq 2$, classifications ‘0’, ‘1’, and ‘2’ were collapsed. These codes represent students explaining or justifying events with something other than science, where as ‘3’ signals the use of science. Table 4-16 displays the post-collapse results.

Table 4-16: Antarctica Car Justification, post-collapse

Justification	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 0 - 2	4	3	48	55
Events coded as 3	94	36	48	178
Total	98	39	96	233

The chi-square analysis does support the rejection of the null-hypothesis for:

9) T1 v. T3, with $\chi^2(1, N = 233) = 52.1.1, p < 0.001$

10) T2 v. T3, with $\chi^2(1, N = 233) = 21.1, p < 0.001$

The chi-square analysis cannot be completed for T1 v. T2 because the expected frequency for this comparison is less than 10 with $df = 1$.

Section 2

The level of understanding and the value that a student places on their reference to science is coded by the next three categories: **Validity**, **Form**, and **Depth**. These three categories were coded only if the event was coded as a “3” in the **Justification** category. Also, for this study, the word “Concept” refers to the use of the *word or term* to reference the science concept, i.e. – “...because of Newton’s Second Law”. “Principle” refers to the use of an explanation or definition to reference a science concept, i.e. – “...if you increase the net force on the car, you will increase the acceleration if the mass stays the same.”

Antarctica Car – Category: Validity

This category determines whether the science concept cited in the event correctly or incorrectly governs the event. Chi-square analysis was not completed for the same reasons described earlier in the Product History section. Coded as 0 for incorrect and 1 for correct. The results in Table 4-17 show that students were connecting the correct science principle to the event cited 98% (92 ÷ 94) of the time in T1’s classes, 89% (32 ÷ 36) of the time in T2’s classes, and 98% (47 ÷ 48) of the time in T3’s classes.

Table 4-17: Antarctica Car, Validity Coding

Validity	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Incorrect – 0	2	4	1	7
Correct – 1	92	32	47	171
Total Events	94	36	48	178
% Correct	98%	89%	98%	96%

Antarctica Car – Category: Form

The event is categorized by the form of science justification the student chooses to justify or explain the event. This coding was completed because not all science-cited events were justified or explained in the same format. Students referenced science concepts in the manners listed. Table 4-18 displays the totals for this category.

- 1 – Phenomenological explanation or interpretation of event.
- 2 – Concept, only, was stated.
- 3 – Principle, only, was stated
- 4 – Concept and Principle were both stated.

Table 4-18: Antarctica Car, Justification Coding

Form	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 1	1	0	5	6
Events coded as 2	55	28	35	123
Events coded as 3	23	7	6	31
Events coded as 4	15	1	2	18
Total Events	94	36	48	178

Table 4-19 displays the occurrence rate of each **Form** classification for each teacher. For example, T2 had 28 events coded as “2” out of total of 36 events. This translates into 78% of all T2 events were coded as “2”, or “Concept, only, was stated.”

Table 4-19: Antarctica Car, Justification, Occurrence Rates

Form	T1 (experimental)	T2 (experimental)	T3 (comparison)
Percentage of events coded as 1	1%	0%	10%
Percentage of events coded as 2	59%	78%	73%
Percentage of events coded as 3	24%	19%	13%
Percentage of events coded as 4	16%	3%	4%

Remember, events coded as '1' – Phenomenological' were eliminated from the analysis in this category. Because the expected frequencies of events coded as 3 and 4 each were less than 5 with $df \geq 2$, classifications '3' and '4' were collapsed. These codes both represent students explaining or justifying events with 'science' using the principle, not just the concept name or term. Table 4-20 displays the post-collapse results.

Table 4-20: Antarctica Car Form, post-collapse

Form	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 2	55	28	35	118
Events coded as 3 - 4	38	8	8	54
Total	93	36	43	172

The chi-square analysis does support the rejection of the null-hypothesis for:

- T1 v. T3, with $\chi^2(1, N = 172) = 6.5, p < 0.025$
- T1 v. T2, with $\chi^2(1, N = 172) = 3.9, p < 0.05$

The chi-square analysis cannot be completed for T2 v. T3 because the expected frequency for this comparison is less than 10 with $df = 1$.

Antarctica Car – Category: Depth

This category codes the level at which the student generalizes the science concept involved in the event. If a student scores a 1 (Phenomenological) or a 2 (Concept) in the Form category, then the student can only achieve a 0 (no score) or a 1 (applied only) in this category. Table 4-21 displays the totals for this category.

- 0 – No depth to the use of science.
- 1 – Applied use of science.
- 2 – Abstract use of science.
- 3 – Applied and Abstract use of science.

Table 4-21: Antarctica Car, Depth Coding

Depth	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Events coded as 0	16	12	18	46
Events coded as 1	68	24	30	122
Events coded as 2	7	0	0	7
Events coded as 3	3	0	0	3
Total Events	94	36	48	178

Table 4-22 displays the occurrence rate of each **Depth** classification for each teacher.

For example, T3 had 30 events coded as “1” out of 48 total events. This translates into 63% of all T3 events qualifying as “1 – Applied use of science.”

Table 4-22: Antarctica Car, Depth, Occurrence Rates

Depth	T1 (experimental)	T2 (experimental)	T3 (comparison)
Percentage of events coded as 0	17%	33%	37%
Percentage of events coded as 1	72%	67%	63%
Percentage of events coded as 2	8%	0%	0%
Percentage of events coded as 3	3%	0%	0%

The chi-square analysis cannot be completed for T1 v. T2, T1 v. T3, or T2 v. T3 because the expected frequency for any of these comparisons is less than 5 with $df \geq 2$.

Summary of Quantitative Results

The following tables summarize the quantitative results of the two written assignments that were coded in this study. The bullets in Table 4-23 and Table 4-24 indicate that the chi-square analysis of the results between the two teachers allows for rejection of the null-hypothesis. That is, any difference observed between the two teachers is not due to chance.

Product History Report

Table 4-1: Product History, Event Coding

Product History Assignment	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Total Assignments Collected	78	50	67	195
Aggregate Events in Assignments	804	224	305	1334
Events/Assignment	10.31	4.48	4.55	
Standard Deviation	2.52	2.13	1.58	

Table 4-23: Product History, Chi Square Analysis Summary

Coding Category	T1 v. T3	T2 v. T3	T1 v. T2
Justification	•	•	•
Form	•		•
Depth	•		•

Antarctica Car Design Recommendation

Table 4-13: Antarctica Car, Event Coding

Antarctica Car Assignment	T1 (experimental)	T2 (experimental)	T3 (comparison)	Total
Total Assignments Collected	21	14	61	96
Aggregate Events in Assignments	98	39	96	233
Events/Assignment	4.67	2.79	1.57	
Standard Deviations	2.09	2.08	1.09	

Table 4-24: Antarctica Car, Chi Square Analysis Summary

Coding Category	T1 v. T3	T2 v. T3	T1 v. T2
Justification	•	•	
Form	•		•
Depth			

Chapter 5

Summary Statement

This study set out to examine the potential effect a new *Design Rules practice* might have on students' science concept understanding and scientific reasoning ability in eighth grade physical science classes. The study also examined the effect this practice has on the ability of these same students to transfer content knowledge and reasoning skill to a novel task. I created an experimental condition where teachers explicitly and iteratively used Design Rules to scaffold students to develop their science talk faculty, to argue and reason decisions with science concepts learned during VIM, and to write explanations and justifications. It was anticipated, at the end of the treatment, that these students would:

- use science concepts and principles learned during the unit to explain, justify, and reason design decisions, problems, and solutions at a higher rate;
- articulate these science concepts and principles in an abstract, generalized voice or manner, demonstrating greater conceptual understanding and greater tendency to reason scientifically; and
- demonstrate transfer of content knowledge and reasoning skills at a higher rate.

The results seem to support these anticipated outcomes. The coded written assignments suggest that students who engaged in the experimental treatment, albeit at varying degrees, demonstrated improved science talk faculty, deeper conceptual understanding, increased reasoning of events via science concepts, and some improvement in their ability to transfer knowledge and skill. Before summarizing the

quantitative results, it is important to review the nature of the qualitative results, as they seem to have an important impact on the quantitative results.

One unexpected qualitative result arose from the implementation fidelity of the participating teachers. It was anticipated that the roles and actions of each teacher might have an effect on student outcomes due to the differences between the two treatments. In this case, however, one could argue that three treatments actually were administered.

If we were to place the variations of the Design Rules protocol, or methodology, on a continuum of treatment fidelity, T1's implementation could be defined as 'high-fidelity'. T1 not only adhered to the prescribed treatment, but she often enhanced and exceeded the requirements of the experimental treatment by:

- highly stressing and scaffolding the use of science talk in developing Design Rules, both verbally and in writing; and
- expecting the use of science talk during multiple occasions, not just during Design Rules activities.

T3, the comparison teacher, implemented a treatment where students did not use Design Rules to connect science concepts and design challenge activities explicitly nor to develop science talk fluency. Furthermore, any scaffolding of student use and articulation of science talk was minimal. T3's fidelity ranks lowest on this continuum, and T3 and her students present a comparison to T1.

T2 evolved into a quasi-experimental teacher, in that she became a comparison teacher to both T1 and T3. T2's fidelity might best be characterized, in terms of this continuum, as medium-fidelity. T2 deviated from the prescribed experimental treatment, but not so much that her practice was void of elements of the experimental treatment.

T2 students engaged in iterative development of Design Rules, but with less frequency and with less focus on abstract science concepts than prescribed. Furthermore, T2's strategy in developing science talk was very teacher-centered, and this afforded few instances for students to engage actively in the development of this skill.

This differentiation among the teachers assists in reviewing and analyzing the results of the quantitative data. This low-medium-high pattern emerges in the results in many of the categories coded for both written assignments. Thus, the differing fidelities of T1, T2, and T3 allow the researcher to distinguish among the three teachers as left, center, and right points along a continuum.

Results Analysis and Discussion

The written assignments offered students the opportunity to explain and justify design problems, features, solutions, experiments, or ideas based upon their VIM experience. The Product History offered a view of each student's ability to engage in science talk, demonstrating propensity and prowess in their conceptual understanding, scientific reasoning, and situational transfer. The students, after all, were recalling their design experience and mapping out the evolution of their car, telling science concepts learned and applied along the way. Transfer of both science content and science talk skills with this assignment could be considered evidence of near-transfer. The Antarctica Car assignment offers more of a far-transfer opportunity to apply science content knowledge to a new, unfamiliar situation while still offering students the opportunity to explain and justify with science talk. Presented here is an analysis and discussion of how

performance on these assignments across the various coding categories maps onto the fidelity continuum described earlier.

Coding Category – Events

In both assignments, T1 students had Events/Artifact ratios that more than doubled those of T2 and T3. T1 students may have performed better in this category for several reasons. First, qualitative results support that T1 students were conducting more experiments within each module, and therefore, had more features (variables) to discuss in their Product Histories. Second, the Antarctica Car Recommendations had a limited number of features, but T1 students, as a result of their treatment, may have had more to offer about each feature than other T2 and T3 students. Finally, T1 students perhaps were prepared, via the treatment, to discuss the science aspects of design issues, and thus, felt greater confidence in discussing more events. Perhaps, T2 and T3 students lacked this confidence and therefore shied away from discussing a greater number of events. T2's students, despite this lack of confidence, discussed more events in the Antarctica Car (far transfer) assignment than T3's students did on average.

Chi-square analysis of the remaining categories accounts for large differences in the events/artifact ration between teachers. Chi-square analysis accounts for this in its assumption regarding the size of the expected frequency (Shavelson, 1981; Heiman, 1992). There were several instances where the analysis was not appropriate. This assumption was violated because the observed frequency in that coding category was too small for at least one of the teachers compared. I indicated in the Quantitative Results section, in Chapter Four, where comparisons are not possible.

Coding Category – Justification

No other coding category makes the case that student performance may have been impacted by teacher fidelity to their treatment like the results from the Justification category. The Product History assignment results clearly show that when students explain or justify events, the likelihood of science being used maps onto the fidelity pattern discussed earlier. Considering the ways in which these teachers expected science to be an anchor and scaffolded this expectation, this interpretation of the results is not surprising. Based on the 80% rate in this category, it would appear that students in T1's class first looked to explain and justify (i.e., reason) with science. T2 students reference science in 46% of their events, and T3 students' rate was just under 25%. The results from the Antarctica Car continue to mimic the fidelity pattern, however, T2's students were more reliant on science than would be predicted by their performance on the Product History assignment. It is interesting that on the far-transfer assignment, despite the medium fidelity, T2's students had a higher rate of science referencing in their events than on the near transfer Product History assignment. Perhaps, the Design Rules treatment encouraged science referencing more than T2's qualitative results would suggest.

Coding Categories – Form and Depth

The results for these two categories begin to reveal how T1's focus on abstracting and generalizing science concepts may have made a difference in her classes and produced students with deeper conceptual understanding. In both the Form and Depth categories there are thresholds in each of the scales. Between '2' and '3' of the Form scale, there is a shift in the way students would cite science in an event. At '3', a

student is applying the principle of a science concept without simply naming the concept. This requires a sound understanding of the concept and its application to the situation or feature. Similarly in the Depth scale, a threshold exists between '1' and '2'. At '2', a student begins to communicate a science concept in a more abstract and general manner, not solely tied to the context of the car. This, too, demonstrates richer understanding of the content

The results of the analysis favor the approach taken by T1. T3's students rarely score above these thresholds. T2 has a greater number than T3 scoring past the threshold, although, the inability to complete a chi-square analysis rules out any significant difference between the two on the Antarctica Car assignment. T1's students, however, had many more events explaining and justifying design aspects at these higher plateaus – more than a third of the events exceeded the threshold in the Form category on both assignments. T1's frequent and varied expectation for the use of abstract science talk, verbally and in written form, may have made an impact on her students. Interestingly, some of T1's students were the only ones to score '2' or '3' in the Depth category on the Antarctica Car (far-transfer) assignment.

Coding Category – Curriculum Target and Validity

The results from these categories help to provide validity to the claims made for the three previous: Justification, Form, and Depth. In all three classrooms, students, for the most part, were referencing only events that were rooted in the VIM unit, and the very few (less than 30) non-unit events coded could not change the interpretation of these analyses. In fact, T1, who clearly had high performing students across these

measures, had the highest out-of unit referencing of all three teachers. Also, the validity results show when students cited science (Events where Justification=3), no matter the class or treatment, students were referencing the correct science concept for the event. The experimental treatment, therefore, could not have been the only intervention to connect science to design activities. After all, the LBD/VIM curriculum provides other means to help students recognize the science connections. It just might be the case that the high-fidelity Design Rules practice produces more dramatic, more meaningful connections than the comparison version of the practice.

Implications for Learning, Transfer, and Teaching

The results from the experimental treatment support several of the ideas illuminated in the literature review. Clearly, experimental students, especially high-fidelity students, engaged in scientific discourse and argumentation: 1) often, 2) as an explicit act to develop understanding and socially construct knowledge, and 3) to practice reasoning as scientists would. Research reviewed predicted that classrooms focusing on this concept would be impacted in the way T1's and, in a more limited way, T2's classes were (Driver, et.al., 2000; Jimenez-Aleixandre & Rodriguez, 2000; Zeidler, 1997; Richmond & Striley, 1996). Experimental students confirmed these studies, by demonstrating firmer conceptual understanding and a tendency to reason scientifically on the Product History assignment.

High-fidelity students are offered more opportunities and practice for speaking and writing science talk. As a result, these students are comfortable expressing science in a sophisticated way, as Roth (1997, 2001) and Chi, et.al.(1991) suggested. The results seem to suggest that scaffolded, iterative writing of Design Rules (Bereiter, Scardamalia,

& Steinbach, 1984) promotes higher science talk faculty, which, perhaps, impacts conceptual understanding and reasoning.

The results also may suggest impacts on transfer. In terms of scientific reasoning, T1 and T2 students scored similarly on the Antarctica Car assignment in the Justification category. Their students chose to cite science at very high rates, 96% and 93% respectively. Compared to T3's 50% rate in this category, T1 and T2 students appear to apply the science learned in VIM on the new, novel task. Despite differences in implementation of the experimental treatment, T1 and T2 students explicitly anchored their Design Rules in science concepts to a greater degree than T3. The end effect may be that these students recognize the importance of doing so, and that they look to identify science concepts in the new contexts more often and more easily than comparison students – a sign of increased situational transfer (Bereiter, 1995).

Also, Antarctica Car Form and Depth results for T1 students reveal how students develop explanations and justifications that not only identify the concept, but provide deeper, abstract explanations of its connection to the feature. The experimental treatment focused on this skill, and here experimental students recognize and employ it in a context other than a Design Rules session or in a Poster Session.

In terms of science content knowledge and far-transfer, the Antarctica Car results and codes of Justification, coupled with the scores in Form and Depth, show that T1 and T2 students were able to identify science concepts and explain the science concepts learned during VIM that are related to their suggestions. This is transfer of content knowledge. As further evidence of situational transfer, these T1 and T2 results

demonstrate a propensity to reason with science in a way that parallels their actions and behaviors for Design Rules development during VIM.

Research on transfer also discusses that if and when transfer occurs, it requires a long time and many experiences (Bransford, et.al, 1999). Learners need multiple representations to start making more general connections. Here, all the LBD students spent 10-12 weeks learning about *force* and *motion* and investigating the aspects of these concepts from multiple angles. In VIM, concepts like Newton's First Law and Friction are examined in every module. Each car type demonstrates and is governed by the rules of these principles. Students engaging in the experimental Design Rules practice methodically develop their understandings and expressions of science concepts, within this context, formulating their own explanations and representations. Thus, any transfer that was occurring might be the result of a lot of time spent, multiple interactions with the concept, and iterative development of generalizations about science concepts.

Some researchers have highlighted that inferences about student transfer can be skewed by the instrument used to assess that transfer (Broudy, 1977; Bransford & Schwarz, 1998). A review of the limitations of summative assessments influenced the assessment artifacts used in this study. The Design Rules posters, *My Design Rules* sheets, the observation notes and videotapes, and the students written assignments were used in an attempt to help avoid the pitfalls of other assessment items. These items helped to reveal the thinking of students over the span of the unit and to revealed the value students place in justifying and explaining with science at the end of the VIM unit. Additionally, they help me to understand and analyze the nature of each teachers' implementation.

It is important in this final discussion to acknowledge the amount of scaffolding, training, and tools provided to the experimental teachers. In the literature review, I discussed the findings of Newton, et. al., (1999) and Geddis (1991), which suggested that teachers were ill-prepared to handle student/peer centered discourse and argument. The experience of this author supports these claims that teachers, themselves, need structure, coaching, and practice to develop student understanding and reasoning via science talk and discourse.

Finally, in Kolodner, et.al. (2003), the LBD research group reported the results of the pre/post test given to LBD classes and non-LBD comparison classes during the 2000-2001 school-year. This pre/post test has 18 questions targeting science concepts taught during the VIM unit. The group reports that T1 showed greater movement than her non-LBD comparison cohort on this pre/post test. T2 and T3 also showed greater movement than their non-LBD comparison cohorts, although the movement was less dramatic than that of T1. It is unknown whether the performances on the pre/post test are related to the treatments of this study, but they may suggest that T1's high-fidelity Design Rules practice played a role in improving science content knowledge of her students.

Limitations of the Findings

This type of study (quasi-experimental, static group comparison design) offers limitations to interpreting the results, because students did not complete a pretest. It would have been difficult to give a fair pretest, because I could not determine the baseline of the students' experience or understanding coming to this study. As others

have indicated, students do not often have opportunities to engage in science discourse and science talk in school or in everyday conversation. A pretest asking students to justify or explain with science knowledge they might not possess would be pointless. Would their vacuous answers be a result of poor content knowledge or poor reasoning skills? The students in this study, however, may have entered the class with some content knowledge or propensity to reason with science, and there was no way to predict or control for that. In rejection of this as an issue, I witnessed T1's students struggle with the Design Rules and the science talk in the early stages of VIM much in the same way T2 and T3 student did. Any future studies, however, need to possess a method for equating groups to avoid validity problems.

There were only three teachers involved in this study. Each teacher, essentially, implemented distinct treatments. This made for some interesting results, but we should be cautious interpreting the implications of those results. It is difficult to get a true sense of the effect of the experimental treatment when only one teacher delivers it authentically. Also, it would have been better to have T4's participation and data to compare to T3's. Perhaps a method where multiple teachers implement each of the various treatments to see how results matched up within a treatment would have been a better method. It is also possible that if more teachers were implementing each of the treatments that the fidelity continuum would have a greater number of defined points. Then, we might see if the results continue to fall into a pattern congruent with the continuum, as was suggested in these results. Additionally, since each teacher only implemented one type of treatment, I cannot eliminate teacher effect. If each teacher

implemented the comparison and experimental treatments in different classes, then perhaps this issue would be less of a concern.

Teachers, also, are unpredictable. Teachers 1 and 2 permitted students, unbeknownst to me, to complete the Antarctica Car Recommendation in groups. This creates a problem in completing the chi-square analysis for this assignment because the number of products was lower than required to satisfy assumptions for this type of analysis. Thus, there were fewer coding categories in which the null-hypothesis could be tested via the analysis.

T1 and T2 students' written assignments seemed to suggest that the new Design Rules practice had an effect on their science talk skill development and ability to reason. It is possible to argue, however, that these students simply were trained to respond to the 'explain or justify your car evolution and design recommendation' stimulus with a standard response: offer science rooted events. It could be that the experimental students were trained to do this through the expectations, foci, and assessments of their teachers during VIM. Then, when the time came to write these papers, the students fell into the habit of explaining and justifying in the manner they were repeatedly trained.

Ultimately, the motivation for giving abstract, general responses rooted in science is difficult to assess without more comprehensive measures. Perhaps, there could be another Design Rules study where students have other opportunities, beyond the written assignments, to reveal their understanding and motivations. The use of student interviews and performance assessment activities might offer researchers the ability to make confident claims regarding the experimental Design Rules treatment (A.diSessa, 1998).

The research suggests that experimental students are reasoning with science, but the effects on transfer may not be as strong. There are signs that experimental students recognized and applied content in the far-transfer assignment, but additional measures might be necessary. In a future study, students might be given a pre/post test. This test would contain force and motion situations, and these situations would vary in similarity to the VIM Car Challenge and Antarctica Car Recommendation. Students would answer multiple choice answers and give written explanations for these answers. The student responses could be coded using the same coding categories developed for the Product History and Antarctica Car assignments. A measure like this might assist in understanding not only how students transfer content, but also the development of their understanding. Several circumstances prevented this for this study, but this author recognizes the potential benefits for future investigations.

Research Possibilities

A potential follow-up research idea is to look closely at student performance as it relates to specific science concepts. Seemingly, certain concepts within VIM are lower on the developmental progression of understanding than others. For example, the concept of friction is readily attainable by most students at this age because it is easily witnessed. Also, many students have had numerous experiences with friction in school prior to the VIM unit and in real life. Understanding of Newton's Third Law of Motion is not as easily grasped. Many students struggle with the idea that inanimate objects provide opposite and equal force when something pushes on them. The concept becomes even more difficult to reason with and apply when objects, in motion, collide.

It is further complicated when the objects are of different mass (Thornton, 1997). While there was no specific data collected regarding this idea of concept-level-of-difficulty, one trend seemed to appear. T1 students seem to cite events rooted in a broad range of science concepts from the VIM unit. T2 and T3 students seem to cite a smaller range of concepts; concepts that could be characterized as more easily attainable than others from VIM. It also would be interesting to re-examine the events coded to categorize them by quantity of differing science concepts. Would high-fidelity treatment students offer a greater range of science concepts than would low-fidelity students? Furthermore, are students only able to speak abstractly on less-complex aspects of the science concepts in VIM? Such a study might have impact on the research examining the developmental understanding hierarchies of the science concepts of force and motion.

During VIM, students frequently and repeatedly collect, discuss, deliberate, and rely on experimental data. Students based their Design Rules on the patterns observed in the data from their experiments. LBD teachers and students are somewhat particular about quality data sets and controlled experiments. Most classrooms do not permit a Design Rule to be suggested or recorded unless there is sound data to support it. Despite this, the most rare codes assigned during the coding were '2's and '4's in the Justification category. These codes signal that an event was explained or justified with data. The argumentation/discourse literature stresses the importance of students learning to use empirical evidence for building science literacy and developing scientific reasoning. Students in the experimental groups seemed to make gains in some respects, but very few events were supported with empirical data despite the fact that all LBD

students keep extensive records. Another Design Rules practice might find a way to explore ways in which students might become more data reliant in reasoning.

Finally, case-based reasoning research tells us that learners who experience multiple representations, but fail in applying knowledge correctly, will be prepared later to succeed as a result of his/her failure (Kolodner, 1993). If a student makes good adjustments in his/her indexes of information, he/she will be better prepared to transfer. Another opportunity for research is to closely examine and count the number of instances students examine the same concept multiple times throughout the unit. Then, see if they are likely to offer events in their written assignments that are based in the more-frequently visited science concepts. Furthermore, it would be interesting to determine whether the science concepts that are more frequently discussed and dissected code at higher levels in the Form and Depth categories.

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APPENDIX

Name _____
Date _____

My Design Rules



Source (Case or Activity)	Design Rules	Why the Rule Works	Ideas for Using the Rule

Questions and Learning Issues

What is "Force?"

The Science of My Car

The word "force" is probably familiar to you. People use it every day, and most everyone has an idea what it means. What do *you* think it means?

My Definition of Force:

Share your definition with the class. See if you can all agree on a good statement of the meaning of "force."

My Way To Measure Force:

In science, words are defined by how you observe or measure the thing you are defining. How would you measure a force on an object? To make it simple, just think about pulling a coaster car. How could you measure how hard you are pulling?

Discuss your measurement methods as a class, and see if you can improve those methods.

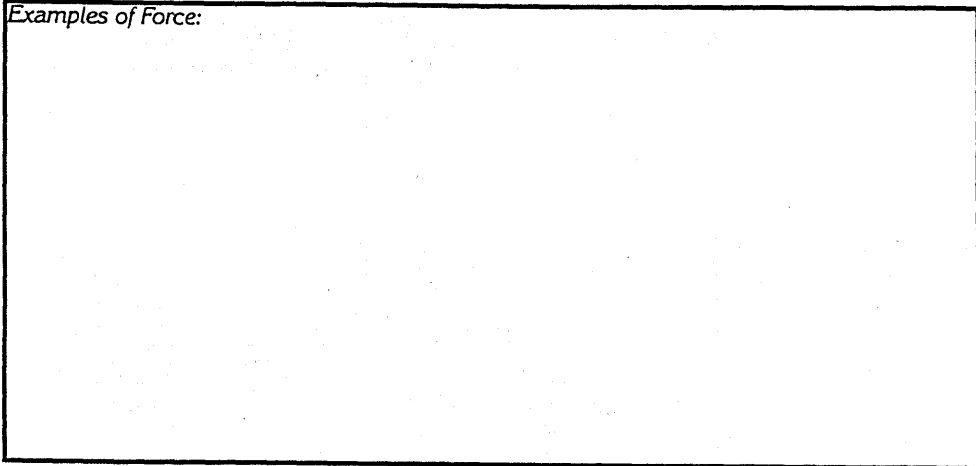
Science page from *Vehicles in Motion* text, pp.28

What is "Force"?

The Science of My Car (cont.)

Can you think of an example of a force? Try to think of some real situations where objects are experiencing forces. Make a list of all the ones your class comes up with. In each case, be sure to write down the force. In some cases, there might be more than one force.

Examples of Force:



Rules for Drawing Labeled Force Arrow Pictures

1. The arrow points in the direction of the push or pull
2. The length of the arrow gives an idea of the size of the force (big force = long arrow; little force = short arrow)
3. The label describes what caused the force



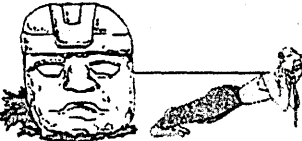
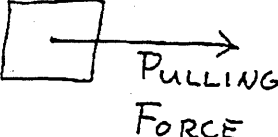
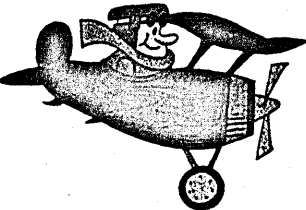
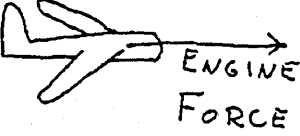
Every Force Has A Direction

A push or a pull is always in a particular direction. You can show the direction of the force by drawing a picture of the object with a labeled force arrow. The label reminds you which force you are describing.

Science page from *Vehicles in Motion* text, pp. 29

Examples of Force Arrow Diagrams

Here are some examples of force arrows.

Situation	Labeled Force Arrow Picture	Force Description
		The car's motor exerts a force that pushes the car forward.
		The person exerts a force that pulls the object along.
		The airplane's engines exert a force that pushes the plane forward.

Often (in fact, most of the time) there might be more than one force involved.

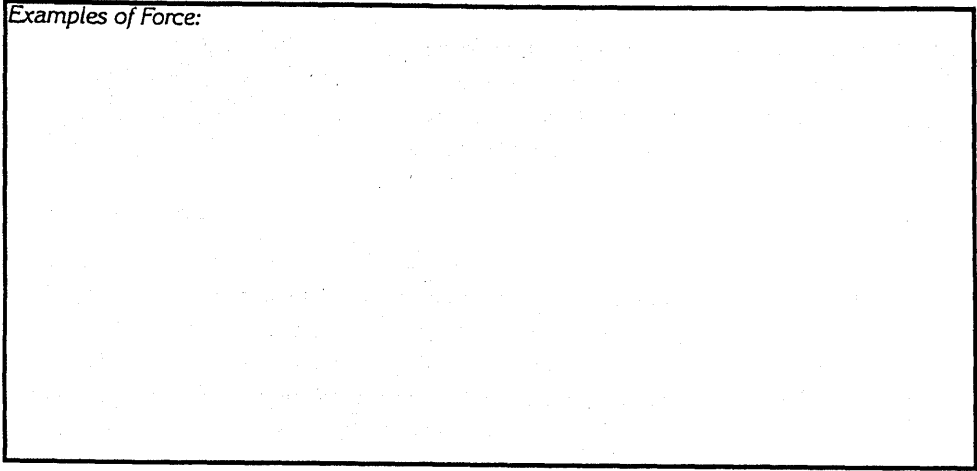
Science page from *Vehicles in Motion* text, pp. 30

What is "Force"?

The Science of My Car (cont.)

Can you think of an example of a force? Try to think of some real situations where objects are experiencing forces. Make a list of all the ones your class comes up with. In each case, be sure to write down the force. In some cases, there might be more than one force.

Examples of Force:



Rules for Drawing Labeled Force Arrow Pictures

1. The arrow points in the direction of the push or pull
2. The length of the arrow gives an idea of the size of the force (big force = long arrow; little force = short arrow)
3. The label describes what caused the force

Every Force Has A Direction

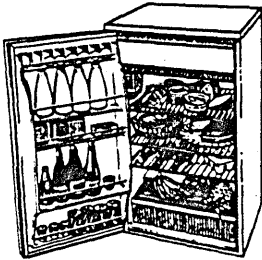
A push or a pull is always in a particular direction. You can show the direction of the force by drawing a picture of the object with a labeled force arrow. The label reminds you which force you are describing.

Science page from *Vehicles in Motion* text, pp. 31

Friction is a Force

A Heavy Case of Friction

Imagine getting a summer job working for a moving company. You observe that some crews know how to do their job a little better than others. They take pride in doing their work with the least amount of effort. One such crew of two movers must move a refrigerator out of a kitchen with a smooth vinyl floor, then through a carpeted room, and finally out the apartment door. One partner is



suddenly sent to another job. His co-worker is left to move the fridge by himself. How can one person move this heavy appliance? Here is how one lone mover did his job: "I knew I had to drag the fridge across the floor – it was too big for me to lift and carry. So, I put a small piece of carpet under the fridge to make it easier to slide across the vinyl floor. When I got to the carpeted room I had to use a dolly (a special cart with wheels) to help me move it to the front door."



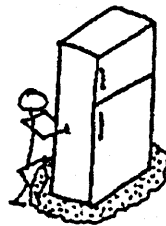
Mover Uses Force

Refrigerators are big and they are heavy. This mover must apply a lot of force to make the fridge move, so he uses a large push or pull to do his job. The fridge not only experiences forces from the mover, but it also experiences forces from the floor. Draw force arrows on the refrigerator, to the right, showing all the forces and the direction in which they act. Do not forget to label your arrows.



Mover Reduces Friction

It will be easier to move the fridge across the floor if the mover pushes harder on the fridge. However, he can only push so hard...there's a limit to the force the mover can create. If he places a carpet under the fridge, he finds that the fridge moves easier too. Again, draw force arrows on the refrigerator, to the right, showing the forces when the mover uses a carpet underneath the fridge. What will be different about this drawing from the one above?



Science page from *Vehicles in Motion* text, pp. 32

Friction is a Force

As you have probably figured out, there is less friction between the fridge and the floor when the carpet is used. Friction is a force that is created when objects that are touching slide or roll past one another. If the friction acting on an object is high, it is tough to slide or roll it past another object. However, if the friction is low, the easier it is to slide or roll it past another object. Draw two examples of situations where an object experiences friction. Label your drawing with a force arrow that describes the direction and size of the force of friction in that situation.

Example 1

Example 2

The mover is also trying to create low forces to help him do his job. He created lower friction by using the carpet and then using a rolling cart. Another way to reduce friction is to use lubricants like oil. We use oil in car engines to lubricate the moving parts so that they slide and move easier. For the two examples of friction you came up with, list a way you could reduce the friction in each, and then a way you could increase the friction in each. Also, for each, provide a situation when this would be desirable.

Example 1

Reduce the friction by...

Desirable when...

Example 2

Reduce the friction by...

Desirable when...

Example 1

Increase the friction by...

Desirable when...

Example 2

Increase the friction by...

Desirable when...

In the three pictures below, draw force arrows showing the friction in each situation.



Science page from *Vehicles in Motion* text, pp. 33

Product History Assignment – Teacher Guide

The Product History assignment is a critical piece of data that I will collect from your classes this year. While you certainly have the freedom to grade this assignment any way you see fit, for the purposes of this study, I will need students to view this assignment in a certain manner.

1. It is important that students write their own Product Histories, not as a group. Students can collaborate in discussing events or pieces of information (sharing experimental result sheets and Rules of Thumb pages), but they must write the assignment independent of other students.
2. They need to view the assignment as something that carries some weight. Each of you obviously have different grading schemes and categories and criteria for determining a student's grade. You have the choice as to what you want to label this assignment, but make sure that students have at least 3 to 4 days to write the assignment. Maybe it could be part of a take-home test, a lab write-up grade, or a major report. It is important that students feel this is a major assignment and that they need to reflect on the assignment a good bit. Let me know if you need to talk with me more about this.
3. This might be the most important item. The Product History, as it stands in the textbook, does not ask students to incorporate the science they learned as their car evolved in their Product History paper. However, the Product History activity prior to writing the paper asks students to consider what drove the evolution of the product and what criteria justified the success of a design change. When assigning this Product History, reinforce the idea that you would like them to include discussion of how "science" influenced design ideas, changes, and assessment. It would be preferred if discussion of this determined a portion of the grade for the assignment, if there is to be a grade assigned. Each sub-unit targets certain science concepts. Students should discuss how those science issues highlight the success or problems they experienced with their cars. Try to communicate your expectations for discussion of the science parallel to your expectations from assignments, tests, discussions, etc. during the VIM unit. If you'd like more direction is prioritizing this for students, contact me and we'll talk further about some ideas.

Product History/Antarctica Car Assignments Coding Rubric Guide for Coders

The following guide is for use in coding student written assignments. Each category and level of category has examples provided to assist you in coding events. Please keep in mind our training sessions and use the notes from those sessions. If you need help, just let me know.

Student – Enter the student number in the first column, only once. Then, fill the rows under that student until the product is completely coded. Then enter the next student number in the first column again.

Event – A reference to a design problem, feature, solution, experiment, or idea. Number each event.

Curriculum Target – The issue discussed is a science content issue targeted by VIM unit. Examples include Newton’s Second Law, Friction, Mass, etc. Examples of non-targeted issues would be impulse, torque, and potential energy. These non-target events will still be coded in the science content section of the rubric. The entry is a 1 or a 0. 1 is for targeted issue, 0 is for a non-targeted issue.

Process Skill Scoring

Justification – This is a process skill measure. It reveals something about the way student choose to communicate and justify/explain the event.

Implicit Justification

0 – No reason is given for the choice or decision. From the student’s perspective, the justification should be obvious to the reader. Or, student chooses to justify answer with a reason based solely on opinion (or at least, that’s all you as a coder can tell).

“We chose to use the balloon car as our final car.”

“We chose to use the balloon car as our final car because it is better than the rubber band or falling weight car.”

Explicit Justification

1 – Student chooses to justify answer with a reason based in their design experience where a criterion is included (*traveled further, work on more surfaces, was faster*). Student may refer to their experiments, but they do not refer to data collected or science concept to bolster the experience relayed.

“We decided to use the balloon engine because it traveled farther than the other engines we looked at.”

“We decided to use CD wheels because they had the smoothest surface of all wheels.”

-or-

Student chooses to justify answer with a reason based in an outside example or experience that demonstrates the same principle or behaves similarly.

"We chose to use the balloon car as our final car because rockets work like the balloon car, and rockets are very powerful and can travel great distances."

2 – Student chooses to justify answer with data collected during experience, but no science references are made. This response receives a different code than those which qualify as a "1" because the student communicates data collected to explain choices or justify choosing one feature setting over another.

"We chose to use the balloon car as our final car because it traveled, on average, 1.4 meters farther than the other types of cars we built and tested."

3 - Student chooses to justify answer with a reason based in a science principle. The principle can be stated in an applied, abstract, or both applied and abstract fashion. Students will use the term ("friction"), or they may just discuss the principle without using the term. These differences will be coded with another criteria later in the rubric.

"We chose to use the balloon car as our final car because it generated more net force on the car, which means traveling a greater distance, than the other types of cars we built and tested."

4 - Student chooses to justify answer with a reason based in a science principle and with data they collected in their experiments. The principle can be stated in an applied, abstract, or both applied and abstract fashion. Students will use the term ("friction"), or they may just discuss the principle without using the term. These differences will be coded with another criteria later in the rubric.

"We chose to use the balloon car as our final car because it generated more net force on the car, which means traveling a greater distance, than the other types of cars we built and tested. The balloon car had an average distance of 6.88 meters, while the other two cars never traveled more than 3 meters."

Science Content Scoring

The level of understanding and the value that a student places on their reference to science is coded. Here, "Concept" refers to the fact that the word or term used to reference the science concept, i.e. – "...because of Newton's Second Law".

"Principle" refers to the use of an explanation or definition of a science concept, i.e. – "...because if you increase the net force, you will increase the acceleration if the mass stays the same."

The last three columns (Validity, Form, and Depth) can only be coded if the student has a value of 3 or higher in the "Justification" column. Other entries do not support the criterion of the last three columns. Otherwise, the value entered for each column is a 0 (zero).

Validity – The science concept cited correctly or incorrectly governs the event cited.

Score as 1 for correct, 0 for incorrect.

“We used CD wheels on our coaster car because they have low friction surface that would allow the car to travel farther”.

Correct, 1 point

“We used CD wheels on our coaster car because with each rotation of the axle, the car travels farther”.

Incorrect, 0 points

Form – The event is categorized by the form of science justification the student chooses to justify a design choice, decision, or response: Phenomenon, Concept, Principle, or Concept/Principle.

Phenomenological Observation

1 – The student only states the phenomenon observed that is related to the design issue or problem. The event qualifies as a science justification because the student is discussing the physics within a narrowed context. The student may use a science term, but it is clear that the student did not intend to use it to define the situation accurately.

“We double ballooned the engines because they force out the air faster and harder making the car go farther.”

-or-

The student approaches it from a design or fabrication standpoint, not really discussing science but rather engineering.

“By increasing the length of the rubber band, we made a soft force release from the rubber band making the car go farther.”

Here the student used “force” but would have been comfortable substituting other terms. The intent was not to define the situation as a “force” issue, but rather to use force in an experiential manner.

Concept

2 – The student states the concept (*term*) related to the design issue or problem only. Code as “2” if the concept is mentioned by name at all.

“We double ballooned the engines because of Newton’s Second Law.”

Principle

3 – The student only states the principle related to the design issue or problem, without stating the concept (*term*).

"If you double balloon you will increase the force and thus the acceleration on the car and your car will travel farther."

Concept and Principle

4 - The student states both the concept and the principle related to the design issue or problem.

- *"If you double balloon, Newton's Second Law says you will increase the force and acceleration on the car and your car will travel farther."*

Depth – This category codes the level at which the student generalizes the science concept involved in the event: Applied, Abstract, or Applied and Abstract. If a student scores a 1 (Phenomenon) or a 2 (Concept) in the Form category, then the student can only achieve a 0 (no score) or a 1 (applied) in this category.

No depth

0 – Student only states the Concept (term, science word) or phenomenological observation with no discussion or supporting points about it.

"With Pringles can tops for wheels, you have too much friction."

Applied

1 - The student states the principle only as it applies to the design issue or problem with in context.

"If you double balloon, you will increase the force on the car and your car will travel farther."

"If you use CDs for wheels, they have less friction which is good for wheels."

Abstract

2 – The student states the principle abstractly only, implying that it is related to the design issue or problem.

"We double ballooned the engines because of Newton's Second Law which says if you increase the net force in a situation, you increase the acceleration which can lead to a greater distance if the mass is constant."

Applied/Abstract

3 - The student states the principle both abstractly and as it applies to the situation explicitly.

"We double ballooned the engines because this increases the net force. Newton's Second Law say you increase the net force acting on the car it means that you will increase the acceleration of the car and most likely the distance the car travels in that run if the mass of the car is changes very little."

Product History Rubric Guide

Student Number	Event	Curriculum Target	Justification	Validity	Form	Depth
62201403						

Rubric Coding Examples

Justification

0 – Implicit

“We chose to use the balloon car as our final car.”

“We chose to use the balloon car as our final car because it is better than the rubber band or falling weight car.”

1 - Experience

“We decided to use the balloon engine because it traveled farther than the other engines we looked at.”

“We decided to use CD wheels because they had the smoothest surface of all wheels.”

“We chose to use the balloon car as our final car because rockets work like the balloon car, and rockets are very powerful and can travel great distances.”

2 - Data

“We chose to use the balloon car as our final car because it traveled , on average, 1.4 meters farther than the other types of cars we built and tested.”

3 - Science

“We chose to use the balloon car as our final car because it generated more net force on the car, which means traveling a greater distance, than the other types of cars we built and tested.”

4 – Science and Data

“We chose to use the balloon car as our final car because it generated more net force on the car, which means traveling a greater distance, than the other types of cars we built and tested. The balloon car had an average distance of 6.88 meters, while the other two cars never traveled more than 3 meters.”

If Justification is 3 or 4, then code for Validity, Form, and Depth. If Justification is < 3, then enter “—“ for Validity, Form, and Depth.

Validity

0 - Incorrect

“We used CD wheels on our coaster car because they have low friction surface that would allow the car to travel farther.”

1 - Correct

“We used CD wheels on our coaster car because with each rotation of the axle, the car travels farther.”

Form

1 – Phenomenological:

Depth

0 – No Depth

“We double ballooned the engines because they push hard.”

1 – Applied

“We double ballooned the engines because they push out the air faster and harder making the car go farther.”

2 – Abstract

No such designation

3 – Both Applied & Abstract

No such designation

2 – Concept:

Depth

0 – No Depth

“We double ballooned the engines because of Newton’s Second Law.”

1 – Applied

“We double ballooned the engines because of Newton’s Second Law says that it if we increase the force on the car, its acceleration will be high.”

2 – Abstract

No such designation

3 – Both Applied & Abstract

No such designation

3 – Principle:

Depth

0 – No Depth

No such designation

1 – Applied

“If you double balloon, you will increase the force on the car and your car will travel with a greater acceleration.”

2 – Abstract

“If you double balloon, you will increase force. An increase in force produces an increase in acceleration and distance traveled”

3 – Both Applied & Abstract

“If you double balloon, you will increase force on the car. Increases in force produces an increase in acceleration and this will make the car travel for a longer distance.”

4 – Concept & Principle:

Depth

0 – No Depth

No such designation

1 – Applied

“We double ballooned the engines because of Newton’s Second Law. It says that if we increase the force acting on the car, we will increase its acceleration.”

2 – Abstract

“We double ballooned the engines because of Newton’s Second Law. It says that by increasing force there will be an increase acceleration and distance.”

3 – Both Applied & Abstract

“We double ballooned the engines because of Newton’s Second Law. It says that by increasing force there will be an increase acceleration and distance. So, by increasing the force of the balloon engine acting on the car, the car experiences greater acceleration and probably greater distance traveled.”

Combining Ideas To Make New Products

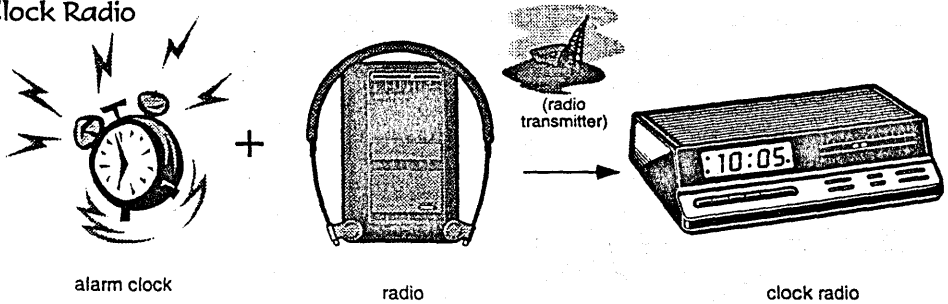
Each year, the United States Patent Office grants thousands of people who claim to have a new idea for a product what is called a "patent". A patent gives developers a certain amount of time to get their products to market without competition. Patents can take one of three forms:

- inventions (e.g., an office chair that gives back massages, or a tapeless digital audio recorder);
- new design ideas (e.g., a new line of dresses or running shoes); and
- new plants (e.g., genetically combined from two plants, used by farmers or greenhouse owners).

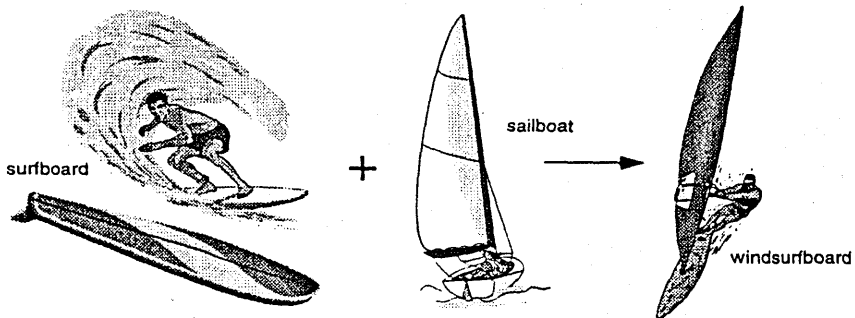
Few patents involve never-thought-of-before products. For example, new hairbrush designs get patented all the time, but they all still basically comb or pick at hair. On the other hand, Thomas A. Edison was the first person to create a machine that recorded and played back voices and other sounds. It worked the very first time he tried it, and was a completely new idea. Many later patents improved on Edison's original concept. Do you know some? Can you think of ideas that were completely new?

In biology, a "hybrid" combines the good traits of two existing strains of an organism. Many patents involve "hybrids" that combine two or more existing product ideas. Here are some examples where new products came from combining old product ideas in new ways.

1. Clock Radio

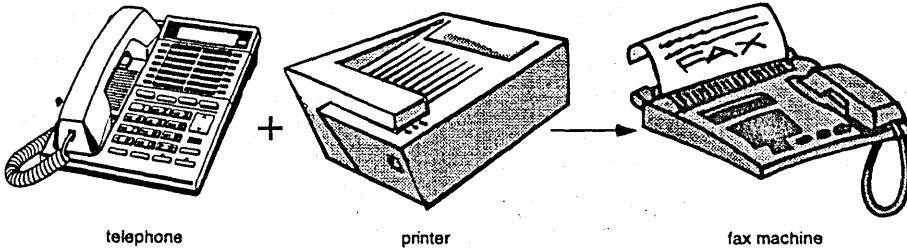


2. Windsurfing Board



Combining Ideas Make New Products

3. Fax Machine



telephone

printer

fax machine

Creativity in Combining Ideas

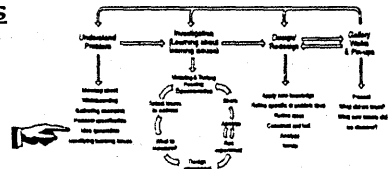
You might think that combining existing product ideas into new designs is a form of cheating, but it's not. People who come up with new and interesting combinations of existing ideas are celebrated the world over as creative, and often make lots of money in the process.

Now try it yourself. Make a list of very different items and products, and see if you can combine them into an interesting and completely new product idea. How do you make the list? One author who writes about creativity, Edward de Bono, suggests picking words (nouns) at random from a dictionary, and then suggests combining them to see if an unusual product idea comes up. Below is a sample list of 15 product words taken at random from a book about a husband-and-wife design team entitled *The Work of Charles and Ray Eames*. Try mixing them together in different ways.

Random Ideas

circus	plywood	showroom
film	sun	flowers
uphstery	blocks	essay
machine	museum	pencil
memorial	railroad	miniature

New Products



Combining Ideas is one way of doing a key step in the LBD™ Cycle: Idea Generation

What combinations hold promise. Did you create something that might be worth patenting?

Homework

1. Look around your school, home and town, and find four items that came from combining two or more existing products. Sketch and describe them in your homework sheet. Remember that the products do not have to be mechanical -- they might be food items, a new service or store, or even an idea for a new television program.



2. Think back to the vehicle propulsion systems you have designed and tested or seen other teams do. Write down and sketch one or more plans for combining propulsion systems for your car. Critique your new "hybrid design" and tell what you think are its strengths and weaknesses.

Writing a Product History Report

Evolution is the story of how something changes over time.

Some scientists study the evolution of language -- when do new words get created, and others dropped? A historian might study the evolution of slavery or democracy in the world, or study change over a period of time, like the 19th century (1801-1900). Other scientists study the evolution of the world's geography -- how the continents appear, disappear, and move over time.



700 million years ago



400 million years ago



100 million years ago

The movement and drift of the continents shows the evolution of the earth's geography.

Evolutionary change can happen in lots of very different cases. Here are a few more, with explanations and illustrations:

<u>Case of Evolution</u>	<u>Explanation</u>
1. Bacteria (living thing)	1. Certain diseases that could be killed with one drug develop an immunity over a number of generations and a stronger drug is needed to kill the disease.
2. Speed of light (idea)	2. Light used to be thought to travel instantaneously (infinitely fast). The speed now is determined to be about 300,000 km/sec (186,000 miles/sec).
3. United States (country)	3. Started as 13 states close to the Atlantic Ocean. Now includes 50 states spanning from the Atlantic to Pacific Ocean, plus Alaska and Hawaii.
4. Soft drink container	4. Product first was stored in glass bottles, then tin cans, then aluminum cans, and now in plastic bottles.

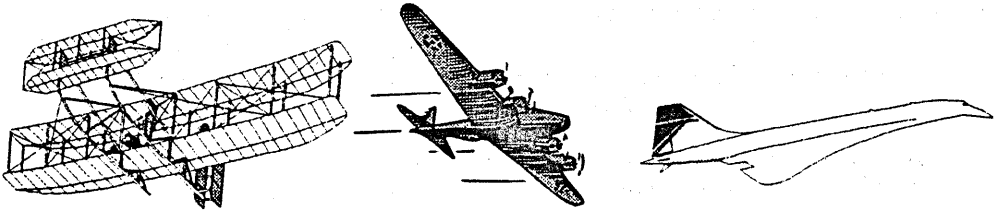


Writing a Product History Report

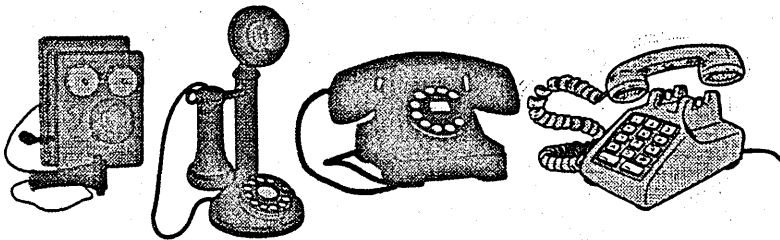
When designers want to improve a product, they often do research and write a report on the history of a product. By doing this, they get a better understanding of the product, its features, strengths and weaknesses, and how to make a better version of the product in the future.

Below are picture histories of aircraft and the telephone. Try to make a list of the criteria, constraints, and specifications for the different versions of the same device. These lists can show how the designers made choices that led to the product's evolution. What other sorts of pictures could you add to either or both?

Picture History of Aircraft



Picture History of the Telephone



What product features have been changed over the history of the telephone?

Classroom Activity

Get together with members of your team for a 10-minute activity that involves doing a mini-product history of some product. You should spend no more than 5 minutes choosing and then discussing products that interest you and that have taken different forms (evolved) over time. You will be given a signal from your teacher when five minutes have past. With the rest of your time, describe with words and rough sketches how your chosen product evolved over time. Be prepared to share this product history with the rest of the class.

Remember that a product can be a device, a service, something that can be produced and bought -- anything that was designed by someone for someone to use.

Writing a Product History Report (continued)

Homework 1 – Writing a Product History

Pick a product line that interests you and that is different from what teams reported on in class. Then write your own essay that describes the history of that product. A good essay will include:



- Description of the invention of the product, if known, including a picture and listing of what that first product could do (product criteria, constraints, specs).
- Description of later stages of the product. Show and describe how the product that was developed later was different than before, yet still performed the same function.
- Description of the current version of the product, with pictures if possible, and a listing of what the product can do.
- Prediction of what you or others think the future may bring in the evolution of the product.
- Illustrations and sketches to accompany what you have written.

Hint: You can treat the writing of this essay like a design task. You could even use the LBD™ cycle to do it. Just think -- you need to understand the task, so you read over the assignment, describe it to yourself in your own words, and get clear on its specifications. You need to do research, just like with LBD™. After you come up with ideas, you have to decide what to include in your paper. And just as you design and test your model car over and over again (iterative design), you need to write, edit, and rewrite to get your best essay. Sound familiar? (Look over the LBD™ Cycle and see if you can identify all the steps that you would use when writing an essay.)

You will be giving a short presentation based on your report to the class.

Preparation for Final Report – Writing Your Product History

In your Design Diary work, you have been collecting lots of information that shows how your model car design has evolved over time. Now is one time when you will draw upon all of this work.



For homework, review your Diary notes and write a product history on the model car your team has developed. Use your notes as a guide only -- don't just copy them directly into your essay. Review the LBD™ Cycle and tell what you did and how your ideas evolved over time when writing your own product history essay. Be sure to justify or explain design decisions, failures, successes or future ideas with science principles that support or "back up" your statements. Think about the science principles that you have learned in VIM (Newton's Laws, Forces, Friction, etc.) and how they related to your design choices. Don't forget to include illustrations in your report. Note: You will be rewriting this essay and handing it in as part of your final project work.

Looking Back to Antarctica

Returning to the Antarctic Challenge

Quite a while ago, in the very beginning of *Vehicles in Motion*, you were told about a design task. A special vehicle was needed for work in the cold environment of Antarctica -- close to the South Pole. Such a vehicle had to be able to work well on different of terrains. Energy was is in short supply there -- and so you had to deal with that constraint. The vehicle had to be simple to maintain -- very cold temperatures cause most machines to break down often, or not work at all. It also could not get stuck in the snow, far from shelter -- people's survival could depend on people the protection from the long, dark, cold nights that the car provides, and upon getting back home from a trip. You were to imagine being part of a research task force. You and others would make recommendations based on research and experiments conducted and write a report that suggests features for a utility vehicle for use in the Antarctic. All of what you have done, all of what you have learned from designing, all the experiments you have performed, and all the ideas you have gotten from other teams, can and should be used in writing a final report on suggestions for an Antarctic vehicle.



Original Challenge: Design a vehicle for use in Antarctica.

As you well know, you didn't test your vehicles in a deep freezer, filled with ice and snow, and a strong fan to simulate conditions in Antarctica. But still, you have learned a lot about how cars work and about how Newton's Laws explain the motion of things. You have been acting as vehicle designers and learned about which factors influence how a vehicle performs. Armed with your new knowledge and skills, make suggestions, even propose new design ideas, for the best Antarctic car.

Looking Back to Antarctica

Designing a Car from the Ground Up

For this final assignment, propose and describe a car for the Antarctic, *from the ground up*. You can design whatever you want -- you don't have to stay with the car ideas you have worked on thus far. This means you don't have to use balloons or rubber bands to make your car move, and don't have to use foamcore or cardboard as a building material. Your wheels can be made of whatever you think will work best in this frigid land. Remember that the vehicle you design may spell the difference between life and death for the people living there.

Base the ideas you include in your final Antarctic report on what you learned from working with the model cars and other research you've done. The aim was for you to learn about how vehicles work, so that, like any good designer/scientist, you could face a new situation and design a great product. Write the report so that it shows your current understanding along with your design ideas. Include results from your experiments and science ideas you learned. Use building skills you gained to recommend how the car should be constructed and maintained.

Remember that designers take risks! Some of the greatest inventors took completely different approaches to doing everyday things. Look at how copier machines make copies (static electricity and powder), about how CD players make sound (lasers), and about how microwave ovens heat food (a kind of souped up radio transmitter). Then look at the problem of moving around in Antarctica with new eyes.

Key Parts of Your Report

The following is a list of the key parts or sub-systems of a car that will work in the "bottom of the world" that you need to describe in your final report.

- propulsion systems
- tires and wheel size
- gearing (none, simple, multiple)
- fuel and fuel storage
- bearings
- materials & construction

Here are some key issues you should address, as well as others you and others think up: How will the vehicle keep its riders safe? How will it get energy and store energy to make it move? Once assembled, how will it stay together? How will it deal with friction and the lack of friction on the ice? How will it navigate ice obstacles and deep snow?

Remember to use evidence from experiments to support your views and drawings to show what you are proposing. Demonstrate your understanding of the science of vehicles and guidelines for designing (e.g., rules-of-thumb) that influenced the recommendations you make in your report.

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Antarctica Car Design Recommendation Assignment, 2 of 2 pages

Experimental Treatment Teachers Guide

Teachers,

Below is a basic sequence for implementing a VIM sub-unit. In addition to the sequence, you will be adding an extra focus on Rules of Thumb development. I have listed next to the sequence some guides for implementing the Rules of Thumb treatment that we have discussed during training. This guide is to help you recall our discussions and help you implement our new Rules of Thumb treatment. Please let me know if you have further questions, concerns or comments. Thanks!

Mike

Step	LBD/VIM Sequence	Rules of Thumb Practice Guides
1.	Challenge Introduction Problems specifications, constraints, and criteria identified.	
2.	Build & Mess About Build basic version of the car, or engine attached to the car, highlighted during the sub-unit. Examine and Mess-About with the basic design; students share observations.	
3.	Whiteboarding Class reviews observations, constructs a Whiteboard to organize ideas and variables to test.	
4.	Design Experiments Students identify specific variables to test, plan experiments.	
5.	Conduct Experiments Students create and conduct experiments to test variables identified.	
6.	Poster Session Students conduct a Poster Session to present their experiment(s) to the class.	
7.	Rules of Thumb Presentation Presenting group generates a Rule of Thumb regarding their variable to help students plan future designs. Rules of Thumb is recorded.	Class participates in Rules of Thumb Session, where all of the Rules of Thumb are reviewed and discussed. Students record Rules of Thumb on the <i>My Rules of Thumb</i> sheet, knowing that it may be edited later.
8.	Science Instruction Student primed for learning science related to their activities, the teacher moves into discussing science principles underlying the sub-unit. The teacher utilizes demonstrations, short investigations, mini-lectures, the textbook, and homework to focus on a specific science concept. For example, classes working with the Coaster Car will research "What is a force?", "Friction", and "Newton's First Law". They	The class formulates some early Rules of Thumb based on their experiments, the class's attention is focuses on the science issue at hand. The teacher emphasizes and models <i>science talk</i> : Rephrasing students answers and asking students to rephrase answers using the science vocabulary. Teacher emphasizes heavily the relationship between the abstract science

	participate in a combination of activities to develop an understanding outside of the context of the Coaster Car.	principles and the examples students have generated, even referring the car often in explanations.
9.	<p>Conduct More Experiments Class returns to experimenting and investigating new variables and verify the results of other experiments.</p>	Before starting the next round of experiments, students review the Rules of Thumb to identify and rewrite any misstatements or misconceptions based on their recent research. Also, students now have a better ability to fill in the column <i>Why my Rule Works</i> . Here is where they explain/justify their Rules of Thumb with an abstract concept. Students amend the <i>My Rules of Thumb</i> sheet, and then begin the next round of experimenting.
10.	<p>Poster Session II Class conducts another Poster Session; groups suggest more Rules of Thumb. Note: <i>Depending on the complexity of the design changes in a sub-unit, steps 8-10 maybe repeated</i></p>	Students once again discuss and deliberate over Rules of Thumb as a class. This time the class is more prepared to fill in the <i>Why the Rule Works</i> column because of their exploration of the sub-unit's science concepts. Often, teachers will reword student justification or explanation (rephrasing as a question) to model the use of abstract decontextualized justification or explanation. The teacher models <i>science talk</i> both in discussion and when writing Rules of Thumb. If steps 8-10 are repeated, a Rules of Thumb Session occurs, and the <i>My Rules of Thumb</i> sheet is edited.
11.	<p>Plan Final Design, Pin-Up Session Students review Rules of Thumb, review experimental results and consult with other groups to plan final design designing the final car (or engine). Each group creates a Pin-Up (a sort of blueprint of their final design idea.</p>	
12.	<p>Build & Test, Gallery Walks Groups build and test their design. Data is collected and Gallery Walks occur.</p>	After redesign, students may verify Rules of Thumb, or sometimes, they may discover flaws in their Rules of Thumb. Once again, the teacher uses guided questioning and discussion (perhaps even more demos, science concept research, homework assignments) in an attempt to have students develop more valid Rules of Thumb and better articulate science concepts within a context as evidenced by their Rules of Thumb. This step highlights the priority and encouragement of an iterative development of science within the experimental classrooms. Also, again the teacher models <i>science talk</i> both in discussion and when writing Rules of Thumb.

13.	Final Presentation Students present their final car and attempt the challenge(s). Depending upon the sub-unit, the car may face anywhere from one to three challenges.	
14.	Review Challenge, Whiteboard Classes review the limitation of the car type, in general, and discuss needs to complete the challenges more successfully which leads into the next sub-unit.	Teacher and students review the Rules of Thumb, identifying those that seemed to have the most influence on successful designs, i.e. – those that met the challenge.
15.	Assessment Students review science concepts from the sub-unit and are given an assessment, usually a quiz or test.	



Georgia Institute of Technology

Research and Graduate Studies

Protocol Number 00A061

August 8, 2000

Dr. Janet Kolodner
College of Computing
Mail Code 0280

Dear Dr. Kolodner:

The full Institutional Review Board (IRB) has carefully considered your proposal "Scaffolding Learning by Design." Following full board review the IRB finds that the proposed procedures afford reasonable protection to the human subjects involved. Approval is granted for a period of one year, effective August 8, 2000 with an expiration date of August 7, 2001. *Note that the enclosed consent forms have been stamped with dates of IRB approval and expiration. Please use exact copies of these forms for consent gathering for the approved period.*

Approval is contingent upon your agreement to obtain informed consent from your subjects, to abide by the Georgia Institute of Technology Assurance of Compliance for the Protection of Human Subjects, and to keep appropriate records concerning your subjects. Consent forms should be retained for a period of at least three years after completion of the research.

You are required to submit to the IRB for review any changes in procedures involving human subjects prior to the implementation of such changes. You must inform the IRB if any evidence of risk is obtained in the form of injuries, complaints, or other indices. Such information must be transmitted to the IRB immediately upon its receipt by the project staff. At the end of one year, you are required to submit to the IRB a review and update of this research if you intend to continue. **Please note that all correspondence or e-mail you send to the IRB regarding this topic must include the full title and Protocol Number (shown in the upper right corner of this letter).**

The enclosed handout provides a listing of resources available to assist you in the regulatory and administrative requirements, as well as the ethical considerations, associated with research involving human subjects. If you have any questions concerning this approval or regulations governing human subject activities, please feel free to contact me at 404/894-6942, or you may contact Dr. Michael Kelly, IRB Chair, at 404/894-8240.

Sincerely,

Jill Burkhalter
IRB Administrator

Enclosure

cc: (without enclosure)
Dr. Michael Kelly, IRB Chair
Janis Goddard, Contracting Officer

Georgia Institute of Technology
Atlanta, Georgia 30332-0325 U.S.A.
PHONE 404-894-8884
FAX 404-894-7035

A Unit of the University System of Georgia

An Equal Education and Employment Opportunity Institution

IRB Administrator
Jill Burkhalter
Voice: 404/894-6942
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E-mail: jill.burkhalter@osp.gatech.edu
505 Tenth Street, NW, 3rd Floor
Office of Sponsored Programs
Georgia Institute of Technology
Atlanta, GA 30332-0420

Information Letter and Consent Form for Gathering Data for the Learning by Design™ Project

Principal Investigator of the Project: Janet L. Kolodner
Professor of Computing and Cognitive Sciences
College of Computing
Georgia Institute of Technology, Atlanta GA 30332-0280

Dear Science Student,

We'd like your permission to include you as a participant in a research project. The project is funded by the National Science Foundation and the McDonnell Foundation. It is a study of different ways to teach. This study will involve about 2,500 middle school science students and their teachers. The science teachers who are involved in this study volunteered to have their classes studied. Some of the teachers took a workshop to prepare them for this study. The principal of your school and the science coordinator read the plans for this study and talked to the project researchers. Your principal and your school district agreed to allow the study to take place in your class. Also, this study was approved by a research supervision board in your school district and one at Georgia Tech.

The project purpose:

The researchers are comparing teaching methods used in middle school science classes. The researchers are trying to find out:

- (1) how well students learn science using various teaching methods and materials;
- (2) how much students enjoy the different methods of teaching and learning;
- (3) what teachers think are good methods of teaching and learning.

The research plan:

To learn about these issues, the researchers ask students in the selected classes to do three things:

(1) Take a test on your knowledge of the science being taught in this study. The test is given to each student twice—once before you begin studying science, and once after the target science content in the curriculum is completed (about halfway through the school year). Your science teacher will give the test, then turn the tests in to the research team,

(2) Do hands-on science activities (science labs) working with a group of students in your class. Students will write answers to questions about the activity results. *Some of the activity sessions will be videotaped.* The researchers will use these videotapes to see how groups of students work together on science activities. There are two of these hands-on science activities scheduled—one about a month after school begins and one once after the target science content is completed (about halfway through the school year or later). These activities may be run by your teacher or by the research team. The research team will study the written answers as well as the videotapes.

Internal Review Board (IRB) Permission for Research Forms, 2 of 7

(3) Members of the research team will visit classrooms from time to time. They will observe how science learning occurs in your classroom. The researchers will take notes about the class. When the researchers are visiting your class, they might ask your permission to ask you questions about your work or to observe you work. They might also ask your permission to tape record or videotape your answers or your work.

Confidentiality:

The researchers will always make sure that no one knows your identity when they study student data. For written work, each student is assigned a special coded number. None of data will have the student's name, teacher's name, or school name on it when it is being analyzed. For analyzing videotapes, tape recordings, and transcripts, student and school identities are concealed.

Your rights, risks, and benefits as a research volunteer:

Taking part in this study is completely voluntary. If you do not want to volunteer, there will be no penalty. You may stop taking part in this study at any time with no penalty. You may refuse to take part in any of the research activities with no penalty. You will always be asked if you may be interviewed, videotaped, or tape recorded, and you may refuse at any point for any reason.

Important: Students who choose not to participate in the research will continue to participate in class activities. We will not collect information from these students. They may do research activities as a part of their class activity, but the teacher will not send their work to the researchers. For research that is not part of the class activity, the students will work on alternate assignments.

The researchers conclude that the risks for harm or discomfort are minimal. This means that the risks should be the same as what would be encountered in routine science class activities, assignments, and tests. Reports of injury or reaction should be made to Professor Janet L. Kolodner at (404) 894-7435. Neither the Georgia Institute of Technology nor the principal investigator has made provision for payment of costs associated with any injury resulting from participation in this study.

Although the activities that are being studied are designed to be learning opportunities, there is no direct benefit for participating in this research. Students will not be compensated for participating: in other words, students receive no money, materials, or higher grades if they take the tests, participate in activities and interviews. The major benefit is to society, because we will understand more about what makes a good science activity and what good teaching is.

→Return this Page to your Child's Teacher←
**Permission Form for Participation in the Learning by Design™
Science Curriculum Evaluation Project**

Teacher Name:(print neatly) _____
Student Name: (print neatly) _____

Sign either the "consent" or "do not consent" space below:

Consent: Your signature below indicates that the researchers have answered all of your questions to your satisfaction and that you agree to participate in this study. Both the student and his/her parent/guardian must sign here for the student to participate in the study.

Subject's Signature _____	Date _____
Parent/Guardian's Signature _____	Date _____
Investigator's Signature _____	Date _____

Do Not Consent: Your signature below indicates that the researchers have answered all your questions to your satisfaction and that you do not wish to participate in this study.

Subject's Signature _____	Date _____
Parent/Guardian's Signature _____	Date _____
Investigator's Signature _____	Date _____

Contact Persons:

If you have questions about the research, call or write

Jennifer Holbrook
Evaluation and Assessment Coordinator
Learning by Design™ Project
College of Computing
Atlanta, GA 30332-0280
Phone: (404) 385-0274
Fax: 404 894-5041
Email: holbrook@cc.gatech.edu

Janet L. Kolodner
Principal Investigator
Learning by Design™ Project
College of Computing
Atlanta, GA 30332-0280
Phone: (404) 894-7435
Fax: 404 894-5041
Email: jlk@cc.gatech.edu

If you have questions about your rights as a research volunteer, call or write:

Jill Burkhalter
Office of Sponsored Programs
Georgia Institute of Technology
Atlanta, GA 30332-0420
Voice (404) 894-6942 Fax 894-5285

Information Letter and Consent Form for Gathering Data for the Learning by Design™ Project

Principal Investigator of the Project: Janet L. Kolodner
Professor of Computing and Cognitive Sciences
College of Computing
Georgia Institute of Technology, Atlanta GA 30332-0280

Dear Science Teacher,

You are being asked to volunteer for a research project. The project is funded by the National Science Foundation and the McDonnell Foundation. It is a study of different ways to teach. This study will involve about 2,500 middle school science students and their teachers. As a teacher who participated in professional development activities offered by the Learning by Design™ project, you have already agreed to implement the Learning by Design™ curriculum in some or all of your science classes during the 2000-2001 school year. The principal of your school and the science coordinator read the plans for this study and talked to the project researchers. Your principal and your school district agreed to allow the study to take place in your classes. Also, this study was approved by a research supervision board in your school district and one at Georgia Tech.

The project purpose:

This year, your class will use curriculum units written by the researchers of the Learning by Design™ project at Georgia Tech. Your classes might also use computer software developed at Georgia Tech to enhance Learning by Design™ activities.

The researchers are trying to find out:

- (1) how well students learn using this approach (the teaching method, books, activities, and software);
- (2) whether students enjoy this method of teaching and learning;
- (3) whether teachers think this is a good method of teaching and learning.

The researchers will compare this method with other teaching methods that are often used in middle school.

The research plan:

To learn about these issues, the researchers ask teachers in these classes to do three things:

- (1) Fill out surveys at designated times (before the Summer Workshop, at the beginning of the school year, and as you teach the units). The survey questions may vary somewhat, but all questions will focus on your beliefs about teaching, your teaching experiences, and your experiences implementing the LBD units.
- (2) Participate in structured interviews at designated times. These interviews will also focus on your beliefs about teaching, your teaching experiences, and your experiences implementing the LBD curriculum. The researchers may ask your permission to tape record or videotape the interview.
- (3) Permit observation of your classes from time to time. Members of the research team will visit classrooms from time to time. They will observe how the class is using LBD™ units (and possibly on days when you are not using LBD™ units). The researchers will take notes about the class. When the researchers are visiting your class, they might ask your permission to ask you questions about your work or to observe you work. They might also ask your permission to tape record or videotape your answers or your work.

Confidentiality:

The researchers will assign a unique participant identification code to you for analyzing your survey data and for interview transcripts. For analyzing videotapes, tape recordings, and transcripts, student, teacher,

and school identities are concealed. However, you should be aware that the researchers are working fairly closely with a small number of teachers. It is likely that members of the research team will be aware of your identity when viewing videotapes or transcribing audio-tapes. We will conceal identities when presenting data or discussing teachers, classes, and schools with people outside the Learning by Design™ research team.

Your rights, risks, and benefits as a research volunteer:

Taking part in this study is completely voluntary. If you do not take part, you will have no penalty. You may stop taking part in this study at any time with no penalty. You may refuse to take part in any of the research activities with no penalty. You will always be asked if you may be interviewed, videotaped, or tape recorded, and you may refuse at any point for any reason.

Important: Teachers who choose not to participate in the research outlined above will continue to implement Learning by Design™ according to their contracts.

The researchers conclude that the risks for harm or discomfort are minimal. This means that the risks should be the same as what would be encountered in everyday life experiences. Reports of injury or reaction should be made to Professor Janet L. Kolodner at (404) 894-7435. Neither the Georgia Institute of Technology nor the principal investigator has made provision for payment of costs associated with any injury resulting from participation in this study.

Although the activities that are being studied are designed to be learning opportunities for the respondent, the most direct benefit for participating in this research is learning about what makes good science teaching, and learning new teaching skills. The major benefit is to society, because we will understand more about what makes a good science unit and what good teaching is.

Internal Review Board (IRB) Permission for Research Forms, 6 of 7

**Permission Form for Participation in the Learning by Design™
Science Curriculum Evaluation Project**

Your Name:(print neatly)_____

Sign either the “consent “or “do not consent” space below:

Consent: Your signature below indicates that the researchers have answered all of your questions to your satisfaction and that you agree to participate in this study.

Subject's Signature _____ Date _____
Investigator's Signature _____ Date _____

Do Not Consent: Your signature below indicates that the researchers have answered all your questions to your satisfaction and that you do not wish to participate in this study.

Subject's Signature _____ Date _____
Investigator's Signature _____ Date _____

Contact Persons:

If you have questions about the research, call or write

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Georgia Institute of Technology
Atlanta, GA 30332-0420
Voice (404) 894-6942 Fax 894-5285

A copy of this form will be returned to you.