PHYSICS PROBLEM SOLVING

IN

COOPERATIVE LEARNING GROUPS

A THESIS SUBMITTED TO THE
FACULTY OF THE GRADUATE SCHOOL OF
THE UNIVERSITY OF MINNESOTA

By

MARK HOLLABAUGH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

December, 1995

PHYSICS PROBLEM SOLVING
IN
COOPERATIVE LEARNING GROUPS

DEDICATION

This dissertation is dedicated to the memory of my grandparents, Herb and Hilda Potter, who were with me at every great step in my life; and to the memory of my uncle, Hank Helmke, a great fifth grade teacher and an even greater uncle.

ACKNOWLEDGMENTS

There are numerous people I wish to thank for encouraging me, prodding me, helping me and inspiring me. To my friends and relatives: You will never again hear me say, “I’m sorry, I can’t, I have to work on my dissertation.” To my former colleagues at WCAL-FM, St. Olaf College, thanks for the tunes that kept me sane on weekend afternoons.

Dr. Konrad Mauersberger, now of the Max Planck Institute, graciously agreed to my videotaping of his Physics 1041 and 1042 students. When I served as Konrad’s teaching assistant, I learned much about teaching physics from a master teacher. With out the cooperation of the Physics 1041 and 1042, this research would not have been possible. Thanks gang!

Several other University of Minnesota faculty where helpful: Dr. Frances Lawrenz of the Department of Curriculum and Instruction, provided me with references, encouragement, thoughtful questions, and ideas. Dr. David Johnson introduced me to group dynamics. Dr. Don MacEachern taught me everything known about statistical analysis in education, and I apologize to Don that there is only one ANOVA in this dissertation! Dr. Roger Jones asked me to team-teach a calculus-based physics course and introduce cooperative group problem solving to our students. Dr. Kenneth Heller lead the development of the problem-solving strategy and took a active interest in my research.

My fellow science education graduate students kept asking me, “When are you going to finish?” Most of them beat me to the finish line but never hesitated to encourage me: Dr. Rob Lonning, Dr. Ron Keith, Dr. Bruce Palmquist, Dr. Doug Huffman, Dr. Val Olness. I am especially grateful to Ron and Bruce for volunteering to be videotape operators, and to Bruce for his thorough independent evaluations of the 14 group’s written solutions. Scott Anderson carefully transcribed the videotapes.

My thanks to the librarians at Normandale Community College who obtained reference materials for me. Joyce Carey and Rex Gaskill of the Speech Communication Department provided me with numerous references on Toulmin and creative conflict in groups. Dr. Bill Chartrand proof read the entire manuscript.

Many former teachers and colleagues encouraged me, expressed an interest in this work and made thoughtful comments: Dr. Jim Cederberg, Dr. Duane Olson, Dr. Dave Nitz, Dr. Dave Dahl, Dr. Bob Jacobel, Dr. Amy Kolan, and former President Mel George all of St. Olaf College; and colleagues from the American Association of Physics Teachers: Allan Van Heuvlen, Thomas Rossing, Herschel Neuman, Fred Goldberg, Curtis Heigelke, Roger Freedman, Peter Urone and Michael Zeilik.

I am grateful to Dr. Roger Johnson (Cooperative Learning and Science Education), Dr. Larry Rudnick (Astronomy), and Dr. Charles Campbell (Physics) for agreeing to serve on my final oral examination committee. The commitment of these faculty to cooperative group problem solving is very much appreciated.

Two people never gave up on me: Dr. Patricia Heller and Dr. Fred Finley, my advisers. Fred asked the hard questions and made me clarify my ideas. Pat, despite her own heavy teaching and research load, always made time for me, always asked the right questions, and never once failed to say "You're doing a great job." I could not have asked for two better advisers. We form a well-functioning cooperative group of three!

ABSTRACT

This doctoral dissertation research investigated the process of argument co-construction in 14 cooperative problem-solving groups in an algebra-based, college level, introductory physics course at the University of Minnesota. The results of the research provide a rich description of argument co-construction, which, while predicted in previous literature, has not been systematically described. The research was a qualitative, case-study analysis of each group's discussion of the "physics description" portion of the group's problem solution. In a physics description physics concepts and principles are use to qualitatively analyze the problem. Transcripts were made from videotapes and the analysis focused on sequential groups of statements, called episodes, instead of isolated, individual statements. The groups' episodes were analyzed and described in terms of Stephen Toulmin's argument structure which consists of claims, grounds, warrants, and backings.

In 13 of these 14 cooperative problem-solving groups, students engaged in co-constructing an argument. The evidence for this is that the claim making shifted among group members, and the lower performance students often provided important components of the solution in the form of skeptical questioning or grounds, warrants, and backings. This means the physics description was a group product and not the work of the best individual in the group. This finding supports previous research.

Individual groups adopted a "group dynamic" and showed a self-consistent argument pattern as they co-constructed a physics description. Group members used additional claim types: "Modified Claims" clarify initially correct or slightly ambiguous claims and "Alternate Claims" correct initially incorrect or very ambiguous claims. These additional claims allowed the groups to engage in "creative controversy." The groups used grounds, warrants, and backings to support their claims. Their backings preferred the professor over the teaching assistant or the textbook.

TABLE OF CONTENTS

CHAPTER 3 - PATTERNS WITHIN A GROUP

CHAPTER 4 - PATTERNS BETWEEN GROUPS

LIST OF FIGURES

Appendix C

Appendix D

LIST OF TABLES

Chapter 4

CHAPTER 1

INTRODUCTION

American higher education is undergoing a paradigm shift (Johnson, Johnson and Smith, 1991). College education is moving from a learning model in which knowledge is transferred from a professor to the student to a model where students construct their knowledge with the help of the professor. The old paradigm was based on ideas of individuality and competitiveness. The new paradigm is based on cooperation and "**active learning**". The image of the old model is the learned professor lecturing from detailed notes to a hall partially filled with students. The new model envisions individuals and small groups of students actively processing ideas while they listen or engage in discussion, debate, and problem solving. The professor serves as a modeler, questioner, and mentor.

This paradigm shift is consistent with the latest research on the practice and theory of higher education. Arthur W. Chickering and Zelda F. Gamson (1987) enumerate seven principles for good practice in undergraduate education:

1. Encourage contacts between students and faculty.
2. Develop reciprocity and cooperation among students.
3. Use active learning techniques.
4. Give prompt feedback.
5. Emphasize time on task.
6. Communicate high expectations.
7. Respect diverse talents and ways of learning.

Higher education practitioners must design curriculum and instructional methods consistent with these principles as well as the latest research on how students learn. (Note: Terms in **boldface** font are listed and defined in the *Glossary* found in *Appendix A*.)

Cooperative learning has been proposed as one instructional strategy congruous with the paradigm shift. While much work has been done in primary and secondary education, it is only within the last decade that researchers have undertaken studies of cooperative learning in higher education. Researchers are now investigating various types of cooperative learning activities such as problem solving. Problem solving is an integral part of college physics courses. Thus physics courses provide an excellent context for this research.

Overview of The Dissertation

This dissertation is a qualitative **case study** of fourteen cooperative physics problem-solving groups and will proceed as follows:

Chapter 1 -- Introduction

- Overview of Dissertation
- Statement of the Problem
- Purpose and Research Questions
- Overview of Research Design
- Assumptions and Rationale for a Qualitative, Case-Study Design
- Methodological Issues and Limitations of the Research
- Significance of the Research

Chapter 2 -- Procedures

- The Role of the Researcher

STATEMENT OF THE PROBLEM

Problem Solving

Traditionally, college physics teachers have emphasized problem solving as a way to learn physics (Fuller, 1982). Teachers and students alike are not always satisfied with their problem-solving efforts. One reason for this may lie in the different approach that an **expert** (teacher) and **novice** (student) take to a problem (Larkin, McDermott, Simon and Simon, 1980). Novices tend to concentrate on the superficial features of a physics problem, whereas experts use principles of physics to analyze and solve a problem. For example, a novice would examine a problem like *At the Gasthaus* (Figure 1-1, page 4), see a sign suspended by a post and a cable, and interpret it as a "sign problem." On the other hand, an expert would most likely see the same problem and interpret it as a "static equilibrium problem." Novices also tend to immediately seek the proper equations that will solve the problem. That is, they attempt a *quantitative* analysis of the problem before constructing an adequate *qualitative* analysis.

Above the entrance door of an old German "GASTHAUS" hangs a sign. A 200 N metal beer mug hangs at the end of a 3 meter long strut that is attached to the wall by a hinge. The weight of the strut is 100 N. A support cable is attached to the strut at a point 2 meters from the wall and makes a 30° angle with the strut. Find all the forces acting on the strut. Useful information: $\sum \mathbf{F} = 0$ *and* $\sum \boldsymbol{\tau} = 0$

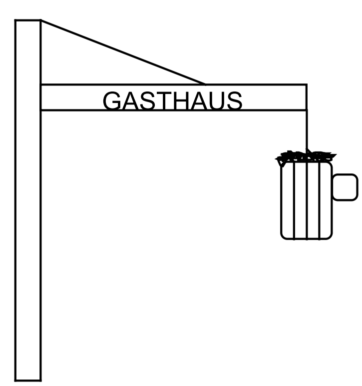


Figure 1-1. AT THE GASTHAUS

This qualitative analysis, or **physics description**, is crucial to a problem solution. The physics description includes aspects of problem solving such as deciding what general approach to take, describing the problem in terms of general physical principles, defining coordinate systems, drawing idealized diagrams, and, in the case of problems involving static or dynamic forces, constructing **free-body diagrams**. The failure of novices to solve problems may be their failure to develop adequate physics descriptions. (Heller and Reif, 1984) Recently, cooperative learning groups have been employed in college physics courses as a means to develop the problem-solving skills of beginning students (Heller and Hollabaugh, 1992).

Cooperative Learning

Research on cooperative, competitive and individualistic learning strategies dates back to at least 1897. Johnson and Johnson (1989) did a meta-analysis of nearly 400 studies spanning 90 years. These studies encompass all age groups of students from kindergarten to college, and all academic fields including science. About 40% of the studies were done with college-level students. In 85% of the studies students were randomly assigned to either a cooperative group treatment or an individual or competitive treatment. Johnson and Johnson note that the statistical probability that the results of these accumulated studies are merely due to chance is less than one in 100,000. Based on this cumulative research, they conclude that a cooperative effort will produce higher productivity and achievement than a competitive or individualistic effort will produce.

It is implied from the cooperative learning research that students in groups are involved in the process of co-construction. That is, students construct the knowledge and procedures necessary to complete a group task or achieve a shared goal. (The criteria for co-construction will be discussed in depth in Chapter 2). Mostly of the evidence for co-construction from the cooperative learning research literature is indirect. That is, much of the prior research in cooperative learning has focused on either comparing individual achievement of students in cooperative groups to students in competitive or individualistic learning environments, or on specific components of cooperative learning such as group size or gender and ability mix in groups. For example, Johnson and Johnson contend that "A conservative interpretation of the overall data would be that participating in cooperative groups does not hurt, and often facilitates the achievement of high-ability individuals, and clearly benefits the achievement of medium- and low-ability individuals" (Johnson and Johnson, 1989; p. 47).

The inference that there is co-construction in groups comes from looking at outcomes and products of the group. For example, a study by Heller, Keith, and Anderson (1992) supports co-construction of a physics problem solution by college students. Students solving physics problems in cooperative groups produced better physics descriptions than the best student in the group working as an individual on a matched problem. It was clear that the superior group product was not the work of the best individual in the group. Indeed, even the lower ability student appears to have contributed to a problem solution (Heller and Hollabaugh, 1992). That is, one thing that is already known about cooperative groups is that the outcome or product of the group is superior to the product of an individual. Groups are engaged in co-construction of a product. What is important to note is that almost all studies have focused on outcomes as opposed to the group process. "Few studies in science [education] have investigated the *collaborative processes within groups* and examined the negotiation of meaning that occurs" (Tobin, Tippins, and Gallard; 1994; p.45, emphasis added). And, "although studies of cooperative learning in the context of science education abound,... the focus of these studies has not been so specifically on the learning *process*" (Tobin, 1990; p. 418, emphasis added).

These findings suggest there is something about the group process that, for example, facilitates the co-construction of an effective physics description. Somehow, the group process guides the translation of the problem statement into a physics description that properly depicts the conceptual basis of the problem. Thus, what we already know about physics problem solving in cooperative groups is that groups co-construct a superior solution that is not merely the work of the best individual in the group. What is not known is *how* this occurs. That is, what is *not* well-understood is the sequence of behaviors and actions that lead to a superior product.

Toulmin Argument Structure

In a major summary of cooperative learning practice and research, Ann L. Brown and Annemarie Palincsar suggest a reason for the superior product of a group: There is "distributed thinking" and a "joint management of **argument construction**" in cooperative groups (Brown and Palinscar, 1989; p. 400). There are three terms that recur in this dissertation and there is a precise sense in which I am using them. Argument implies the students are engaged in developing an idea. It is very important to understand that *argument* doesn't mean *arguing*. An argument is a logical, thought-out conceptual statement, and as such, it has a structure. Construction implies the students "build" or “construct” their argument out of prior knowledge and ideas that surface in the course of the discussion. Co-construction means the group members are doing this together.

Brown and Palinscar suggest using a systematic argument structure to describe the co-construction process.

> “Because these tasks [i.e., co-construction] result in a great deal of spontaneous argument, systematic examination of relations between the discourse form and the type of posttest improvement should be possible. Such fine-grained analysis of what happens in group discussions and what type of learning occurs are badly needed.” (Brown and Palinscar,1989; p. 408)

Brown and Palincsar point to the argument structure proposed by Stephen Toulmin as a useful analysis tool in contexts such as cooperative groups (Toulmin, 1958, 1990; Toulmin, Rieke, and Janik, 1984; Nickerson, Perkins, and Smith, 1985). Toulmin’s structure is in keeping with the goal of a fine-grained analysis of the cooperative group process: “An argument is like an organism. It has both a gross, anatomical structure and a finer, as-it-were physiological one... The time has come to change the focus of our inquiry, and to concentrate on this finer level” (Toulmin, 1958, 1990, p. 94). Although arguments in different scientific fields may differ in fundamental ways, there is a commonality in the construction of an argument. In Toulmin's structure there are grounds, claims, warrants, backings, modalities and rebuttals. In developing his ideas he uses examples from both jurisprudence (“substantial arguments”) and mathematics (“analytic arguments”).

A **claim** is a fundamental assertion that is the goal or endpoint of the argument. **Grounds** or data, are the particulars of a situation that support the claim. When solving a physics problem , the grounds are the data given in the problem statement. In many argumentative contexts, one may never make explicit just *how* the grounds support the claim. In this dissertation I will use the term grounds as opposed to data. In physics, "data" often implies a *quantitative* feature. In the physics problems I will discuss here, the "data" sometimes consist of a non-numerical, *qualitative* pictures or statements.

A **warrant** is a general rule connecting particular grounds to their implications. The laws of physics or rules of mathematics are general warrants. The distinction between the grounds, or data, and warrants is not always clear, especially in science. In the simplest definition, "....data are appealed to explicitly, warrants implicitly" (Toulmin, 1990, p. 100). This lack of distinction between grounds and warrants will sometimes make it difficult to classify statements in this study. A warrant requires support called a **backing**. The appropriate backing for a warrant differs from field to field. In physics, backings are typically the generally accepted validity of well-established laws and principles such as Newton's Laws of Motion, or the citation of other authorities such as the professor or textbook to support a warrant.

Brown and Palinscar cite studies in which elementary-school students who are learning to read follow a Toulmin-like argument form (Brown and Palinscar, 1989, p. 404-405; citing Paley, 1981; and Pontecorvo, 1985). They note that "adults' argument structure follows certain identifiable sequences," but that children follow the structure at a "very simple level" (Brown and Palinscar, 1989; p.404). The cited examples reproduce transcript excerpts and identify statements as providing "factual support" or "appeal to general principle." Statements are not explicitly identified as Claims, Grounds, Warrants, or Backings. There is apparently no direct attempt to analyze systematically the movement of the argument from statement to statement or from person to person. What these prior studies lacked was a systematic, detailed analysis. What is *not* known is how to undertake such an analysis.

Summary

Previous research has revealed many findings about individuals working alone, competitively and in cooperative groups. We know the physics description is a key component of the problem solution. We know physics problem-solving groups co-construct a superior problem solution that is not merely the work of the best individual in the group. What will be different about this study is that the Toulmin argument structure will be used to systematically analyze the argument co-construction *process* within physics problem-solving groups.

PURPOSE AND RESEARCH QUESTIONS

The purpose of this study is to undertake a systematic, fine-grained examination of the argument co-construction process in fourteen college physics problem-solving groups using Toulmin's argument structure. The research focuses on the groups while they completed their qualitative analysis ("physics description") of algebra-based introductory physics problems. The following research questions guided the exploration:

1. Do these fourteen problem-solving groups engage in argument co-construction as they complete a physics description?

2. Are there self consistent argument co-construction patterns within a group?

3. Are there similarities in the argument co-construction patterns between the fourteen groups?

a) *Do their argument co-constructions begin or end with a Claim?*
b) *What roles do challenges to the original claim play in the argument co-construction process of these groups?*
c) *Do the groups have a preferential means to support claims made in argument construction (e.g., Grounds, Warrants, Backings)?*

OVERVIEW OF THE RESEARCH DESIGN

The nature of the group problem-solving process ultimately determines the research design and methods of analysis. For this study, I videotaped students in a University of Minnesota introductory, algebra-based, physics course while they were solving physics problems in cooperative groups. Fourteen problem-solving groups, spanning two 10-week academic quarters, comprise this investigation. Six different problems are represented in the sample and the texts of these problems are re-printed in Appendix B. This dissertation is a case study of these 14 groups, which compose the "elements" of the study.

The research proceeded as follows: First, the 14 groups were videotaped while solving problems and the tapes were transcribed. The transcriptions then were compared with the original videotape to insure accuracy as well as to annotate non-verbal behavior and to make references to the written problem solution.

Second, I devised a method that considered not only the types of statements students made, but also the overall manner in which the group's constructed their problem-solving arguments. An important feature of this method is that the statement categories are based on what was observed in the groups' discussions. That is, the coding categories were not predetermined. Predetermined analysis categories are often better suited for quantitative research (Gustafsson, 1977; Delamont and Hamilton, 1984). Even so, some starting point was needed for analyzing the groups' discussions. I chose the argument structure of Stephen Toulmin for three reasons. First, I heard of the Toulmin argument structure in the context of scientific reasoning. Second, I believed I could identify Claims, Grounds, Warrants, and Backings in the students' conversations. Third, Brown and Palincsar make specific mention of Toulmin as a useful argument structure in looking at cooperative groups (Brown and Palincsar, 1989).

Then I made "rich descriptions" of the argument co-construction of four groups solving the same problem (*At the Gasthaus*). The basic unit of analysis was defined to be the **episode**. An episode is made up of students' statements, but it contains a complete thought. B. Othanel Smith and Milton O. Meux used episodes to categorize *student-teacher* interactions in an analysis of classroom behavior (Smith and Meux, 1970; Smith, Meux, Commbs, Nuthall, and Precians, 1967). An episode is "defined as one or more exchanges which comprise a completed verbal transaction between two or more speakers.

A new episode is determined by a shift in what the speakers are talking about, which may be a new aspect, or part of a topic or a complete change of topic" (Sandefur and Bressler, 1971, p. 23). In a sense, the episodes become "mini-contexts" that fit together into a larger context, namely the group's construction of the physics description.

Next, I drew flowcharts that describe visually the "flow" of the physics description construction process. Differing symbols for claims, grounds, warrants, backings, and other statement types, enabled an easy visualization of an individual group's argument pattern. Finally, common and unique features between the fourteen groups were noted. Generalizations answering the research questions were then made on the basis of all fourteen groups.

ASSUMPTIONS AND RATIONALE FOR A QUALITATIVE, CASE-STUDY DESIGN

Because a *qualitative*, case-study research design differs from the more common quantitative design, I will briefly explain the assumptions of the design and rationale for choosing this design. The design of *quantitative* research is well-established in science education. That type of research is based on a pre-determined set of analysis criteria, generally utilizes statistical measures to draw conclusions, and is readily duplicated. The qualitative, case-study research design has contrasting characteristics and actually emerges *from* the research being conducted (Creswell, 1994). In this case, examination of the group process itself determines the nature of the analysis criteria (Delamont and Hamilton, 1984).

Two features of this dissertation research suggested that a qualitative approach was more appropriate than a quantitative approach. First, cooperative learning research is, by its very nature, research into applied social psychology. In this area of research, rich, qualitative descriptions of groups of people are as important, if not sometimes more important, than quantitative descriptions. People function in a social context, in this case the cooperative group. The group dynamics, hard to quantify, are crucial to understanding the group's product *and* process. In an attempt to understand what students in a problem-solving group actually *do*, I will make "rich descriptions" of the problem solving groups. From these qualitative descriptions I will look patterns within and between the groups.

Second, although the groups' solutions consists of verbal statements, I will argue that just *counting types* of statements students make is *not* a "fine-grained analysis." While individual statements are important, and form the basis of the analysis, the larger picture must also be considered. That is, the *context* of the statements must also be described and understood. Each group functions in the context of its cooperative group *process*, and each physics description, which is the product of the group, is jointly constructed in the same context. I will look for patterns in the co-construction of the argument that are a part of this problem-solving process. The emphasis is on the *process* of co-constructing the problem solution as opposed to the *product*, namely the "correct" answer.

These two features of this dissertation research suggested that I take this qualitative **case study** approach to the research. The case study is a qualitative research method in which the researcher explores a single entity, process, or phenomenon, and uses a variety of data collection tools including qualitative descriptions and records (e.g., video or audio tapes) (Creswell, 1994; Strauss, 1987). For this research, the qualitative descriptions and records include videotapes of groups solving the problems (and the subsequent transcriptions), copies of their written solutions, and pertinent notes made by the videographers. Some quantitative data are available, such as the scores on the students' in-class examinations. These characteristics of this *particular* case study, along with the definition of the population being studied, delimit the boundaries of the study. These boundaries will also serve to define and limit the outcomes of the research (Stake, 1988).

This design choice will influence the form and structure of this dissertation. The traditional "outline" will be modified. For example, instead of a separate "Review of the Literature" chapter, references to pertinent literature in cooperative learning, physics problem solving, and research methods will be made as they are needed to describe the "procedure" that evolved.

METHODOLOGICAL ISSUES AND LIMITATIONS OF THE STUDY

Any research, be it in physics or in education, has limitations. Some of the limitations of this study result from the choice of design, some from the analysis tools, and some from the data set (the 14 groups). Some of these limitations were apparent to me at the onset of this study. Other limitations emerged as the work progressed and these will be discussed when appropriate.

Toulmin Argument Structure

A fundamental component of this research is the argument structure proposed by Stephen E. Toulmin. A case must be made for the use of this argument structure over other possible structures. It would, for example, be possible to return to the 2500 year-old method of Aristotle and examine the arguments of these 14 groups in terms of syllogisms (Mills, 1968). This form of deductive reasoning consists of a major premise, a minor premise, and a conclusion. For example, *When an object is in a state of static equilibrium* (the major premise), *the forces add to zero and the torques add to zero* (the minor premise), *therefore for this sign* $\Sigma F=0$ *and* $\Sigma \tau=0$ (the conclusion). It is possible to develop a thorough model of scientific reasoning and argumentation using the Aristotelian structure (Giere, 1984). Some aspects of the Aristotelian structure could be useful in this research, but overall, the syllogistic approach is too cumbersome for use in analyzing everyday speech (Thompson, 1971).

The argument structure of Chaim Perelman is an "audience centered" theory of argumentation. Also based on Aristotle, Perelman's structure emphasizes increasing the "mind's adherence" to an idea. To accomplish this, one must carefully consider the audience to which one presents the argument (Rieke and Sillars, 1975). This structure focuses on the hearer of the argument and not on the speaker. Since this dissertation research is concerned primarily with a group process, and not what individuals hear and how it effects them, this structure is not particularly useful.

Interestingly, many authors writing about argumentation often start with a nod to Aristotle and but end with a lengthy discussion of Toulmin (Thompson, 1971). Toulmin is essentially a philosopher and historian of science (Toulmin and Goodfield, 1961). Although well-grounded in classic logic, he goes a step beyond it. A large percentage of the existing scholarly papers and talks which use Toulmin are from various speech communication association meetings and journals. Within two years of the publication of

The Uses of Argument, Brockriede and Ehninger (1960) introduced Toulmin to the field of speech and rhetoric. "Toulmin's analysis and terminology are important to the rhetorician for two different but related reasons. First, they provide an appropriate structural model by means of which rhetorical arguments may be laid out for analysis and criticism; and, second, they suggest a system for classifying artistic proofs which employs argument as a central and unifying construct." Within ten years of publication, Toulmin had been discussed or used as an analysis tool in at least eight speech textbooks, five doctoral dissertations (including one at the University of Minnesota), and several scholarly articles (Trent, 1968; Mills, 1968). Not everyone in the academic fields of speech and debate enthusiastically welcomed the Toulmin argument structure. Willard (1976), for example, eschewed the use of Toulmin-like argument diagrams because they were "mired in considerable (and unavoidable) conceptual confusion.... [and] persuasive arguments are too complex and dynamic to be adequately depicted diagrammatically." Despite criticism Toulmin has nonetheless become pervasive in speech, communication theory and debate. Why is this?

While Aristotle might be useful in devising a legal argument, for example, the syllogism would be less helpful in normal, everyday speech. In the modern world, human speech is very unlike the speeches of the orators at the acropolis. Toulmin offers a more contemporary and *useful* model. Most high school and college debate courses include an introduction to Toulmin's argument structure (Smith and Hunsaker, 1972). In such contexts, the emphasis is on the spoken word and supporting one's ideas with evidence. Hence the language of Claims, Grounds, Warrants, and Backings is very beneficial. Thus, part of Toulmin's appeal, and hence usefulness, is that his structure is more amenable to analyzing *spoken* arguments (Rieke and Sillars, 1975). The videotapes of these 14 problem-solving groups are a record of spoken words. But there is an even more important reason for using Toulmin in analyzing cooperative group problem solving.

The purpose of this research is to search for *patterns* in argument construction. This suggests that the argument construction must be described, both in terms of words and a "visual" pattern or diagram. There are four aspects of the Toulmin structure that make it attractive for this purpose. First of all, Toulmin would say an argument is *constructed* (Bettinghaus, 1966; Toulmin, 1958, 1990) by the maker of the argument. The support of a Claim with Grounds, Warrants, and Backings is constructivist: The meaning, and hence validity of the Claim rests in the choice of appropriate support statements. That is, the claimant constructs reality out of his or her understanding of the Claim. Second, the Toulmin structure is useful in *describing* an argument (Smith and Hunsaker, 1972). This is because it is based on actual speech patterns of people (Rieke and Sillars, 1975). The Claims, Grounds, Warrants, and Backings are types of statements. While the Claim is like a major premise, the Grounds, Warrants, and Backings classifications allow for greater descriptive nuances than just classifying secondary statements as minor premises. In a response to Willard (1976), Burleson (1979; p. 146) notes that an important condition for the Toulmin model to work "is the careful consideration of the context from which units of analysis are drawn, for it is the context which gives meaning to statements as features of an argument." In this research, the arguments are based on a very specific context: physics problem-solving groups. Third, Toulmin himself notes "...scientists in all cultures develop *systematic procedures* *for representing* the natural world and its makeup, functions and origins" (Toulmin, Rieke, and Janik, 1984, p. 315, emphasis in original). This suggests scientific arguments are systematic and have a structure. Finally, Toulmin's structure readily allows for *diagraming* an argument (Rieke and Sillars, 1975; Trent, 1968). All books and articles that use Toulmin's structure include diagrams to illustrate the argument's flow and progress. Because I am looking for patterns of argument co-construction in this research on physics problem solving, it will be helpful to use Toulmin's argument structure because this systematic structure is readily described in constructivist language and lends itself to being diagrammed. Ultimately, the choice of this argument structure is very utilitarian: Toulmin works. This is like physics. Physicists use wave mechanics and the Schrödinger Equation because, despite "uncertainties," they work in many situations.

Hence, much of the validity of this study depends on the Toulmin structure of argumentation. Despite its appeal, the structure has inherent limitations. People do not *strictly* follow the Toulmin structure in normal, everyday speech, which is what is spoken in a problem-solving group. Likewise, the groups are concerned with not only the solution of the problem, but also the maintenance of the group, that is with the procedures of the group. The distinction between procedures and content isn't always clear. The question arises, are the procedures a part of the co-construction of the argument? When reading the transcripts of the groups, it is easy to notice statements that relate to content (i.e., the physics) and are very analytic ("sum of the forces equals...."), those that relate to group functioning ("we've got to watch the time"), and those that relate to the Problem-Solving Strategy ("What's our target variable?"). It would be possible to classify statements relating to group functioning or the Problem-Solving Strategy as procedural, but the strategy contains elements of physics content.

It will be difficult in the descriptions of the groups to cleanly separate the analytic, physical principle arguments from the procedural arguments. The reason is because the problem-solving *arguments* specifically relate to the problem-solving *strategy*. Students were taught, for example, that a free-body diagram was an important part of the Physics Description. Thus, “We've got to draw the free-body diagram” is an anticipated procedural Claim that is a very necessary part of the solution. This inter-relatedness of the process and content may not allow for the clean distinction Toulmin would make between “analytic” and “substantive” or procedural arguments:

> We shall therefore class an argument as analytic if, and only if, it satisfies that criterion-- if, that is, checking the backing of the warrant involves *ipso facto* checking the truth or falsity of the conclusion-- and we shall do this whether a knowledge of the full backing would in fact verify the conclusion or falsify it (Toulmin, 1990, pp. 133).

In the context of the *Gasthaus* example, drawing a free-body diagram is both a substantive *and* an analytic argument. If the negative statement was true, namely that drawing a free-body diagram is unnecessary, then the conclusion from that action, namely that the sign is in static equilibrium, would be false. This clearly contradicts the given information. Hence, it seems reasonable to utilize the Toulmin structure when describing the problem-solving group’s procedural conversations. These “arguments” are much more akin to legal arguments in that they focus on the procedure, process, and promotion of orderly progress through the problem.

I should note that a given segment of a group’s conversation may not contain *all* components of the Toulmin structure. In Toulmin’s structure, the argument *ends* with the claim. But, verbal arguments often *begin* with the claim. It will be seen that the groups also use statements that are clearly not Grounds, Warrants, Backings, or Claims. Thus, I will define additional statement categories. This again is characteristic of the qualitative design: Analysis categories grow out of the data.

Validity, Reliability, Generalizability

If this research is to be meaningful and add to the sum of what we know about cooperative group physics problem solving, then it must have meaning beyond this discussion of these 14 groups. This issue generally is discussed in terms of validity, reliability and generalizability. Quantitative research is replete with statistical measures, such as analysis of variance (ANOVA), that allow for an objective determination of validity, reliability and generalizability. The validity, reliability and generalizability of a qualitative study are much more subjective, and hence open to different interpretations. Statistics are not always useful. The careful reader of this dissertation will uncover the single ANOVA buried within these pages. Even so, qualitative researchers have found ways to establish validity, reliability and generalizability (Wolcott, 1990; Maxwell, 1992).

A study, method, or technique is said to be valid if it actually measures what it claims to measure. One technique researchers have used to promote the internal validity of a study is triangulation. This research technique uses two or more data collection methods to study some phenomena or process. The term originates in navigation where two bearings are used to locate one's position (Stake, 1988; Cohen and Manion, 1994). There is only a limited degree of triangulation possible in this study because there is only one data set (the videotapes of the 14 groups) and one data analysis method (the coded transcripts and flowcharts). I will, however, attempt whenever possible to view important findings from multiple vantage points. There are four of these vantage points, or as I will call them, “reference points.” These reference points are the videotapes, written problem solutions, quantitative data, and subjective opinions based on viewing the videotapes. Figure 1-2 (page 23) illustrates this idea.

One specific analysis technique that will become apparent is that one set of four group solutions continually revealed new insights into the groups’ argument construction processes. Before a new analysis idea was introduced or an new analysis tool applied to all 14 groups, it was first applied to groups 4A, 4B, 4C, and 4D. That is, the system was fined tuned on the four groups. This was done to promote “internal validity,” or consistency of the analysis method.

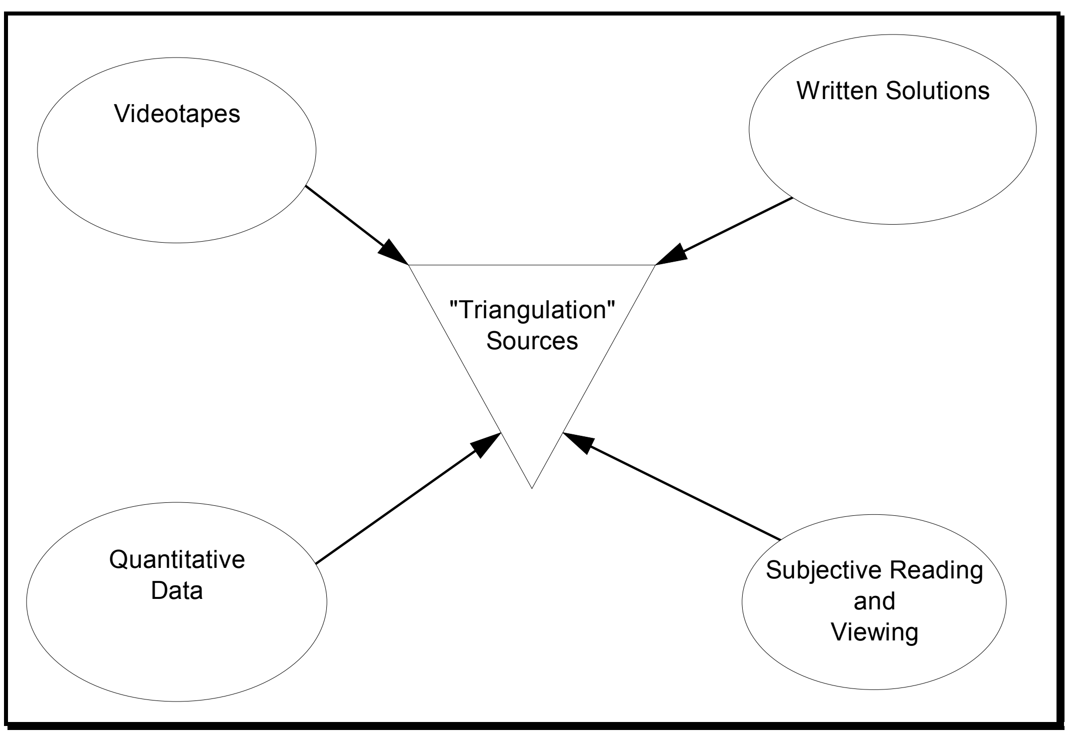


Figure 1-2. Four Points of Reference.

A case-study approach allows for *limited* replication. This is the issue of reliability. For this research to be reliable, it is important to carefully document the data collection and analysis procedures. Assumptions must be clearly stated. If these guidelines are followed, another researcher, with *similar* knowledge of the content and context of the research should be able to replicate the research. Even so, "...it is impractical to make precise replication a criterion of generalizability in qualitative work. Qualitative research is so arduous that it is unlikely that high-quality researchers could be located to engage in the relatively unexciting task of conducting a study designed specifically to replicate a previous one" (Schofield, 1990; p. 203). What is probably more important than precise replication is the stimulation of further qualitative and quantitative research.

Finally, the generalizability, or external validity, of the this study depends on applying it to a *similar* context and content. That is, are the results generalizable to other introductory, algebra-based, college physics courses, with *similar* implementation of cooperative learning and problem solving? Because each physics course has unique features, such as the professor, teaching assistants, textbook, and student population, it is not possible to *exactly* replicate the study. Rather than think in terms of generalizing the findings to the *same* context and content, it might be better to think in terms of *translating* the results to a *comparable* situation (Schofield, 1990; Goetz and LeCompte, 1984).

This Research is Exploratory

The very nature of a qualitative case-study approach makes this research exploratory and speculative, as opposed to definitive. This research will tell us "where to look" in attempting to understand cooperative group problem solving. That is, the patterns found in the group processes will help set the future research agenda, both qualitative and quantitative, in cooperative group problem solving.

The Researcher as a Participant

Finally, there is an epistemological question I must acknowledge. In a qualitative case-study design the researcher "interacts" with that which is being researched. Because of this, and because the design emerges from that which is being studied, the research is value-laden and biased. That bias, however, does not attempt to force specific results or conclusions. It rather recognizes that, for example, my choice of an analysis category reflects my world-view. In a sense, I am a participant in the research, despite my efforts to distance myself from any causal effect on the outcomes. The Heisenberg Uncertainty Principle is a useful analogy. The act of making the measurement disturbs the system. The art of qualitative research is to keep the disturbance to a minimum (although perhaps not as small as Planck's constant).

Significance of the Study

With all of these limitations, it may seem that the choice of a qualitative case-study design severely limits the outcomes of this study. Although it may not be possible to specify what *all* physics students do in cooperative group problem solving, it will be possible to describe what *these* students in *these* 14 groups did. That in itself will be an accomplishment due to the relative paucity of insights into what students actually do in cooperative problem-solving groups. The ultimate value of this research is to extend the theoretical basis for understanding cooperative group problem solving. A better understanding of the theory of cooperative-group problem solving will enable the design of both qualitative and quantitative research to further investigate the theoretical base. Then, teaching strategies and instructional materials to foster effective cooperative problem solving can be designed and tested.

Likewise, since research depends on valid analysis schemes, the design of a qualitative, case-study approach will contribute to research methods in science education. As far as we know, this is the first time a qualitative case study has examined cooperative group physics problem solving. At a very local and personal level, this study expands the types of research being done by the Physics Education group at the University of Minnesota.

Ultimately, I believe this study will be much like the manned missions to the moon in the 1970's. About 400 kilograms of rock were collected from "only" six locations. Their analysis, plus seismic and other data, led to countless questions, and several new theories about the origin and evolution of our nearest celestial neighbor. Raising new questions and giving birth to new theories to test is the best goal of all research.

CHAPTER 2

PROCEDURES

Chapter Overview

In this chapter I will discuss the procedures used in this research. Because the researcher in a qualitative case study engages in different tasks than in quantitative research, I will explain how this study differs from the more common quantitative study. A description of the research setting, a college physics course, will include a discussion of prior research in physics problem solving and in cooperative learning. Because this study is based on the Toulmin argument structure, this chapter focuses on the identification of the Toulmin statements.

Readers familiar with the more common quantitative research design will note there is not a separate "Review of the Literature" chapter in this dissertation. Instead of a "positivist" approach to the literature, I will take a more "inductive"one. That is, the available literature on research and theory relevant to my research goals will serve to "frame" the discussion. I will introduce applicable ideas and findings as they are needed. This, by the way, is consistent with a constructivist approach to qualitative research.

THE ROLE OF THE RESEARCHER

One of the characteristics of a qualitative case-study approach is that the researcher is an integral part of the process. That means the research is dependent upon the researcher's own presuppositions, assumptions and biases. The task I faced was to make sure that I was, first, aware of my own presuppositions, assumptions and biases, and second, aware of how these might prejudice or skew the outcomes of the study. Throughout this dissertation, I will attempt to explain where I believe I "interacted" with the data, the method, and the results.

I discovered some interesting aspects about doing this type of research from my perspective as a physics teacher. Physics by its very nature is exceptionally quantitative. Initially I tried to answer my research questions using quantitative measures. These efforts yielded few useful insights. So first I learned to throw away my *quantitative* analytical skills and concentrate on *qualitative* analytical skills. Second, I learned that a physicist is uniquely qualified to undertake this kind of qualitative research. Understanding what the students were doing in solving these problems required that I understand the physics. That understanding came not only from graduate work in physics, but also from having taught (at Normandale Community College) the same algebra-based course as the University of Minnesota course used in this study.

RESEARCH CONTEXT AND SETTING

The physics courses used for this study were the two-quarter sequence Physics 1041 and 1042, taught winter and spring quarters 1991, at the University of Minnesota, by Professor Konrad Mauersberger (now at the Max Planck Institute, Heidelberg). This algebra-based, introductory course was taken primarily by pre-health science and pre-architecture students, plus others needing an introductory physics course. The textbook was *Physics: A General Introduction*, 2nd Edition, by Alan Van Heuvelen (1986). Each week, students met for three 50-minute lecture periods, one double-period lab (1 hour, 50 minutes) , and one 50-minute "recitation" period. A given group of students were in the same lab and recitation cooperative group. The graduate teaching assistant was the same for their lab and recitation. The only factor in determining the recitation/lab section in which a given student was registered was his or her individual employment or class schedule. That is, there was not a random assignment of students to a particular section. The teaching assistants, however, assigned students to their cooperative groups within the recitation/lab section. It was *intended* that there would be a heterogeneous mix within a group in terms of the students' performance in the class (high, medium, low). However, the teaching assistants only occasionally followed this plan. Also, it was *intended* that there would be all groups of three, and no groups where the number of men was greater than the number of women. We found in previous research that heterogeneous cooperative groups of three, with attention paid to the gender mix, worked best for physics problem solving (Heller and Hollabaugh, 1992).

In reality, of the 14 groups in this study, there were 11 groups of three. Only four of these three-member groups met the gender criteria, and of these four, only one (Group 3A), met the ability composition criteria. That is, the assignment to groups was not what I would do in my own classes. However, I didn't interfere with the teaching assistants, although at their weekly meetings I made some suggestions about the group compositions. Even so, I believe that these departures from the "desirable" may have contributed to some interesting outcomes.

Students in a group worked a "practice" problem one week, and then worked a problem for a grade the following week. Students were then reassigned to new groups for another two-week period. During each of the two quarters, there were four graded problems, offering eight data collection opportunities.

The main reason for reformulating the groups after each graded problem was to promote heterogeneous grouping. This also tends to avoid a situation where group members become dependent upon one person for the solution. Sometimes personality conflicts arise in a group and reformulation can alleviate the difficulty. A negative aspect of the periodic reformulation is the short "residence time" of a student in a group. Two weeks *may* be too short a time for students to become cohesive and work cooperatively.

The students were introduced to the four group roles of Manager, Recorder, Skeptic and Engergizer. Table 2-1 (page 32) is a handout we use in our classes to teach the group roles. The teaching assistants were introduced to these roles in their initial training and were asked to instruct their students in the use of the roles. There are numerous comments by the students in the transcripts that reference these roles. Also, some of the actions they take are actually the *outcome* of these roles. Hence, the "sounds like" ideas later helped me when I had to code statements in the transcripts. These roles are "metacognitive." That is, they are thinking tasks individual, competent problem solvers do when faced with a physics problem. For example, physicists are very good at asking themselves skeptical questions when faced with a new situation. Novice problem solvers typically do not have the metacognitive skills necessary to engage in this type of activity. These roles are based on observations of what competent problem solvers actually do (Dreyfus and Dreyfus, 1984; Heller, Keith and Anderson, 1992).

Students were taught a problem solving strategy which was modeled in class by the professor (Heller and Hollabaugh, 1992). They were expected to use this five-step strategy in the recitation period when solving a complex problem as a group. Throughout their discussions, they make references to the steps of this strategy. Thus, it will be helpful for the reader to be somewhat familiar with the strategy and its theoretical background. Table 2-2 (page 33) summarizes the main features of the strategy.

ACTIONS	WHAT IT SOUNDS LIKE
<u>MANAGER</u> DIRECT THE SEQUENCE OF STEPS. KEEP YOUR GROUP "ON-TRACK." MAKE SURE EVERYONE IN YOUR GROUP PARTICIPATES. WATCH THE TIME SPENT ON EACH STEP.	*"LET'S COME BACK TO THIS LATER IF WE HAVE TIME."* *"WE NEED TO MOVE ON TO THE NEXT STEP."* *"CHRIS, WHAT DO YOU THINK ABOUT THIS IDEA?"*
<u>RECORDER/CHECKER</u> ACT AS A SCRIBE FOR YOUR GROUP. CHECK FOR UNDERSTANDING OF ALL MEMBERS. MAKE SURE ALL MEMBERS OF YOUR GROUP AGREE ON PLANS AND ACTIONS. MAKE SURE NAMES ARE ON GROUP PRODUCTS.	*"DO WE ALL UNDERSTAND THIS DIAGRAM?"* *"EXPLAIN WHY YOU THINK THAT."* *"ARE WE IN AGREEMENT ON THIS?"*
<u>SKEPTIC</u> HELP YOUR GROUP AVOID COMING TO AGREEMENT TOO QUICKLY. MAKE SURE ALL POSSIBILITIES ARE EXPLORED. SUGGEST ALTERNATIVE IDEAS.	*"WHAT OTHER POSSIBILITIES ARE THERE?"* *"LET'S TRY TO LOOK AT THIS ANOTHER WAY."* *"I'M NOT SURE WE'RE ON THE RIGHT TRACK."* *"WHY?"*
<u>ENERGIZER/SUMMARIZER</u> ENERGIZE YOUR GROUP WHEN MOTIVATION IS LOW o BY SUGGESTING A NEW IDEA; o THROUGH HUMOR; OR o BY BEING ENTHUSIASTIC. SUMMARIZE (RESTATE) YOUR GROUP'S DISCUSSION AND CONCLUSIONS.	"*WE CAN DO THIS!"* *"THAT'S A GREAT IDEA!"* *"SO HERE'S WHAT WE'VE DECIDED..."*

Table 2-1. Cooperative Group Roles.

FOCUS the PROBLEM

Picture and Given Information

- Construct a mental image of the problem situation.
- Draw a picture which show the important objects, their motion, and their interactions.
- Label all known information.

Question

- What is being asked?
- How does this translate into some calculable quantity?

Approach

- Outline the concepts and principles you think will be useful in solving the problem(e.g., definition of velocity and acceleration, Newton's Second Law, conservation of energy).
- Specify convenient systems to use in the problem solutions.
- Specify specific time intervals over which the application of each principle will be the most useful.
- Identify any constraints present in this situation.
- Specify any approximations or simplifications which you think will make the problem solution easier, but will not affect the result significantly.

DESCRIBE the PHYSICS

Diagram and Define Variables

- Translate your picture into a diagram(s) which gives only the essential information for a mathematical solution.
- Define a symbol for every important physics variable on your diagram.
- Usually you need to draw a coordinate system showing the + and - directions.
- If you are using kinematics concepts,, draw a motion diagram specifying the objects' velocity and acceleration at definite positions and times.
- If interactions are important, draw idealized, free-body, and force diagrams.
- When using conservation principles, draw "before", "transfer", and "after" diagrams to show how the system changes.
- To the side of your diagram(s), give the value for each physics variable you have labeled on the diagram(s) or specify that it is unknown.

Target Variable

- What unknown is it that you must calculate from the list of variables?
- Will the calculated quantity answer the question?

Quantitative Relationships

- Assemble your toolbox of mathematical expressions which use the principles and constraints from your approach to relate the physics variables from your diagrams.

PLAN the SOLUTION

Construct *specific* algebraic equations

- Determine how the equations in your toolbox can be combined to find you target variable.
- Begin with an equation that contains the target variable.
- Identify any unknowns in that equation.
- Find equations from your toolbox which contain these unknowns.
- Continue this process until your equations contain no new unknowns.
- Label each equation for easy reference.
- Do **not** solve equations numerically at this time.

Check for Sufficiency

- You have a solution if your plan has as many independent equations as there are unknowns.
- If not, determine other equations or check the plan to see if it is likely that a variable will cancel from your equations.

Outline of Math Solution

- Indicate the order in which to solve the equations for a desired variable and which equation to substitute the expression for that variable.
- Typically, you begin at the end of your plan and work backwards to the first step, which is an equation containing your target variable.

EXECUTE the PLAN

Follow the Plan

- Do the algebra in the order given by your outline.
- When you are done you should have a single equation with your target variable
- isolated on one side and only known quantities on the other side.
- Substitute the values (numbers with units) into this final equation.
- Make sure units are consistent so that they will cancel properly.
- Calculate the numerical result for the target variable (s).

EVALUATE SOLUTION

Is answer properly stated?
Is answer reasonable?
Is answer complete?

- Do vector quantities have both magnitude and direction?
- Can someone else follow your solution?
- Is the result reasonable and within your experience?
- Do the units make sense?

Have you answered the question?

Table 2-2. Summary of Problem Solving Strategy

THEORETICAL FOUNDATIONS

Many features of the Physics 1041/1042 course design and the cooperative groups result directly from fundamental research in problem solving and cooperative learning. This section presents a summary of research and practice in physics problem solving and cooperative learning.

Problem Solving Strategy

Perhaps Morton Hunt (1982) gave the most concise definition of problem solving: "A person is confronted with a problem when he wants something and does not know immediately what series of actions he can perform to get it" (p. 236). This definition suggests several things about problem solving. Problem solving is a *process*, consists of a series of *steps*, and the problem solver is involved in *constructing* the solution. Much of the research on problem solving has proceeded with this kind of an operational definition. The research on physics problem solving has evolved over the last twenty years. Initial work on the acquisition of general problem-solving knowledge and problem-solving skills progressed to problem solving in general, mathematics problem solving, and finally problem solving in areas like physics.

Early Research in Problem Solving

In their classic work *Human Problem Solving*, Herbert A. Simon and Allen Newell (1970) summarized the "**information processing model**" approach to human problem solving. First, one perceives the raw data and processes these perceptions far enough to recognize the problem context. Next, the solver makes a mental representation of the problem. This is an interpretation of what the goal is, where the solver is in relation to it, and what kinds of acts one must perform to get to the goal. The total set of mental operations used in the effort to move from the given data to the goal is what Simon and Newell call a "production system" or a program. In the course of carrying out the program, the solver notices whether any step, or series of steps, decreases the distance to the goal; if so, you continue with it, but if not, you move on to the next step or steps in the program (Hunt, 1982).

Due to the narrow limits of our short-term memory, we work our way through a problem in serial fashion, taking one thing at a time rather than simultaneously searching in disconnected parts of the problem. This avoids a trial and error approach. Sometimes the solver searches experience for an analogy, because all learning is based on prior knowledge and experience. (This emphasis on prior knowledge and experience is also a characteristic of constructivism in science education.) Simon and Newell's work forms the foundation of subsequent research in problem solving.

Some of the earliest work recognized that there are stages of development in a person's knowledge or skill. For example, Dreyfus and Dreyfus (1984) delineated five stages of skill acquisition in any type of "problem solving":

> ***Novice***: learns to recognize various objective factors and features relevant to the skill and acquires rules for determining actions based upon those facts and features.
> *Advanced Beginner*: Performance improves to a marginally acceptable level only after the novice has considerable experience in coping with real situations. Uses context-free facts.
> *Competence*: With more experience, the number of recognizable context-free and situational elements present in a real-world circumstance eventually becomes overwhelming. People learn a hierarchical procedure of decision making.

> *Proficiency*: Intuition is neither wild guessing nor supernatural inspiration, but the sort of ability we all use all the time. The proficient performer, while intuitively organizing, will still find himself thinking analytically about what to do.
> *Expertise*: An **expert** generally knows what to do based on mature and practiced understanding. When things are proceeding normally, experts don't make decisions; they do what normally works.

This model represents a progression in the sense that a typical learner's best performance in a particular type of situation will initially stem from novice rule-following, then from the advanced beginner's use of aspects, and so on through the five stages. There is a progression from analytic behavior of a detached subject, following abstract rules, to involved, skilled, problem-solving behavior based on an accumulation of concrete experiences, and the *unconscious* recognition of new situations as similar to past ones. Because experts act rationally, competent performance is rational and the transition to proficiency is a *process*. This emphasis on process is equally important to cooperative learning.

Research in Physics Problem Solving

Research in physics problem solving has served to inform general problem solving research and has become a fruitful area for understanding the acquisition of problem solving skills. There may be two reasons for this. First, the research is empirically based on the performance of problem solvers. Thus the research changes the emphasis of the problem solving from the problem to the solver. Second, physics problems, which usually are highly quantified, function well as a key component of this research (Fuller, 1982). There are several examples of research on physics problem solving that show how research in this specific area has broadened the scope of problem-solving knowledge.

In science education, much of the early research in the cognitive psychology tradition was done in physics problem solving by Jill Larkin and her associates at Carnegie-Mellon University. She compared the problem solving performance of expert problem solvers (professors in physics) with that of novices (beginning students in physics courses) (Larkin, McDermott, Simon and Simon, 1980). This seminal article is cited in almost all other research papers on physics problem solving. Students were given training in qualitative analysis and "chunking." Chunking is a process that allows experts to combine minor steps into a single procedure and thereby arrive quickly at a solution. Larkin sets a research agenda to enable students to solve problems in physics more effectively: "1. observe in detail what experts do in solving problems; 2. abstract from these observations the processes which seem most helpful; 3. teach these processes explicitly to students" (Larkin, 1979; p. 285). By observing what experts do, procedural "chunks" are decomposed into smaller more manageable, and teachable, steps.

The work of Chi, Feltovich, and Glaser (1981) used physics problems to investigate the organization of knowledge. "Results from sorting tasks and protocols reveal that experts and novices begin their problem representations with specifically different problem categories, and completion of the representations depends on the knowledge associated with the categories. For, the experts initially abstract physics principles to approach and solve a problem representation, whereas novices base their representations and approaches on the problem's literal features" (p. 121)

A problem representation is a cognitive structure corresponding to a problem, constructed by a solver on the basis of his or her subject-related knowledge and its organization. The *quality* of a problem representation influences the ease with which a problem can be solved. The hypothesis guiding their research is that the representation is constructed in the context of the knowledge available for a particular type of problem. Experts categorize problems differently than novices because of a more highly developed knowledge structure.

Joan I. Heller and Frederick J. Reif (1984) further showed the importance of knowledge organization and problem representation with their work on the "physics description" of a problem. It is important to “describe” a problem with care before attempting to search for its solution, explicit knowledge about what types of information should be included in an effective description, and explicit systematic procedures specifying how to generate such a description. The physics description contains the "physics" of the solution.

The work of Alan Schoenfeld in mathematics problem solving must also be mentioned. The problem-solving strategy students followed in this dissertation research is heavily based on Schoenfeld's work. Running as a thread through Schoenfeld's work, one can find the following many-sided argument for the merits of heuristic instruction (Schoenfeld, 1985; Schoenfeld, 1989; Nickerson, Perkins, and Smith, 1985):

1. **Heuristics** help students to solve problems when the students know and apply the heuristics.
2. Students lack a good set of heuristics.
3. Students do not reliably pick up heuristics spontaneously from examples; heuristics have to be taught explicitly.
4. Students do not reliably apply heuristics they know about; some sort of guidance or prompting is necessary.
5. A "managerial strategy" for approaching problems, taken together with heuristics, can help students to apply heuristics and lead to substantially improved problem solving performance in mathematics.

The Managerial Strategy of Schoenfeld has the following five phases:

1. *Analysis*: Understand the problem and get a feel for it by examining the givens, the unknowns, and so on. Simplify the problem by reformulating it without loss of generality.
2. *Design*: Maintain an overview of the problem-solving process, develop a broad plan for how to proceed, and ensure that detailed calculations are not done prematurely.
3. *Exploration*: Exploration is the choice when the problem presents difficulties and no clear plan for directly producing a solution is at hand. Exploration allows three heuristic steps of increasing extremity: Consider essentially equivalent problem, consider slightly modified problem, consider broadly modified problem.
4. *Implementation*: Plan should lead to tentative solution.
5. *Verification*: Check the solution.

Physics Problem Solving in Practice

Regardless of the context, research has shown that problem-solving can be studied by researchers and effectively taught to students. This large body of prior research forms the basis of the problem-solving strategy used in Physics 1041/1042 (Heller, Keith and Anderson, 1992; Heller and Hollabaugh, 1992). For example, there are five steps, similar to Schoenfeld. The Physics Description is the key step, and hence is the focus of my inquiry into argument co-construction. Many problem solutions of beginning physics students are incorrect because of an improper **free-body diagram**, a key step in the Physics Description. The subsections of a step teach students to "un-chunk" larger ideas. That is, smaller, more manageable pieces of the problem are tackled a step at a time. The emphasis on the *qualitative* analysis of the problem attempts to get students away from categorizing problems on the basis of the surface features, but rather on the basis of the physical principles involved.

The problem-solving strategy employed in Physics 1041/1042 is formulated on the idea that any problem can be solved if one has the right approach to the problem. The problem is broken down into a series of more manageable steps. The ultimate goal is to move the student from the novice stage to a competence state (cf. pp. 36-37). The steps in the strategy were summarized in the Table 2-2, pages 33-34.

Students adopt this strategy more readily if they are given peer support through the use of cooperative groups (Heller and Hollabaugh, 1992). In fact the original motivation for using cooperative learning in physics courses at the University of Minnesota was to facilitate problem solving. The language of the problem-solving strategy is very evident when a group discusses a problem.

Several aspects of this research on problem solving shaped the design of this study as well as the Physics 1041/1942 course. Students worked in groups of three and used this specific problem solving strategy. The strategy broke larger steps into smaller, more manageable steps. This research focuses on the physics description due to the fundamental importance of the description to the solution of the problem.

Cooperative Learning

It was the intent of the Physics 1041/1042 course designers that the "Minnesota Model" of cooperative group problem solving would be followed. This model is based on the work of Roger Johnson (Science Education) and David Johnson (Educational Psychology) at the University of Minnesota. The language of their model of cooperative learning permeates this research, so a discussion of the model is necessary. Throughout this dissertation I will refer to this as the Johnson Model. At the University of Minnesota Kenneth Heller (Physics) and Patricia Heller (Science Education) have further applied this model to physics problem solving. Their motivation for utilizing cooperative learning was to provide a supportive environment to help students abandon their novice problem-solving strategies and adopt more “competent” approaches.

Cooperative Learning Theory and Practice

Cooperative learning is an educational strategy for personal and cognitive change that can be contrasted to competitive or individualistic strategies of learning (Johnson and Johnson, 1987). Much of the research on cooperative learning in science education has focused on elementary or secondary school children. This suggested to me that research was definitely needed on cooperative learning in college science instruction. Moreover, because of the emphasis on problem solving and laboratory work, college physics classes provide excellent contexts for cooperative learning research.

At its most basic level, cooperative learning methods require students to work in groups. Although working in groups is a primary requirement, it is not sufficient. Cooperative learning must be structured. The instructional strategy in the courses used in this research relied on the Johnson Model (Johnson, Johnson and Holubec, 1988), and its application by Karl Smith (1989) to college teaching. There are five elements in this model of cooperative learning. Examples of how these elements are implemented in a classroom will serve to explain their use.

1. **Positive Interdependence** links students together so that their success in a course is dependent on one another. Group members work together, striving for consensus on goals, problem solving strategies and answers. Frequently there are shared resources and common rewards. One method to facilitate positive interdependence gives a group only one set of materials needed to solve a problem or answer a question.

2. **Face-to-face Interaction** promotes students' support for one another to learn. It is necessary to have a classroom where students can physically face each other ("eye to eye and knee to knee"). Traditional lecture halls will not work because moveable furniture is necessary.

3. **Individual Accountability** requires the instructor to assess each person's performance by asking questions randomly of individuals. Name tags can be worn to help the instructor to learn the students' names.

4. **Using Collaborative Skills** encourages leadership, trust, communication, conflict-management, and decision-making. Students who lack cooperative experiences frequently lack these experiences. Students come to college with thirteen years of learning experience that probably did little to build these collaborative skills.

5. **Group Processing** involves an evaluation by the participants of their group: What they did well and what they could do better the next time to improve the functioning of the group. Feedback can be formal and informal. Forms can be developed to give feedback to the instructor on a given exercise. It is important to focus the student evaluation on the process of the group in contrast to the product. Feedback is a dialog. Giving students praise and encouragement, such as "you can do it", helps tremendously in subject matter where students might feel inferior.

Group structuring distinguishes this type of cooperative learning from other models. Indeed, structuring can be the key to effective cooperative learning groups (Johnson and Johnson, 1987; Johnson and Johnson, 1989; Johnson, Johnson, and Holubec, 1988; Smith, 1989; Heller and Hollabaugh, 1992). A structured model of cooperative learning considers, for example, how many students will be in a group, how they are to be assigned to the group, what roles they will assume in the group, and structuring the task. Structured groups fare better than unstructured groups. Structured cooperative learning does utilize more class time. Content may be sacrificed in order to make time for group activities. The results, however, are supportive of the method.

This cooperative learning model is based on extensive research on competitive, individualistic, and cooperative learning strategies (Johnson and Johnson, 1989). In a sense, the research in cooperative learning is an example of **action research** as advocated by Kurt Lewin who said, "...there is nothing so practical as a good theory" (Johnson and Johnson, 1987; Johnson and Johnson, 1986). Theory informs practice and practice informs theory in cooperative learning research. This interplay is not unlike the relationship between theoretical and experimental research in physics. There is always a dialog between these two approaches to understanding the physical world.

Frequently, theoretical questions originate in observations of cooperative learning in practice. Thus, in discussing the research foundations of cooperative learning, there is not always a clear dividing line between “theory” and “practice.” This is, perhaps, due to the complex nature of human learning and even how we attempt to understand learning itself (Hunt, 1982). Although many components of the research are quantitative, there is also a decidedly qualitative aspect to research in cooperative learning.

Much of the current research in cooperative learning focuses on the practical. While there is nothing inherently misdirected about that emphasis, research into theory is also needed. In keeping with the Lewinian notion of action research, some of the theoretical research program is actually formed by questions raised in the practice of cooperative learning. In forming research questions, it is important to have a framework in which to ask the question.

Johnson and Johnson (1986) identify three types of "action research" studies that can be conducted on the use of cooperative learning in science education. A replicating study would give further support to cooperative learning theory. A refining study would look at ways of making cooperative learning more effective (e.g., Heller and Hollabaugh, 1992). An extending study examines the critical factors that make cooperative learning work, such as examing the patterns of argument co-construction in a cooperative group. Thus, this dissertation research is an example of an extending study.

For an example of this theory and practice interplay, consider the work of Karl Smith, of the Department of Civil and Mineral Engineering at the University of

Minnesota. Smith has made extensive use of cooperative learning in college engineering classes. His techniques, are based on the cooperative learning theoretical research, especially that of Roger and David Johnson. In a research summary, coupled with arguments for the use of active learning strategies, Smith (1988) makes a strong statement for the efficacy of cooperative learning in engineering education. Although he specifically addresses engineering education, many of his findings and proposals can be transferred to science education in general.

Engineering education and physics education share an important goal: Movement towards becoming an "expert". They also share a common obstacle: Students' **misconceptions**. Based on Smith's actual classroom experience, one might conclude cooperative learning may indeed be the best way to teach problem solving and overcome misconceptions at the same time (Smith, 1987). This is due to the way students develop expertise.

Smith (1987) points out that the rehearsal aspect of cooperative learning is an effective means of developing expertise. This relates to the theory of encoding ideas in long term memory. The process of discussing a concept, or solving a problem, with peers allows for instant feedback. There is a higher probability the "proper" connections will be made among ideas. This is the opposite of generating misconceptions. There is, of course, the possibility all students in a learning group will share and reinforce the same misconception or naive, novice approach. The monitoring function of the instructor serve as a check on student-generated misconceptions. While this may occasionally make more work for the instructor, it permits the assessment and addressing of misconceptions, observation of conceptual maturation, and ensures quality.

Cooperative Learning in College Physics

If one is to use cooperative groups in physics education, then it must be demonstrated that cooperative learning is superior to a competitive or individualistic strategy in a given context. Problem solving in physics offers one test of the efficacy of cooperative learning. A common complaint against using groups for problem solving is that the product of the group is merely the product of the best individual in the group. A means of testing this is to compare the product of individuals with that of a group.

Using a problem-solving strategy based on the expert-novice research, Heller, Keith, and Anderson (1992) found the group solutions on six introductory physics examinations to be superior to that of the best individual in a group on matched individual problems. They used the Wilcoxon rank-sum test for two matched samples to compare group and individual scores. On one exam, the group score was better at the $p < .05$ level, and on five exams, the group score was better at the $p <. 01$ level. That is, the group solution on a matched problem was significantly superior to the individual solution of the best person in the group. In examining each group's solutions, it was found that the group produced a better physics description with fewer misconceptions. This research supports co-construction of the problem solution.

The research on cooperative learning worked its way into the Physics 1041/1042 course design. Students were introduced to the group roles. The group membership changed every two weeks. The Teaching assistants who formulated the groups were *supposed* to keep a gender balance and performance mix. In applying the cooperative learning research to my own research, I knew that a superior group solution means co-

construction of an argument. Hence, I knew I should define criteria (Chapter 3) for recognizing evidence of co-construction of an argument. These results, plus my own experience with cooperative learning, suggested that I should be attentive to not only *what* was being said, but *how* it was said and *who* was saying it. Thus, in the transcripts of the groups' conversations reproduced in this dissertation, there will be numerous annotations indicating tone of voice or body language, as well as the identity of the speaker.

DATA COLLECTION PROCEDURES

In this section I will discuss the procedures used to gather the "raw" data. The videotaping of the groups began with the *second* graded problem. I felt the students needed at least one chance to experience a graded problem situation before experiencing the taping process. Also, the first taping session was not included in the analysis of the data. It served to solve logistical and technical problems associated with the taping. The original research plan called for the taping of 24 different groups working six unique problems. However, due mainly to technical problems (poor sound quality, equipment failure or unavailability), only 14 groups solving the six problems were actually included in the final study.

I visited the entire class before the first taping session and explained the nature and purpose of my research. All students in a group had to agree to be taped and signed consent forms. The other videographers (other graduate students, a munificent advisor) and I, remained passive observers of the groups as they were videotaped, but at times we made verbal or written comments about something interesting that had transpired in a group. A log sheet recorded the students' names, phone numbers, addresses, a serial number identifying the tape, and comments by the videographer.

Photocopies of the written solutions of the videotaped groups were made available to me, as well as the complete quarterly grade records for the class. Teaching assistants worked in pairs and took turns grading all the written problem solutions so there would be consistency within a given problem. The teaching assistants and the professor were not allowed to view the videotapes.

The six problems which comprise the study dealt mainly with two areas of physics: Newton's Laws of Motion and the Conservation of Energy. Table 2-3 (page 49) summarizes the problems. Compete texts of each problem are found in Appendix B.

Immediately following each taping session, the videotapes were transcribed by a transcription assistant. Although the transcriber was a passive observer of the groups, he frequently mentioned to me certain "fascinating" things he had observed a group doing. I then watched each tape, making corrections to the transcript, noting any interesting non-verbal behavior, and annotating references to the written problem solution. Each taping session was assigned a number (2,3,4,5,6,7) and within each session each group was assigned a letter (e.g., 4A, 4B, 4C, 4D). Thus a reference in this dissertation to Group 3A means the "A" group of the third taped problem. It is important to note that each videotaped group was in a *different* room and under the tutelage of a *different* teaching assistant. Thus, the teaching assistant who appears on Tape 4B is *not* the same teaching assistant who appears on Tape 4D .

Problem	Problem Title	Problem Goal	Applicable Physics
2	Toy Train	Finding the tension in strings connecting the cars of a toy train.	Newton's Second and Third Laws, Free-body diagrams.
3	Equilibrium	Finding the maximum weight for which a system will remain in equilibrium.	Newton's Second and Third Laws, Free-body diagrams, Frictional forces.
4	At the Gasthaus	Finding the forces acting on a suspended sign.	Newton's Second and Third Laws, Free-body diagrams, Torque.
5	Space Cannon, Inc.	Finding the launch velocity necessary to place a probe in orbit at an altitude of 900 km.	Conservation of Energy, gravitational potential energy.
6	Fahrenheit 451	Finding the temperature change in a container of water on a heater.	Conservation of Energy, temperature conversions, calorimetry.
7	A Quick Lift	Finding the time and cost for an elevator trip.	Conservation of Energy, power, Ohm's Law

Table 2-3. Characteristics Of Problems.

I numbered the statements for easy reference. Originally I numbered each statement where there was a change of speaker. Some students said several things in one statement and so I subdivided these statements. So there might be lines numbered 40, 40B, 40C, etc. This is particularly true in Session 4. In latter transcripts I learned to individually number each statement and there are fewer of the subdivided statements. Following this transcription procedure, 14 videotapes, transcripts, and written solutions were available for my analysis.

Data Analysis Procedures

Since a primary part of this research focuses on the argument structure of Stephen Toulmin, I needed to find a way to look at the 14 groups using his structure of argument construction. The first step in applying the Toulmin structure to the groups' problem solutions was to learn how to identify Grounds, Warrants, Backings, and Claims. It was soon learned that other categories would be needed as well. I chose a single problem, solved by four diverse groups, to begin the process.

The primary "reference point" for this part of the analysis is the set of 14 videotapes and the transcripts made from them. The other three reference points will help explain the analysis process I developed. For example, the written problem solutions will be very useful in determining what the students were writing while they talked. Diagrams from their written solutions will appear in the transcript excerpts.

Initial Transcript Coding

I selected the fourth graded group problem of Physics 1041, given during the eighth week of the Winter Quarter. I chose this problem (Shown in Figure 2-1, page 51) for two reasons. First, this is the one problem for which I had four videotapes and transcripts. These four groups exhibit a spectrum of ability and functioning, and this is what I had hoped to find. Secondly, I felt that by this time of the quarter, the students would have become accustomed to the problem solving strategy as well as working in cooperative groups. It seemed that it would be "easier" to understand what they were doing as I viewed the tapes.

Above the entrance door of an old German "GASTHAUS" hangs a sign. A 200 N metal beer mug hangs at the end of a 3 meter long strut that is attached to the wall by a hinge. The weight of the strut is 100 N. A support cable is attached to the strut at a point 2 meters from the wall and makes a 30° angle with the strut. Find all the forces acting on the strut. Useful information: $\sum \mathbf{F} = 0$ *and* $\sum \tau = 0$

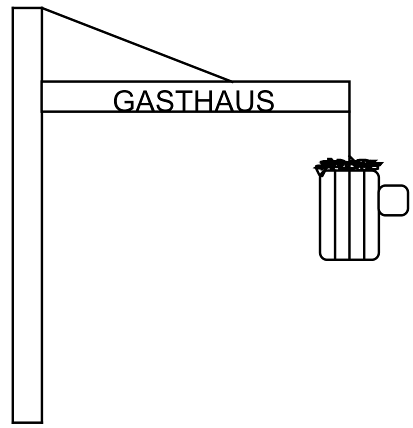


Figure 2-1. ***AT THE GASTHAUS***

Applying the Toulmin categories and argument structure to the *At the Gasthaus* problem, an overall diagram of the solution can be visualized. This kind of visualization helped me understand the types of statements students made as they solved the problem. Figure 2-2 (page 53) shows the overall structure of this problem using the Toulmin terminology.

The students are immediately presented with a picture and information. In a sense they do not have to "decode" the problem and can start immediately with the Physics Description. The data in the problem statement (e.g., 200 N, 3 m, etc.) constitute the "Grounds" for the problem. Throughout the solution, students will refer back to the problem statement for these grounds and will make either explicit or implicit references to the grounds.

The "Warrants" in this problem are the same for other problems in statics, namely that the sum of the forces and torques must be zero for equilibrium. A general warrant in this problem is that both $\Sigma \mathbf{F} = 0$ and $\Sigma \tau = 0$ must be used. This general warrant has many specific and detailed sub-warrants, such as the selection of the point about which to take the torques.

In a problem involving static equilibrium, the application of Newton's Second Law to the situation requires that $\Sigma F = 0$. Students (or physicists for that matter) seldom apply this law and *explicitly* state "This is valid because of the generally accepted validity of Newton's Laws." Toulmin, I believe, would see physics warrants as unequivocally supporting a claim:

> Warrants are of different kinds, and may confer different degrees of force on the conclusions they justify. Some warrants authorise us to accept a claim unequivocally, given the appropriate data--- these warrants entitle us in suitable cases to qualify our conclusions with the adverb 'necessarily'; others authorise us to make the step from data to conclusion either tentatively, or else subject to conditions, exceptions, or qualifications--- in these cases other modal qualifiers, such as 'probably' and 'presumably', are in place (Toulmin, 1990, pp. 100-101).

It is, however, necessary to support warrants with backings.

> In what ways does the backing of warrants differ from the other elements in our arguments? To begin with the differences between B and W: statements of warrants, we saw, are hypothetical, bridge-like statements, but the backing for warrants can be expressed in the form of categorical statements of fact quite as well as can the data appealed to in direct support of our conclusion (Toulmin, 1990, p. 105).

It would, for example, be somewhat unlikely that a physicist would directly or explicitly state, "categorically," that Newton's Laws are valid. When students cite backings, they may refer to the professor in deference to the teaching assistant or textbook. "That's how he did it in class," is the simplest example of this type of statement.

In the context of introductory physics problems, there is seldom an opportunity for "rebuttal" of a claim. A rebuttal is a condition that *negates* the claim. In this problem, a rebuttal might be "The sign is not in equilibrium if the tensile strength of the cable is too small." However, the diagram given with the problem statement clearly shows the sign in an equilibrium position and thus the rebuttal is invalid. A rebuttal usually begins with "unless," implying that situation is true *unless* other conditions apply. (A rebuttal in kinematics might be, "Unless the object is moving at or near the speed of light.") A rebuttal is *not* the same as a challenge to a claim.

A challenge is generated by the student and not by the inherent characteristics of the problem. Although the Toulmin structure does not explicitly allow for a challenge, I expected to see challenges because of the roles the students were introduced to in their cooperative groups. The skeptic role is basically a challenging role.

GROUNDS
$W_B = 100N$, $W_M = 200N$,
$L = 3$ meters, $\theta = 30°$
Picture ⇒ Equilibrium
↓

WARRANTS
$\sum \mathbf{F} = 0$
$\sum \boldsymbol{\tau} = 0$
Vector components
↑

BACKINGS
General validity of Newton's Laws, nature of vector algebra, both as expressed in the text, by the professor, or teaching assistant.

→

CLAIM
Unknown forces can be found by applying $\sum \mathbf{F} = 0$ and $\sum \boldsymbol{\tau} = 0$.
↑

REBUTTAL
External forces (none are indicated) could cause the sign to collapse. Thus, *no* rebuttal in this case.

Figure 2-2. Toulmin Analysis of *At The Gasthaus*.

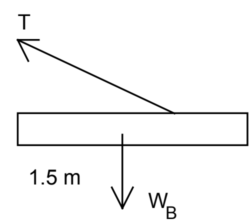
Individual subsections of *At The Gasthaus* could be diagrammed in a similar theoretical fashion, illustrating an idealized solution to the problem. Likewise, discussions relating to the group process and procedures or the problem solving strategy can be diagrammed. It will not always be possible to cleanly distinguish or separate content (i.e., the physics, as described above), group maintenance, and Problem Solving Strategy statements in the course of one argument.

Identification of Statement Types Using Descriptions of the Session Four Groups

The four groups (4A, 4B, 4C, 4D) used to develop a coding scheme were diverse and presented a variety of group dynamics, personalities, and problem solving competence. I will draw from these four groups to illustrate two types of statements: Those statements which are specifically Toulmin-like and those which do not fit a Toulmin category, and hence provide the basis for defining new categories. I do not consider these statements as outcomes, because in themselves they do not say anything about patterns. I will repeatedly draw upon some examples from the four groups that solved *At the Gasthaus*. Each time I re-read their transcripts, or watched the videotapes, I saw something I had missed in the prior reading or viewing. The process I experienced over four years will be mimicked by seeing the different levels of analysis unfold within these four groups. Although the dialog becomes familiar, new meaning appears at every turn.

Group 4A consisted of two women (MK and MR) and one male student (RM). Based on their individual cumulative exam scores at the time of this problem session, this was an above average group. The women were each in the top third of the class and the man was in the middle third of the class. This ability mix is seen in their aggregate class average: they were above the class mean at the time of the group problem (z = .8). All three students were full-time, residential students at the University. MK was the Recorder, MR was the Skeptic (She actually wrote "Spy" on the video log sheet, but verbally identified herself as the skeptic), and RM identified himself as the Energizer. Here is an extended example from Group 4A, an example of a "raw" transcript.

MK: OK, so then what? We'll need to draw the bar. [Draws bar.] And this is a weird force. We have a weight going. We have tension this way, right? [draws T vector]
RM:/MR: Yeah
MK: So we label that T?
RM: You have a weight right here. [Points to where W_B goes on diagram.]
MR: The bar weight. In the middle.
RM: Yeah, goes in the middle.
MR: That [weight] always goes in the center [i.e., center of mass].
MK: OK, so this is weight bar. [labels diagram while talking.]
MR: That should be at one end, 1.5 meters.
MK: What?
MR: The weight of the bar? They always do it from the center. We always do it from the center. We're going to have to know how far over it is. [Indicating labels for the distances.] So it's always at 1.5.
MK: Oh, OK [Draws and labels the 1.5 meters.]
MR: Meters



In problems involving forces (either static or dynamic), students were taught the importance of drawing an idealized sketch of the problem situation, a free-body diagram, and force-vector diagrams. The grading of the solution considered the correctness of this step and this group thus gives much attention to drawing these three diagrams. This segment of their dialog opens with a procedural discussion about drawing the "free-body" and "force thingy" diagrams. These statements are all claims that relate to the process of the solution.

An excellent example of an explicit claim with implicit, or non-verbal grounds, is found in RM's statement about the location of the center of weight of the bar: "You have a weight right here." When he points to where W_B goes on diagram, he is supplying support in the form of grounds. This is an example of grounds because the idea is inferred from the diagram. When member MR says, "always goes in the center" she is supplying a warrant that the center of weight for a uniformly dense object is at the center of geometry. Note then that both members RM and MR support the initial Claim by simply reiterating the statement in their own words.

Note student MK's statement, "OK, so then what?" She often ends a segment of dialog with such statements which either can be seen as requesting another problem solving claim, or as summarizing what she has just done. In fact, a prime characteristic of MK's contribution to the group is the summarizing statement. Likewise, when she says, "So we label that T," she is not questioning but summarizing. MR's statement "Meters," while hardly profound, clarifies the previous "1.5". Such clarification statements are an integral part of the elaboration process but do not precisely fit into any of the four Toulmin categories.

In this segment of dialog, there is a variety of statements. Some statements (Claims, Grounds, Warrants and Backings) clearly follow the Toulmin categories, and some statements do not. (For a summary of the Toulmin Claim, Grounds, Warrants, and Backings categories, refer to Table 2-4, page 58). Assuming that students do use grounds, warrants and backings to support claims, and assuming they also make requests, clarify and summarize statements, I defined additional categories to account for these other statements.

I defined these additional statement categories after a thorough analysis of what students actually said and did in the Problem 4 session. Categories such as Summarizing, Skeptic, and Consensus checking, as well as Challenges, result from the assigned roles based on the Johnson Model. In addition, I noticed that utterances like "OK", "What", and "umm" don't fit any category, and I realized I was seeing statements of Clarification, Support, Acknowledgment, and Request. So, in addition to the four Toulmin statement categories, I defined nine additional statement types. These additional statement types augment the Toulmin statement types summarized in Table 2-4. The examples are drawn from the *At The Gasthaus* problem to illustrate the various statement types. My new definitions and some example statements are summarized in Table 2-5 (page 59). The section of transcript shown above in its "raw" form is shown coded in Table 2-6 (page 60). I have added annotations, explanations and diagrams to clarify the students' discussion.

It is very important to note that these non-Toulmin categories were not determined *before* the analysis began, but grew out of the analysis. That is, the coding scheme originated *within* the students discussions (Gustafson, 1977). The result of the process was nearly 3000 lines of coded transcripts for the 14 groups. In the following two chapters there will be numerous examples of coded transcripts.

Statement Type	Definition	Example
Claim (C)	A claim is a *fundamental assertion* central to the argument at hand. Warrants, grounds, and backings establish the validity of a claim.	For an object in equilibrium, a claim might be, “It's not moving so it's in equilibrium.”
Warrants (W)	Warrants make reference to *general physical principles* or laws. Warrants also apply to *mathematical principles* such as resolving vectors into components.	Newton's Laws of motion are warrants fundamental to physics. Statements like “because it's in equilibrium, the forces must all add to zero” are examples of warrants that derive from these physical laws.
Grounds (G)	Surface features of a problem or the *physical data* give meaning to a claim and are classified as grounds.	“The sign weighs 100 N,” or “the angle is 30 degrees,” are data from the problem itself. In problem-solving groups, a gesture at a diagram can also serve as a ground. (Toulmin also refers to grounds as data.)
Backings (B)	Any *appeal to an authority* such as the textbook, teaching assistant, or professor is a backing.	“That's how she did it in class.”

Table 2-4. Summary Of Toulmin Categories.

Statement Type	Definition	Verbal Cue Examples
Consensus checking (Ck)	These statements ensure there is agreement among group members before proceeding to another point.	"Are we agreed on this?" "So is that OK?"
Summary (Sm)	Summary statements restate a claim. Ideally a summary statement ends each episode. These statements may be used in concert with consensus checking (Ck) statements.	"So we're saying here that..." Some groups frequently use summary statements in the form of a question, "So, this is the x-component of the force?"
Skeptic (Sk)	The skeptic inhibits too quick agreement on any point by asking "why" questions and by demanding warrants, grounds and backings for any claims made.	"What?" "Why?" "Why is that?" "Why do you say that?"
Encouraging (En)	This often occurs as an informal, often humorous, energizing of the group when it gets stuck. Groups lacking in fundamental physics knowledge make frequent use of this type of statement.	"Hey, this makes sense!" "Wow!" "Great."
Challenge (Ch)	A request for proof of a statement or a disagreement with a statement.	The most simple challenge is "No." Other examples include, "I don't think that's right," or, "No, it should be..."
Clarifying (Cl)	Clarifying statements further explain an idea by means of analogy or by restating in different but equivalent words. These statements do not necessarily carry the idea forward or develop it further.	A student who is talking aloud while writing may say, "1.5," meaning a distance. This clarifies the written material. Another student may add, "meters," which further clarifies.
Support (Sp)	Supports statements previously given.	"Yeah," "Yes," or "OK."
Acknowledgment (Ak)	These statements recognize a previous statement without making any judgment or qualification.	These include "Umm" and sometimes "OK" if the response can be interpreted as not being in support of the previous statement. Context, tone of voice, or body language help suggest this difference.
Request (RQ)	The *Request* (RQ) code precedes any request or question. RQCl requests clarification, RQW requests a Warrant. RQ may be answered with another claim, warrant, ground, backing, or clarification.	"What?" is the simplest example of a request. However, "What?" could indicate a challenge if tone of voice or a gesture suggests that interpretation.

Table 2-5. Defined Categories.

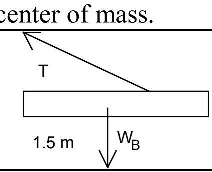
Dialog	Coding	Comments
43. (MK) We'll need to draw the bar. [Draws bar.]	C	Answers her own question. 
44. (MK) And this is a weird force. [This statement is unclear. MK *could* be referring to the normal, or that the free-body diagram will be "weird."]	C	This is a new aspect of the solution. Sets up a discussion of the forces.
45. (MK) We have a weight [of the bar] going.	C	Second part of her Claim.
46. (MK) We have tension this way, right? [draws T vector]	C W RQSp	Third part of her Claim. Implicit Warrant = a tension in the cable caused by the weight. "right?" = RQSp.
47. RM / MR. Yeah	Sp	
48. MK. So we label that T?	Sm	Sm = summary
49. RM . You have a weight right here. [Points to where W_B goes on diagram, i.e., in the center.]	C G	The Claim is the location of the weight.
50. MR. The bar weight.	Cl	
51. In the middle.	Cl	Weight is at the center.
52. RM . Yeah, goes in the middle.	Sp	Supports the previous warrant.
53. MR. That [i.e., the weight] always goes in the center.	W	Supports the previous claim.
54. MK. OK, so this is weight bar. [labels diagram with W_B while talking.]	Sm	This is a good example of the Recorder summarizing before moving on.
55. MR. That should be at one end, 1.5 meters.	G	
56. MK. What?	RQCl	RQCl = Request for Clarification.
57. MR. The weight of the bar.	Cl	
58. They always do it from the center. We always do it from the center. We're going to have to know how far over it is. [Indicating labels for the distances.]	C B RQG	C = Do it from the center. B = "They always do it." RQG = Request for Grounds.
59. So it's always at 1.5.	G	Always at 1.5 implies it is always in the middle, i.e., at the center of mass.
60. MK. Oh, OK [Draws and labels the 1.5 meters.]	Sp	
61. MR. Meters.	Cl	

Table 2-6. Group 4A, Lines 43-61, Coded.

Additional Quantitative and Qualitative Data

Quantitative data on the groups' written solutions was available to me. This data relates solely to the *written* solutions and I view the written solution primarily as a source of insights into what the groups were talking about. Table 2-7 (page 62) lists this quantitative data for the 14 groups. The percent of the total points possible is listed, and the mean and standard deviation are given at the bottom of each column. There are two types of data listed. First, there is an objective evaluation by an independent evaluator (Dr. Bruce Palmquist) of how closely each written solution follows the steps of the problem-solving strategy. Table 2-8 (page 63) lists the criteria used to judge the written solution. It is important to note that *only* the data on "Generating a Physics Description" is included in the tabulated scores. Hence, the total possible points is six. These evaluation scores are the only *quantitative*, objective measure of the completeness of their physics description in terms of following the prescribed problem-solving strategy.

Second, the grade the teaching assistant gave their solution is reported in the second and third columns of Table 2-8. The two columns break down the grade on the physics description portion of the problem and on the remainder of the problem. The percent of possible points is shown. For example, Group 5A received 75% of the points possible on the Physics Description portion, but only 50% of the possible points on the remainder of the problem. I did not use these grades the students received on the problem in forming my opinions about how well they functioned as a group.

Session	Independent Strategy Evaluation	TA's Grade on Physics Description	TA's Grade on Remainder of Problem	Comments
2A	33	86	0	Incomplete Plan, no Execution
2B	83	86	14	Didn't follow plan, improper Execution
2D	67	100	0	No Plan, no Execution
3A	33	100	100	
3B	33	100	100	
4A	83	100	100	
4B	33	75	50	Messy FBD, incorrect answer
4C	33	75	67	FBD not clear, Found F but not τ
4D	33	100	33	Didn't have clear plan, numerical error
5A	17	75	50	Didn't do all calculations
5B	83	75	50	Used wrong units in Execution.
5C	83	100	33	Execution Errors.
6B	67	60	80	Lost points on temperature conversion.
7A	50	60	40	Didn't execute Plan.
Mean	52	85	51	
σ	24.3	15.2	34.7	

Table 2-7. Written Solution Grades.

The interpretation of this data table is that these groups typically did better on the physics description than on the remainder of the problem. In all cases, the major errors in the entire solution were algebraic or arithmetic mistakes in the Plan and Execution portions of the problem. The lack of a discernible correlation between the teaching assistants' grades on the problems' physics descriptions and the independent, the objective evaluation probably represents the subjective nature of the teaching assistants' grading of the problems. The 52% average score for following the physics description section of the problem-solving strategy is not surprising either. A perfect 100% would result from following the problem-solving strategy "to the letter" and these groups never did that.

I. Generating a Physics Description

TD: Translation of Problem into Physics Description

- 0 - No physics description
- 1 - Problem is not translated into appropriate physics representation (e.g., vector components do not reflect independence of motion in x and y direction; force vectors are not balanced for objects at rest, incorrect force of motion, etc.)
- 2 - Problem is translated into appropriate physics representation

QD: Quality and Completeness of Physics Description

- 0 - No physics description
- 1 - Description is barely there (majority of relevant physics variables and relationships not shown).
- 2 - Description is incomplete (e.g., only one diagram in a before and after situation)
- 3 - Description does not include a specification of target variable
- 4 - Description is complete or contains only minor omissions (e.g., axes are not labeled; one variable is not defined)

II. Planning a Solution

TP: Translation of Physics Description into Mathematics

- 0 - No plan
- 1 - Physics description is not translated into corresponding mathematical expressions of the relationships and interactions shown in student's physics description (e.g., vectors drawn in diagram, but vector equations are not used).
- 2 - Physics description is translated appropriately from student's description.

QP: Quality and Completeness of Plan

- 0 - No plan
- 1 - Plan is barely there
- 2 - Plan does not begin with general equations - numbers are substituted into specific equations.
- 3 - Plan is unclear and/or omits an explicit strategy for solving for target variable
- 4 - Plan is complete, but includes a mistake (e.g., either miscounted equations and unknowns, or equations are not linearly independent or no outline, but execution shows they did carry out reasonable steps.)
- 5 - Plan is complete.

III. Executing the Plan

TE: Translation of Plan into Execution

- 0 - No Execution
- 1 - Execution does not follow plan, or if no plan, consists of plugging numbers into specific equations in an attempt to calculate the target variable
- 2 - Execution follows plan, or if minimal plan, equations are algebraically manipulated to isolate target variable before numbers are substituted into equation

QE: Quality and Completeness of Execution

- 0 - No execution
- 1 - When obstacle is encountered, either, "math magic" (e.g., mass is small, so set m=1) or additional relationships (not in physics description or plan) are introduced in order to get an answer.
- 2 - When an obstacle is encountered, execution is terminated
- 3 - Executes mathematics correctly (or with minor mistakes)

Table 2-8. Evaluating Written Problem Solutions.

Table 2-9 (page 65) summarizes the results of the qualitative data collection. The table contains descriptive information on each group such as the gender and performance makeup of the group. The rankings High, Medium, and Low were determined from the student's standing in class at the time of the problem. This standing was based on the class-wide examinations. A one-word or phrase description attempts to summarize the group in as concise a word as possible. The longer comments actually elaborate upon this one-word classification. Later, these one-word descriptions will hold true in the patterns of argument construction found in this study.

Group	Gender	Perf.	Comments
2A	MMFF	LLMH	Imbalance. No plan; incorrect free-body diagram; at least 3 misconceptions. Didn't solve for the proper target variable.
2B	MMF	LMH	All participate. Undefined coordinate system. Plan improperly translates free-body diagrams.
2D	MMF	LMH	Talkative. Unclear solution, no execution. KE and LS were the original group and SU joined them as a single. Did not attempt to solve for proper target variable.
3A	MFF	LMH	Precise. At least 1 misconception. Good use of problem solving strategy.
3B	MMMF	LLLM	Digression. A 12 line digression about their last exam was omitted from the analysis. Attempted to model their solution after what professor did in class.
4A	MFF	MMH	Deliberate. Group frequently uses Sk, Ck, Sm. Episodes are evident and often end with Sm or Ck. Although MK is the most involved, each student adds important ideas. Thoughts are connected. Any two-way episodes tend to be very short. Claims are usually supported by grounds and warrants. They carefully follow the PS Strategy. Probably the "best" group observed.
4B	MMF	LMH	Equals. Ideas are left in isolation. Few Sm, Ck, Sk. Some challenges left "Unanswered." Their written solution grade was low due to an incorrect free-body diagram.
4C	MMF	LMM	Dysfunction. Long discussion regarding procedural matters. Probably the "worst" group observed.
4D	MMF	LLH	Lack ability. No Sk, Ck, Sm. Frequent use of En when stuck on content or procedure. Many interventions by TA when they are going astray. One student had missed class the day before this session and often they seem to lack physics knowledge.
5A	MMF	LMH	Confused. AW (Recorder) had not taken the pre-requisite course. They easily confuse energy and velocity; orbital and escape velocities.
5B	MFF	LMM	Verbose group. A high number of Cl statements. Persistent misconception about orbital velocity.
5C	MMF	LMM	Clarify statements. DC was a silent partner, often working on his own and gave little input to the group (This seemed very consistent with his personality). High proportion of Cl statements. Some "equation searching." Confuse the Phys. Descr. and Plan.
6B	MFF	MMM	Work & Compare. Members of this group frequently worked on their own, comparing results. Some "number crunching" and a few misconceptions. KF visibly tired.
7A	MMFF	LLLM	Slow start. This group took about 90 lines to get to the physics of the problem. They spend a lot of time discussing the “surface features” such as the numerical data.

Table 2-9. Summary of the Fourteen Groups.

Summary

At this point, the data collection and initial analysis was complete and I was ready to embark upon answering the research questions. The research process to this point consisted of these procedures:

- Videotaping 14 groups solving six physics problems (“raw” data).
- Transcribing the videotapes.
- Editing the transcripts with annotations to written solutions and the videotapes.
- Identifying the Toulmin statements of Claims, Grounds, Warrants, and Backings.
- Identifying new statement categories based on the cooperative group roles and the problem-solving strategy.
- Characterizing each group qualitatively and their written solutions quantitatively.

This “processed” material comprises the “data” in this research. Next I turned to a major part of the analysis. Since my research question involves looking for patterns, I realized I could not look for patterns within single statements. Rather, I had to look for patterns in a group of statements. That group of statements became known as “the episode”. In order to answer the research questions, another analysis tool was used, the flowchart. Both of these tools will be discussed in the next chapter.

CHAPTER 3

PATTERNS WITHIN A GROUP

Chapter Overview

The very nature of a qualitative case study makes this research an exercise in discovery. As I worked out the procedures, I had some outcomes in mind, but the true nature of the outcomes did not come into focus until I actually attempted to answer the research questions. As I addressed the research questions, I continuously devised new ways to look at the data. Hence the usual distinction between "method" and "results" is not always clear and sharp. The "patterns" emerged very slowly.

At every turn, there was a surprise embedded in the students' conversations. The whole project was much like Forest Gump's box of chocolates: I never knew what I was going to get. Thus, although the following discussion of "Outcomes" discusses the research questions one at a time, it will be clear that additional "procedures" evolved as I attempted to answer the questions. The reference point of my own subjective interpretation of the outcomes will play a large role in this chapter and the one that follows.

This chapter examines argument co-construction *within* individual groups. Before patterns or similarities common to all fourteen groups can be examined, each separate group must be examined. It also is necessary to demonstrate that these groups are engaging in the process of argument co-construction.

ARGUMENT CO-CONSTRUCTION

A major hypothesis behind this study is that these fourteen groups are engaging in argument co-construction. The superior product of the group's solution over an individual's problem solution is in itself evidence that argument co-construction is occurring. Yet, the solution could be primarily the work of one individual in the group. Thus I asked myself, "What are the criteria for group argument co-construction? How can it be recognized?" These are fundamental questions and there are two points to be made in answering them.

First, the choice of the Toulmin argument structure presupposes there is an *argument*. If there is an argument, then within a group's transcript, there should be Claims that are supported by Grounds, Warrants, and Backings. That is, the discussion should contain recognizable, classifiable components of the Toulmin structure. Likewise, these components, particularly Grounds, Warrants, and Backings, should appear in repeating patterns. Brown and Palincsar recognized this as an important component of the Toulmin structure: "Adults' argument structure follows certain identifiable sequences. For example, an argument is usually supported by data; these data are then supported by warrants for their pertinence and credibility, and finally further backing is provided in terms of recourse to general law (Brown and Palincsar, 1989; p. 404)." This is the *argument* portion of argument co-construction.

Second, there is *co-construction* of the argument. the discourse should be connected, that is, group members listen to each other and discuss the *same* claim. Claims should not always be made and supported by the *same* group members, that is, claim-making shifts among group members. When there is a disagreement, group members resolve the disagreement in a reasonable manner. That is, they resolve conflicts of ideas without arguing or criticizing the another person. In short, the conversation should progress in an orderly manner and all group members should participate.

To summarize, these are the criteria for argument co-construction in the Toulmin structure: (1) Claims are supported by Grounds, Warrants, and Backings, (2) Grounds, Warrants, and Backings appear in repeating patterns, (3) Group members listen to each other and discuss the *same* claim, (4) Claim-making role shifts among group members, and (5) disagreements are resolved in a reasonable manner.

QUESTION 1. DO THESE FOURTEEN PROBLEM-SOLVING GROUPS ENGAGE IN ARGUMENT CO-CONSTRUCTION AS THEY COMPLETE A PHYSICS DESCRIPTION?

When I first began looking at the transcripts, I saw that students made Claims, supported them with Grounds, Warrants, and Backings, and made the other types of supporting statements that are identified in Table 2-5 (page 59). As an initial analysis, I plotted the "flow" of the discussion from one student to another. The conversations were like a tennis game with the ball moving from one player's court to another. I noticed that the groups seemed to discuss a single idea for a short period of time. Typically, there was a Claim and supporting statements. In most of the groups, there was progression from idea to idea. That is, the discussion was in "chunks." The students were discussing the problem and interacting with each other in an episodic fashion. This led me to see their conversation in terms of **episodes**.

Episodes and Interaction Analysis

For the last forty years, many instruments have been devised to analyze classroom interactions. The emphasis has been almost entirely on the *teacher-student* interaction. This emphasis arose out of a need to understand what happens in the classroom. It was thought that in order to prescribe instructional materials or strategies, the teacher-student relationship had to be observed and understood. While this dissertation research is concerned with *student-student* interactions in groups, it is important to understand the limitations of interaction analysis as found in the *teacher-student* research.

One of the best known instruments was the Flanders System of Interactional Analysis. It endeavored to provide a measure of the degree to which a teacher's verbal behavior in the classroom was student-centered. Other interaction scales included the Roark Dimensions of Psychological Distance, Hill Interaction Matrix, and the Teaching Strategies Observation Differential. These instruments have three things in common (1) they focus on a limited aspect of classroom behavior, (2) each one has a bias, and (3) they measure only what actually occurred in the classroom (i.e., statements) without making any qualitative judgments (Amidon and Hough, 1967; Stanford and Roark, 1974).

In general, all classroom observation instruments, schemes, or techniques focus on exact, *prespecified* behaviors on the part of the teacher or the student. Because the observation instruments are linked to specific behaviors, they often tally verbal statements made by the student or the teacher. One might, for example, define categories such as elaborating, explaining, or defending, and then classify student statements into those categories. Typically, a researcher would then count the number of times a student gave the teacher an explanation, and perhaps evaluate the validity of the explanation.

Comparisons could then be made between different students, teachers, or instructional strategies by using variables related to the types of statements.

It is important to note that this type of analysis is appealing because of its quantitative nature. It allows for a factor analysis (ANOVA) of classroom behavior on the part of the students and teachers. This method, however, is self-limiting. In a summary of research on classroom observations, Delamont and Hamilton (1984, pp. 8-10), gives seven reasons why the teacher-student interaction coding schemes are inherently limiting. These warnings are appropriate to student-student schemes as well.

> 1. The aim of coding schemes using prespecified categories is to produce numerical and normative data. ...the data produced tell the reader about 'average' or 'typical' classrooms, teachers, and pupils.
> 2. Systematic observation schemes typically ignore the temporal and spatial context in which the data are collected. Divorced from their social and temporal (or historical) context in this way, the data collected may gloss over aspects relevant to their interpretation.
> 3. Prespecified coding system are usually concerned only with overt, observable behaviour. They do not take directly into account the differing intentions that may lie behind such behaviour. ...by concentrating on surface features, interaction analysis runs the risk of neglecting ***underlying but possibly more meaningful features***. [emphasis added]
> 4. Prespecified coding systems are expressly concerned with what can be categorized or measured. They may, however, obscure, distort or ignore the qualitative features which they claim to investigate by using crude measurement techniques or having ill-defined boundaries between categories.
> 5. Prespecified coding systems focus on small bits of action or behaviour rather than global concepts.
> 6. [These] category systems may assume the truth of what they claim to be explaining.
> 7. ...by placing arbitrary (and little understood) boundaries on continuous phenomena category systems may create an initial bias from which it is extremely difficult to escape.

Brown and Palinscar (1989) continually point out the necessity of the "fine-grained" analysis to understand the process of cooperative learning. "Unfortunately, the written reports, on the outcomes of Jigsaw [a specific cooperative learning method] leave us somewhat in the dark about the learning process... A further look at Jigsaw and other cooperative learning methods...should concentrate on ***what students actually do*** in these groups" (Brown and Palinscar, 1989, p. 402, emphasis added).

If there is argument co-construction, then students in the group should participate in a dialog about one idea, and then the next idea, and so on. They would not make isolated statments. The dialogical nature of the group suggested looking at *groups* of statements. For this study the **episode** is the unit of analysis. An episode is made up of students' individual statements, but it contains a complete thought. And it turns out, episodes are not a new idea in education research. Smith and Meux used episodes to categorize *student-teacher* interactions in an analysis of classroom behavior (Smith and Meux, 1970; Smith, Meux, Commbs, Nuthall, and Precians, 1967). In their scheme, an episode is "defined as one or more exchanges which comprise a completed verbal transaction between two or more speakers. A new episode is determined by a shift in what the speakers are talking about, which may be a new aspect, or part of a topic or a complete change of topic" (Sandefur and Bressler, 1971, p. 23). This definition of an episode is essentially the same as the definition I am using for this research. However, I defined the episode in my research *before* actually reading this prior research.

Episode Delineation

When does a new thought take over? This is the basis of defining an episode. Defining the episode is one of the most difficult, and subjective, aspects of this analysis. Groups may use recognizable episode delineators, such as "OK, what's next?" There also might be a change of speakers. In a rigid analysis, using the Toulmin categories, there would be a series of statements leading up to the claim. But an episode does not necessarily begin or end with a claim. For example, an episode may begin with a request. Since the order of events in an episode is a part of the research questions, I tried to not prejudice the outcomes by saying all episodes must begin (or end) with a claim.

Group 4A provides an example of a coded, delineated discussion. Further examples will be drawn from this group and other groups' discussions. Many of the examples will reappear later. This repeated use will parallel my increasingly deeper understanding of what the students were doing. In Table 3-1 (page 75), and the tables that follows, the group's discussion is presented in the first column (*Dialog*), the statement identification (*Coding*) is in the second column, and my comments are in the third column. These comments will help the reader understand my interpretation of what the group is doing. When appropriate, the third column will contain diagrams taken from the group's written solution. If a diagram changes substantially I will show it as it exists at the beginning of the transcript segment and then at the end. The lines are numbered sequentially for easy reference. In some cases, I broke sentences by a single speaker into separate lines during my initial editing (e.g., 42, 43, 44, 45, 46). In some cases, as I was coding statements, I realized there was a significant shift in the thought and broke the sentence into smaller fragments (e.g., 41, 41B, 41C). This second numbering method makes it easier to follow one person's statements. The first numbering method, makes it easier to count lines or, as will be seen in the next chapter, construct flowcharts. In some cases I have included a few lines preceding or following the episode of interest in order to make the discussion more sensible. Table 3-1 (page 75) illustrates how the statements in the "raw" transcript discussed on page 55 were coded and episodes delineated. The reader should note that some longer transcript excerpts span two pages. Often I will discuss an idea and then reproduce the corresponding transcript excerpt.

Table 3-1 illustrates three episodes. The group first discusses the fact they need to draw a free-body diagram and a force-vector diagram ("force thingy"). Then they move on to discuss the tension force in the cable due to the bar.

Dialog	**Coding**	**Comments**
39. MK. OK, so what do we know? Well, OK, this is the description. [Writes "Description" and underlines.]	C	*New Episode*. This Claim relates to the problem-solving strategy.
40. MR. Do the free-body.	C	
41. RM . Just make a force thingy [force-vector diagram?].	C	40. and 41. are procedural since they prioritize the task.
42. MK. OK, so then what?	RQC	RQC = Request for Claim. Could also be Sm
43. (MK) We'll need to draw the bar. [Draws bar.]	C	Answers her own question.
44. (MK) And this is a weird force. [This statement is unclear. MK *could* be referring to the normal, or that the free-body diagram will be "weird."]	C	*New Episode*. This is a new aspect of the solution, hence a new episode. Sets up a discussion of the forces.
45. (MK) We have a weight [of the bar] going [down].	C	Second part of her Claim.
46. (MK) We have tension this way, right? [draws T vector]	C W RQSp	Third part of her Claim. Implicit W because a tension in the cable caused by the weight is a principle of physics. "right?" = RQSp.
47. RM / MR. Yeah	Sp	
48. MK. So we label that T?	Sm	This is a statement of summary, not a question.
49. RM . You have a weight right here. [Points to where W_B goes on diagram, i.e., in the center.]	C G	*New Episode*. The Claim is the location of the weight.
50. MR. The bar weight.	Cl	

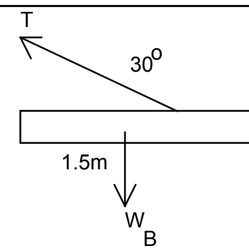
51. In the middle.	Cl	Weight vector is at the center of the bar.
52. RM . Yeah, goes in the middle.	Sp	Supports the previous warrant.
53. MR. That [i.e., the weight] always goes in the center.	W	Supports the previous claim.
54. MK. OK, so this is weight bar. [labels diagram with W_B while talking.]	Sm	This is a good example of the Recorder summarizing before moving on.
55. MR. That should be at one end, 1.5 meters.	G	
56. MK. What?	RQCl	RQCl = RQ for Clarification.
57. MR. The weight of the bar.	Cl	
58. They always do it from the center. We always do it from the center. We're going to have to know how far over it is. [Indicating labels for the distances.]	C B RQG	C = Do it from the center. B = "They always do it." RQG = Request for Grounds.
59. So it's always at 1.5.	G	Always at 1.5 implies it is always in the middle, i.e., at the center of mass.
60. MK. Oh, OK [Draws and labels the 1.5 meters.]	Sp	
61. MR. Meters.	Cl	

Table 3-1. Group 4A, Lines 39-61.

The students in Group 4A had just written down the "Question" and identified the principles they will use (equilibrium and torque). In this specific segment they are beginning to draw the free-body diagram. In the first episode (lines 39 to 43) they identify the diagrams ("free-body" and "force thingy") they will draw in the Physics Description. Member MK, who is the Recorder, makes the Claim (line 43) that they will need to draw the bar before they can draw the free-body diagram. From identifying the necessary diagrams in this episode they next go to a discussion of which forces to include on their free-body diagram. This was a change of thought, and thus the new episode takes over in line 44. The statement "And this is a weird force," is difficult to interpret.

It could be a reference to the normal force, which, in my experience, some students call a "weird" force. It could also be a part of an interrupted statement, "And this is a weird force diagram." Because the students begin a discussion of specific forces in line 49, I believe this was a cryptic reference to the normal force.

In line 29, member RM takes over the conversation and indicates the location of the weight of the bar. This is a new episode for two reasons. First, there is a change of speaker. Second, now they begin a discussion of a *specific* force, whereas in the previous episode, they were talking about all the forces in general. From this discussion of the weight of the bar, which ends in line 61, they then went on to talk about the weight of the mug, the normal force, and the tension. In Table 3-3 (page 79) the translation of their free-body diagram is evident in the force-vector diagram they drew earlier. Thus, in this transcript segment there are three episodes: In lines 39 to 43 they discuss which diagrams to include in the Physics Description. The conversation turns to which forces to include on the free-body diagram in lines 44 to 48. Finally in lines 49 to 61, they discuss in detail one particular force, the weight of the bar. It is interesting that as they move from the general to the specific and the discussion becomes more detailed, their episodes become slightly longer. To summarize, there are two primary cues that a new episode has begun: (1) a change of thought or topic, and (2) a change of speaker. When these two cues are both present, the new episode is easiest to define.

Examples of Coded Discussions

Examples from Groups 4A, 4B, 4C, and 4D will further illustrate the episode definition process, as well as the details of each group's discussion. In each case, I will draw upon the four reference points. The videotapes and transcripts continue to be the primary reference point. The quantitative data such as standing in class will help form a better picture of the groups and the students in them. The written solutions provide the diagrams that illustrate the problem solutions. My own subjective opinions, as well as those of the transcription assistant and my adviser, provide the fourth vantage point for viewing these groups.

Example of Group 4A

I will now turn to some more examples from Group 4A. In an appeal to a "higher authority" (Backing) they note how the professor solved a similar problem in class. Note, in the example in Table 3-2 (page 78), how RM plays the skeptic role, and how MR responds to his inquiry. RM is the "silent partner", and his academic standing in the class is lower than the two women. He does, however, contribute important concepts to the discussion or voices support for ideas of others. RM's lesser degree of participation in this group is a part of this group's dynamic. It was frequently observed that in groups of two women and one male, particularly where the male's academic standing is lower that both the women, the male student frequently was less active. Nonetheless, RM's contributions are an important part of the solution of this problem.

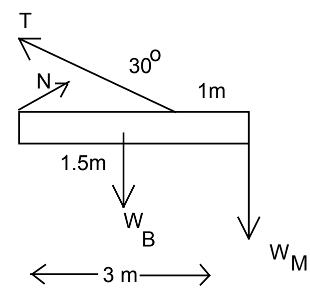
Dialog	Coding	Comments
108. MK. OK, so don't we draw this here...we draw tension here, right?	C	Relates to her recorder role, but is a physics claim about how and where one draws in the tension.
109. RM . Not...	Sk	Begins a Skeptical question
110. MK. Right?	RQSp	Request for Support
111. RM . Not like that, do you?	Sk	Continues questions started in 109.
112. MR. Yeah, that's how he [professor] drew it, didn't he, on his force diagrams?	B	
113. MK. And then the normal right here. [Drawing N as she speaks.]	W (C)	The Claim is implicit in the drawing of the figure: 
114. RM . Oh, yeah.	Sp	He agrees with her.
115. MK. Right?	Ck	MK Checks for consensus before continuing.

Table 3-2. Group 4A, Lines 108-115.

In the dialog example between members MR and MK in Table 3-3 (page 79), they consider asking the teaching assistant for help in determining where to put the "fulcrum." This type of intervention by the teaching assistants was discouraged on graded group problems. However, references to the professor or the teaching assistant frequently surface when a group is stuck on a point as they are in lines 124-127. This is the point in their solution when they draw the force-vector diagram.

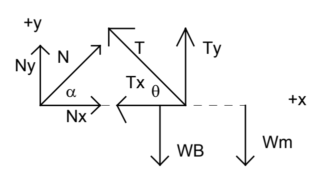
Dialog	Coding	Comments
116. MR. Well, that's your focal point, right?	C	*New Episode*.
117. See some of those [forces] cancel out	C	Continues thought in 116.
118. because you're in the line of action.	W	This is one of the best examples of a warrant in this session.
119. MK. Oh, yeah, for right now, let's just draw them out. Let's just draw them all in. [Taps pencil on diagram.]	C	Relates to Recorder role, but is a managerial statement.
120. OK, and then our weight...we put that all here, just it, just like we did over there [on the free-body diagram], is that right?	C RQSp	Could be RQCl = Request for Clarification. RQSp = Request for Support
121. MR. Yeah	Sp	
122. MK. Or no?	RQCl	RQCl = Request for Clarification.
123. MR. Yeah	SP	
124. MK. You sound not definite.	Ck	
125. MR. Not real confident what's going on in class.	RQEn	RQEn = Request for Encouragement.
126. MK. Me either.	RQEn	
127. MR. But, I think that's right.	Sp	
128. MK. M... [i.e., mug]	Cl	
129. MR. W-b	Cl	
130. MK. We should ask him [TA]...when he comes around, ask him.	RQI	RQI = Request for TA Intervention.
131. MR. Uh, huh	Sp	
132. MK. If this is right, to draw it that way. [i.e., the force-vector diagram. What they drew is shown at right.]	Cl	
133. MR. You have to decide where to put the fulcrum point. [RS looks at his own problem statement sheet.]	C	*New Episode*.
134. MK. OK, well let's first find N and T...uh, catch him [TA] when he comes around.	C RQB	RQB = Request for Backing, or Intervention.
135. MR. I don't even know if he's even going to come and see us because we're on candid camera.	X	(Statements coded X were omitted from the analysis.)
136. MK. Well, then go...you have to go to the bathroom, don't you...all right.	X	

Table 3-3. Group 4A, Lines 116-136.

In Table 3-4, lines 81 and 82, member MK uses summarizing statements as transitions between thoughts. She almost always talks aloud as she writes or draws, and is continually seeking support for what she is saying and writing. All of these "OK" or "so then" or "what else" statements summarize and check for consensus even when they are embedded within other statements:

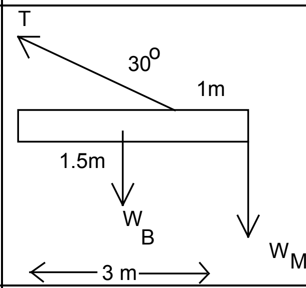
Dialog	Coding	Comments
81. MK. OK, so what else?	RQC	*New Episode*. RQC = Request for Claim.
82. Is that all the forces we need to draw?	Cl	This is an explicit statement of what she said in 81.
83. RM . Yeah	Sp	Means we've drawn all the forces.
84. MR. We might want to, the total distance is 3 meters	G	
84b....I guess that's all we need to know.	C	This serves as a summary in the form of a claim.
85. MK. OK, so then, what do we know first.	C	*New Episode*. Means "Do what we know first."
86. Let's just work down the questions [i.e., knowns, unknowns] we know.	C	Restates 85.
87. MR. W-b [MK writes while MR is talking]	Cl	
88. MK. We know W-b, W-m...umm,	C	MK is the recorder, thus her claim is based on that role.
89. tension we don't know.	C	
89B. We know θ, what else? [Labels as she talks.]	C	cf. the "what else" in 81. This serves as a summary.

Table 3-4. Group 4A, Lines 81-89B.

A key idea of this research is the co-construction of an argument. There are several points at which Group 4A illustrate they are developing their argument *as a group* and *not individually*. In the exchange in Table 3-5 (page 81), member MK completes MR's sentences. In fact, the essence of this problem is the correct application of the principle that in static equilibrium, the "Sum of the forces equals zero" and the "Sum of the torques equals zero." The students are indeed thinking about the physics of the problem.

Dialog	Coding	Comments
137. MR. Sum of the.	W	
138. MK. Sum of the forces equals zero. [Writing Σ F= 0 while she speaks.]	W	Although this is a warrant, it is a part of the Recorder role. MK talks aloud while writing.
139. MR. Sum of the torques.	W	
140. MK. Sum of the torques equals zero. OK, umm, OK... [Writing $\Sigma\ \tau = 0$ while she speaks.]	Sm	
141. MR. Well, should we just try putting...	C	Incomplete thought. Probably refers to where they would put the "fulcrum."

Table 3-5 Group 4A, Lines 137-141.

The other "reference points" provide additional insights. The class average on this group problem was 7.46 (Out of 10 total points, $\sigma = 1.80$). Their teaching assistant graded their problem solution at a perfect 10 points ($z = 1.46$). Their written solution to the problem was very neat and clear and generally followed the five-step problem solving strategy. I looked at the group as a whole, subjectively evaluating their functioning. While MK is the most involved of the three students, both MR and RM made significant contributions. Upon reading the transcript, one sees MK making many statements related to her role as the Recorder. She is very conscientious about checking for consensus among the group members before continuing to the next step. For example, she says at one point, "OK, so don't we draw this here...we draw tension here, right?" (Line 108, Table 3-2, p. 78) This is a part of the role of the Recorder/Checker. Although RM is the least involved of the three, and although he identifies himself as the Energizer for the group, it is clear he adopts the role of Skeptic through the types of questions he asks of the other two students. His skeptical statements can be as simple as "Not like that, do you?" (Line 111, Table 3-2). Group member MR expresses her discomfort with the problem when she says, "Not real confident [about] what's going on in class." (Line 125, Table 3-3, page 79)

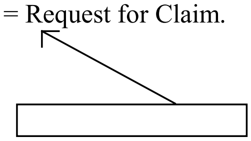
This group worked very well together. In fact, it was one of the best functioning groups observed in this study. This assessment of the group was initially made when viewing the videotape for purposes of annotating and correcting the transcript. The transcription assistant, who by this time had transcribed several groups' problem sessions, also commented that this was a very good group. It was clear that Group 4A would be the prototype "well-functioning" group. There are the instances where one student completes another student's thought. These observations eventually lead me to believe there is a co-construction of their problem solution. (Interestingly enough, about one year after this data was collected, MK worked as a part-time student assistant in the science education group.)

Example of Group 4C

Group 4C consisted of two men and one woman and provides a stark contrast to Group 4A. Members JV and EW are males, SV is a female, foreign student. (This was determined from her name on the log sheet and her slight accent from the videotape audio. Her "King's English" was impecable and there was no difficulty communicating with her group mates.) EW was identified as the recorder, JV as the Skeptic, and SV as the Manager. Their cumulative exam scores at the time of this group problem indicate JV and EW are from the middle third of the class and SV is from the lower third. Compared to the class mean at the time of this problem, their aggregate standing was very close to the class average ($z = .06$). Their written solution to Problem 4 was given 7 points by the teaching assistant, slightly below the class mean of 7.46 ($z = -.26$).

The students in Physics 1041/1042 were introduced to the roles of the manager, recorder, and skeptic. Probably because this aspect of cooperative learning was not stressed in the course, most groups were somewhat cavalier about using the roles. This group is very casual about their group roles, and do not take time to sort out who is doing what, as is seen in Table 3-6 (p. 84; lines 21-23). This casualness also subverts the step by step process of the problem-solving strategy. Instead of stopping after each step, and checking on their progress, they tended to jump around. Although they seem to follow the steps of the problem solving strategy, they are "backfilling" at some places. In this example (Table 3-6), they try to include pictures so as to better their score (Line 27). All cooperative groups will, at times, use humor. Here, (lines 30-34) humor is injected to alleviate their frustration with the problem. This does, however, prohibit any physics from being discussed.

Even with one viewing of the video tape, it becomes clear that SV is a forceful leader of the group and essentially dominates the process. She is more than a manager in the way it was defined for the students, as is seen in Table 3-7 (page 85). She effectively took charge of the group and made sure the group followed the problem-solving strategy. Her commanding presence is best seen in line 39. The off-task talk may have been a reaction of the others to her order giving. Her dialog with EW in the lines that follow (Table 3-7, page 85) are typical of how he was shut out of the solution.

Dialog	**Coding**	**Comments**
19. SV Very good, you took calc, didn't you?	En	*New Episode*.
20. EW You a brain? How what's our picture/given information? I should draw this force.	RQC	RQC = Request for Claim. 

21. SV Are you the recorder? Oh, my gosh.	RQC	
22. EW I think Jason is, but I'll do it.	C	Relates to their roles.
23. JV I don't know how to record.	RQEn	
24. EW OK, so our picture (unintelligible), right?	C	*New Episode*. This claim relates to the problem solving strategy.
25. JV I'll be the skeptic.	C	Relates to their roles.
26. SV No wait, yeah.	Ak	
27. JV We have to write stuff there so they don't take our points off, don't we? [Digression that lasts about 1/2 minute]	C	This claim relates to the problem solving strategy. Relates back to 24.
28. SV They will anyway...OK, just draw the picture...find all the unknown forces exerted on the strut.	C	This claim relates to the problem solving strategy as well as the question. Relates back to 27.
29. JV OK...(mumbles)	Ak	
30. EW Now that, my friend, is a beer mug. [each works separately]	En	
31. SV Froth filling up.	En	
32. JV Oh, a beer mug.	En	
33. SV It's a beer mug, OK	En	
34. EW A beer mug.	En	
35. SV OK, now, umm...what is it we want to put down for our question we want to find? Unknown forces exerted on the strut.	C	A physics claim that ends this episode.

Table 3-6. Group 4C, Lines 19-35.

Dialog	Coding	Comments
35. SV OK, now, umm...what is it we want to put down for our question we want to find? Unknown forces exerted on the strut.	C	A physics claim, ends the previous episode. Relates to the "forces" part of the question.
36. EW Find the tension so we want, we basically want to find the tension.	C	*New Episode* A physics claim, relating to the strategy, and the target variable.
37. SV Tension.	Cl	Clarifies the statement in 36.
38. JV And also this force here. [points to the hinge]	C	A physics claim.
39. SV Write down we want to find out unknown forces on the strut. On the strut, unknown forces...find them!	C	No follow through on her claim. [said forcefully] [off task chatter ensues]
40. EW What are the unknown forces on the board? OK, so we have.	C	Relates back to his claim in 36.
41. SV Now, no, no. That's the question.	Ch	Challenges EW's claim in 40.
41B. We have to use our approach.	C	She offers an alternative idea based on the problem-solving strategy.
41C. We have to use the equilibrium.	C	
42. JV It's a uniform strut, it's not a board.	G	He offers information from the problem statement.
43. EW We use these.	W	Refers to equations on sheet.
44. SV Excuse me?	RQCl	RQCl = Request for Clarification.
45. EW OK, first of all, we have to know that x of y.	Cl	Clarifies his statement in 43, which relates back to 40 and 36.
46. SV No, no...just write that	Ch	
46B. we have to use like Newton's law or whatever. Don't write that, those are formulas. That goes in the physics description.	C	Her challenge suggests an alternative idea to what EW has said in 36, 40, 43, and 45.
47. JV Newton's 2nd law.	Cl	
48. EW No.	Ch	
49. JV No?	RQCl	He doesn't understand the Ch.
50. SV Yes, we have to use the sum of forces, babe.	C	An additional claim. This dialog is very typical of SV.
51. JV OK	Ak	
52. SV Newton's 2nd and then the equilibrium stuff.	C	An additional claim.
53. JV Equilibrium stuff?	RQCl	
54. SV Statics, statics...don't we have to figure out? What are we finding?	Cl RQCl	

Table 3-7. Group 4C, Lines 35-54.

One of the major facets of the problem-solving strategy is the Physics Description and the attention to drawing diagrams, particularly free-body diagrams. Free-body diagrams preceed the "Plan" section of the problem-solving strategy where equations are constructed. Long before they have *properly* drawn diagrams, on which they all agree, they begin to look for equations that will solve the problem (Table 3-8):

Dialog	Coding	Comments
56. SV Just forces?	C	*New Episode*. This is a claim in the form of a question, i..e, "We just need forces."
57. EW We want to find like F-x, F-y.	C	A physics claim.
58. SV And we have to use torque.	C	A physics claim.
59. EW No, we basically want to find tension...yeah, I know. That's the whole force diagram, right there.	Ch C	An additional claim immediately follows the Challenge.
60. JV Do we have to use torques?	RQC	RQCl = Request for Claim
61. SV Yeah, that's statics.	C W	Claim (Yeah, use torques) with implicit warrant (that's statics).
62. JV OK, whatever you call it.	Sp	
63. EW OK, use Newton's second law... [writes F= ma while JW and SV talk and look at their own papers.]	C	*New Episode*. A physics claim. This begins a discussion of what principles to use.
64. JV Don't we have to write down those things then?...umm, all the forces of torque equal, what are these? What's that? [He is referring to what EW has written on the paper.]	C	An additional Claim that changes the idea.
65. SV Tau?	Cl	
66. SV Tau equals L times.	C	A physics claim.
67. JV Oh, yeah, moment arm times...	W	They use very few obvious warrants.

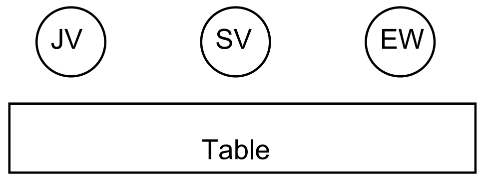
Table 3-8. Group 4C, Lines 56-67.

Another thing noticed about this group was the rapid fire character of their conversation. Subjects of sentences change abruptly and thoughts are left uncompleted. EW's mumbling (Table 3-9, page 87; Line 86) is partially due to his soft voice, but also because SV didn't let him say much. The other two students easily acquiesce to her ideas. This example (Table 3-9) captures some of that behavior. Students were taught to draw an idealized sketch of the problem, then a free-body diagram, then force diagrams. In most problems, the correct solution requires the properly drawn free-body and force diagrams. In this example, there is no resolution as to whether they are drawing a free-body diagram or a force diagram.

Dialog	Coding	Comments
82. JV What's that, the free-body or the force?	RQCl	*New Episode.* RQCl = Request for Clarification.
83. SV That's the free-body.	C	This claim relates to the problem solving strategy.
84. EW Yeah	Sp	
85. SV No, that's the force.	C	An additional Claim that changes the idea.
86. EW (mumbles)	X	
87. SV He'll just redraw this [i.e., the picture of the sign in the problem statement] for the free-body...that's all right.	C	
88. EW Oh, and you gotta have the w [i.e., the weight] of the board.	W	W = Weight belongs on FBD.
89. JV Fine with me.	Sp	
90. SV See, I told you we have to use statics and Newton's second...and statics.	C	*New Episode.* This claim relates to the problem solving strategy, as well as the physics.
91. JV Yeah	Sp	Support for the claim.
92. SV What is this? [writing on her paper] It's L times what? Is it L times f? L times t? I can't remember what it is in the book.	RQCl	She scribbled this on a piece of paper she had and EW didn't write it on the solution sheet.
93. JV It doesn't matter, because it's, they're all forces, isn't it? I mean, it's just a matter of what force you're talking about. If it's a tension or a weight or a...	RQCl ?	

Table 3-9. Group 4C, Lines 82-91.

There are essentially three simultaneous two-way conversations going on in this group. Very little *three-way* conversation occurs in this group, and I do not believe there is any three-way group *communication* occurring. A key component of cooperative learning is face-to-face interaction. This means the participants in a group are physically placed so as to enhance their communication. The original seating arrangement of this group along a table followed this order:



Throughout the first half of this session, members JV and SV tended to hold their own two-way conversation exclusive of EW. When there was a three-way conversation, frequently, SV acted as a mediator between JV and EW. That is, she talks to JV and EW more than JV and EW talk to one another. The effect of this is that EW, the recorder is left to solve the problem by himself without any significant input from SV or JV. For a brief time near the end of the problem session, EW moved to the *middle* position at the table where both SV and JV could see what he was writing.

When this research was in the planning stage, much thought was given as to how one would recognize a *poorly* functioning group. When all four groups that made up the fourth taping session initially were viewed, it was clear that Group 4C was an excellent example of a poorly-functioning group. The contrast with Group 4A is remarkable. The transcription assistant made an initial comment on the poor functioning. He noted the difficulty in transcribing this session due to the rapid fire nature of their conversation.

The segment of their dialog in Table 3-9 (page 87) also illustrates how problematic it is to define episodes for this group. It is difficult to determine if a new episode begins in line 90 or 92. Member SV's thoughts come so fast, they do not seem to connect with what comes before or after. Member JV's comment in line 93 doesn't clarify the situation. If lines 90 to 93 comprise one episode, then they are an episode in which there is minimal co-construction occuring.

Several factors may have contributed to this group's dysfunctional situation. Based on cooperative learning research and practice, I can hypothesize three specific factors: First, the seating arrangement prohibited true face-to-face interaction. Second, the gender imbalance may have caused EW (male) to tune out SV (female). Third, the relatively homogeneous ability of the group may have inhibited skeptical questioning. An interesting question about this is, why, despite such poor functioning, does the group still produce a partially correct, only slightly below-average written solution to the problem? One reason may be that their written solution is largely the work of EW who probably had the best grasp of the three group members of the physics of the problem.

Group 4C provides an excellent example of the lack of co-construction. In Table 3-9 (page 87), the group illustrates how they jump from thought to thought. There is no resolution of which diagram they are constructing and which forces belong on the diagram. The discourse is disorderly and does not flow from person to person or from thought to thought. The Claims often are not supported with appropriate Grounds, Warrants, and Backings. Hence I came to the conclusion that Group 4C is the one group of the 14 that did not consistently engage in co-construction. Their lack of co-construction will be seen in discussing the other research questions as well. We came to refer to Group 4C as "the different group." These kinds of observations led me to believe that this group is not co-constructing their argument.

Example of Group 4B

Group 4B consisted of one woman (KJ) and two male students (LP and JH). Based on their individual cumulative exam scores at the time of this problem session, this was a below average group. ($z = -.81$). All three students were full-time, residential students at the University. JH was the Recorder. Due to an audio problem, the usable portion of the videotape began as they were starting the "Plan" section of the problem solution. However, several portions of the physics description are contained in the analyzed segment. Students frequently retroactively worked on the physics description.

This group's free-body diagram was not clearly drawn. Although the tension, weight of the mug, weight of the sign, and normal vectors are indicated, the diagram is very cluttered and it is not clear which label is attached to which vector or vector component (cf. Table 3-10, page 92). This group did not draw idealized, free-body and force-vector diagrams. This omission hindered their proper identification of the variables.

In the "Physics Description", they wrote only one quantitative relationship:

$$\text{Weight x distance} = \text{torque}$$

They neglected to also write Newton's Second Law. However, in the approach section, they wrote $\Sigma F = 0$ and $\Sigma \tau = 0$, which of course is a *mathematical* statement of the basic principles of statics. They identified target variables τ_1 and τ_2. The vector identified as τ_1 clearly refers to the tension in the support cable. It is not clear if the other target variable τ_2 refers to the normal force or a vertical component of a resultant force at the point of contact between the strut and the wall.

This first example (Table 3-10, page 92) is at the point where they are retroactively working on the physics description. What is clear from examining this diagram and their conversation is that they confused tension in the cable, normally abbreviated *T* with torque τ. Hence, they write two equations in the "Plan" which they subsequently solve numerically:

$$\tau_1 = \frac{(W_m \cdot 3) + (W_s \cdot 1.5)}{\sin\theta} \qquad \text{and} \qquad -\tau_2 - W_m \cdot 1 + W_s \cdot 5 = 0$$

They proceed to solve these two equations for the two unknowns and find the answers in units of newton-meters, which of course is not a unit of force but of torque. (τ_1 = 1500 N·m and τ_2 = -150 N·m) In other words, they find the torques, but not the forces on the bar, which was the question posed in the problem statement. Although in the dialog seen in Table 3-10 they say "t", on their diagram they drew "τ" which only compounded their confusion.

Despite some poor physics, Group 4B managed to interact well with one another. The dialog in Table 3-11 (page 93) illustrates how they request and give clarification of ideas. The motioning with the pen (Line 105 ff.) serves to visually clarify the idea. Of the 22 statements in this section, KJ makes 8, JH makes 8 and LP makes 6 statements. That is, their conversation is well-balanced and all students are participating equally. Their group functioning is rather good. The reason for this can be seen in the manner in which they elaborate on ideas. Each student is an equal partner in the solution. Although there is co-construction of the argument, they are basing the construction on some erroneous physics, and that resulted in a poorer grade on the problem.

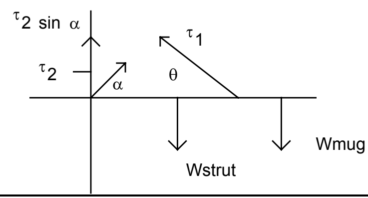
Dialog	Coding	Comments
68. JH So now we're finding out t-2.	C	New Episode.
69. LP We use that, the fulcrum at that point [where t-1 attaches on their diagram] and we don't have to solve for t-1. We got two known weights and then just t-2.	C W	Implicit Warrant They say “t” when they mean “τ“.
70. KJ Oh...so he's just drawing a force diagram for t-2? [JH writes "Fulcrum at hinge" under the free-body diagram]	RQCl	RQCl = Request for Clarification. 
71. LP Yep, yeah.	Cl	
72. KJ Unless you want to just stick it [JH writes T2 cos θ] in there.	C	Additional claim
73. LP Had no idea we would be changing the fulcrum point.	Cl	
74. JH Yeah	Ak	
75. LP The forces would remain the same.	C	i.e., if the vectors are moved.
76. KJ Everything would be the same. All he would get is the circle on it...to where you had it.	W?	Cryptic statement
77. JH (mumbles)		

Table 3-10. Group 4B, Lines 68-77.

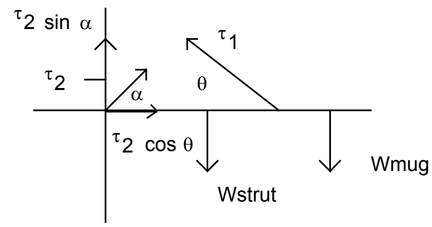
Dialog	Coding	Comments
105. LP Now wait a second, we can check that on here. We'd be looking at it in...would that be sine? Yes. [places pen on force diagram and rotates the pen around an axis centered on the origin]	C W	*New Episode*. Excellent example of a "visual" warrant. 
106. JH Which way we going?	RQC	RQC = Request for Claim.
107. KJ Yeah, because if here's your angle, right?	C	Claim relates to complementary angles.
108. LP Yep.	Sp	
109. KJ Yeah...	Sp	
110. JH How'd you know the angle?	RQCl	[all look at the force diagram]
111. KJ Well, you'd use it, if you...well it's going to be the angle with the arm, isn't it?	C	Claim relates to complementary angles. [motions along the horizontal axis of the force diagram with his pen]
112. JH Well, it's [the angle] ninety degrees. You break it down.	C	Claim relates to complementary angles.
113. KJ The wall arm, that's ninety degrees, but not the force.	C	Additional Claim
114. JH It's going to be going clockwise, so t's going to be negative, right?	C	Additional Claim
115. KJ Yeah	Sp	
116. JH So then what's plus?	RQCl	
117. LP Plus...would be minus the weight of the mug.	Cl	
118. JH So what, 3?	RQCl	[begins writing equation 3]
119. LP Umm, no. It wouldn't be...	Ch	Ch = Challenge (albeit a weak one.)
120. JH Well, wait. The mug doesn't matter, because that's where our origin is. [erases something in equation 3]	C	*New Episode*. This new episode shifts their attention to the location of the mug.
121. LP No it ain't.	Ch	More forceful. Challenge to the idea.
122. KJ No, it's at the angle.	C	Additional Claim relates to 120 and disagrees with it.
123. JH Where do we put our origin? Oh, OK...	RQCl	
123B. LP It would be times one.	Cl	
124. KJ Yeah.	Sp	
125. JH Sure now?	Ck	
126. KJ Yeah	Sp	

Table 3-11. Group 4B, Lines 105-126.

Example of Group 4D

Group 4D consisted of one woman (CB) and two male students (ME and ST). Based on their individual cumulative exam scores at the time of this problem session, this was a below average group (z = -.81). All three students were full-time, residential students at the University. ST was identified as the Recorder. This group also lacked some physics knowledge due to ST being the only one in class the day before when the instructor did another similar problem as an example.

ST: Were you, you were in class yesterday, weren't you?
ME: No.
CB: You're the only one. [i.e., who was in class]
ST: Oh, and I don't remember this. [covers face with palms]
ME: I was drained, I was drained two days...

Such self-disclosures were useful in identifying poorly prepared groups. Their lack of physic knowledge influenced their approach to solving the problem. In the dialog segment in Table 3-12 (page 96), the students coax the teaching assistant into giving a hint. Although the teaching assistants were discouraged from directly answering questions, they would occasionally intervene to make a point about the physics. Dialog sections in which there was considerable teaching assistant intervention were not included in the analysis procedure. This segment is included here as an example of a teaching assistant intervention.

An error in the construction of the free-body diagram eventually led to a mistake in the writing of the equations for the equilibrium condition. They neglected to place the weight of the strut in the *center* of the strut. Later, when finding the torques, they used a moment arm of 2 meters instead of 1.5 meters. A sketch of their free-body diagram appears in Table 3-13 (page 97) opposite line 22.

One reason this group produced a fairly acceptable solution to this problem was because they interacted very well as a group and despite the lack of physics knowledge, and the previously mentioned error, managed to get several portions of the problem correct. The section of dialog in Table 3-14 (page 99) illustrates their attention to the details of the physics description. The difficulty with this diagram, of course, is that the tension, normal force and weights of the mug and strut do not act all at the same place as they have drawn it. In their “Plan”, they thus made a error when applying $\Sigma\tau = 0$, and as has been noted, use a moment arm of 2 meters instead of 1.5 meters. Even so, there is a good use of warrants to support their argument. Their fatal error was the perpetual problem with novice problem solvers: an improperly drawn free-body diagram! Later, they drew an incorrect force-vector diagram because of this error in the free-body diagram. The cluttered nature of the force-vector diagram is very evident in the sketch opposite line 93 in Table 3-14.

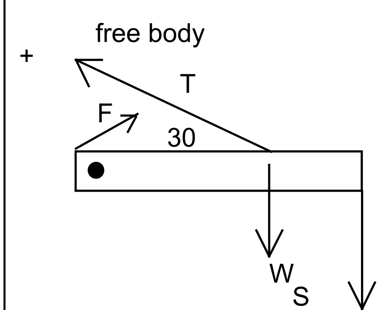
Dialog	Coding	Comments
99. ME I don't...we don't have to be specific. Alpha sounds good to me.	Sp	This statement ends a discussion of how to label the angle.
99B. OK, now we've got 3, 2 forces down. Where's that going? That's going...	C	*New Episode*. Claim = direction of forces.
100. ST That's the 200 Newtons. That's the same, that's the same as the pull on the mug.	G	The 200 N comes from the data, but the second part of the phrase could be seen as a claim, or simply clarifying that the weight is 200N.
101. ME OK, so that's transferred into the strut.	W	i.e., the weight is transferred.
102. ST Oh, God. I don't remember. [drops head to desk]	RQCl	RQCl = Request for Clarification.
103. TA Forget about memory. Work from...sum of the forces equals zero. Otherwise it'll start accelerating somewhere, which is bad for a welcome sign.	I	I = Intervention (TA = teaching assistant)
104. ME The accelerated welcome sign.	En	
105. ST OK, so this is...if we call this one t-1, this is, and this is θ. This, we'll call this one t, since that's what it is.	Cl	
106. TA What are you adding in, an extra...	I	
107. ST No, that's the way he had it yesterday. It was coming out...	B	Good example of using what the professor did as a backing.
108. TA Forget what he had yesterday.	I	
109. ST I know.	Ak	
110. TA Work from...look at that lovely diagram over there. That's what it looks like. Sum of the forces is equal to zero. Around any point. Young Luke, why make it hard on yourself?	I	He points to this diagram: 
111. ME Wait a minute, he's flipping a coin. Oh no, let's see what we want today. Let's get a two.	En	Probably refers to where to locate the fulcrum point.
112. CB OK, you know how. If you've done any of the problems in the book, you know where they tell you to draw the little dotted line through where the force would go, you know what I mean?	B W	B = text problems W = resolution into components

Table 3-12. Group 4D, Lines 99-112.

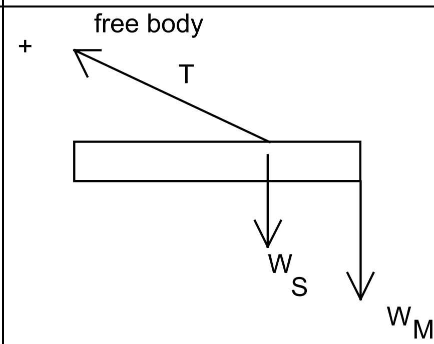
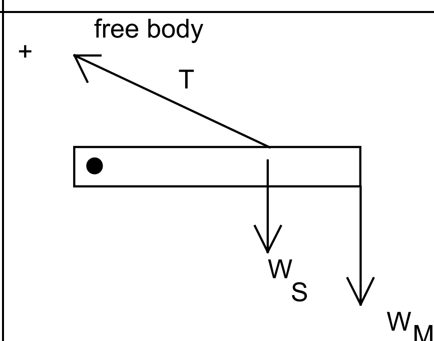
Dialog	Coding	Comments
11. CB OK, what it says. It says that the uniform strut is 100 Newtons. Oh, wait, wait...that the beer mug is 200 Newtons. Could we say that this is, then?	G	Data from the problem statement. Cryptic statement probably refers to label on W_M.
12. ME The tension in here is 200 Newtons.	W	The 200 N is an implicit G, That this gives rise to a tension is a W.
13. ST (unintelligible)		
14. CB 200 Newtons, OK. And, uhh...	Ak	
15. ST There's a tension here, this one.	R	
16. ME Yep. So this weight [W_S] should be coming down directly here, about midway. Right here. [They drew under the point where the cable attaches.]	C	
17. ST Oh, geez. So problem conception...let's draw a ...well, that's the problem conception. We just gotta draw that over again. [TA interrupts entire class with some information on the problem.]	C	Interruption may account for the unconnectedness of this section. Line 16 and 18 seem to follow in order.
18. ME No, this wouldn't be coming straight down.	C	Additional Claim
19. ST The weight, right here is.	Sp	Supports Claim in 16.
20. ME Yeah, straight down.	W	Warrant in 20 supports Claim in 19.
21. ST Whatever.	Ak	
22. ME Our location is here then. Crucial. Because these are all going to create a torque on this point. [draws on his paper]	C	
23. ST Uh, huh.	Ak	
24. CB OK.	Ak	
25. ST OK, well then.	Ak	

Table 3-13. Group 4D, Lines 11-25.

Dialog	Coding	Comments
75. ME But they're in equilibrium. So really, the only component we're interested in is this one. This one is balanced, that one's balanced.	W C	*New Episode*. Claim - one component Warrant - Equilibrium means they are balanced.
76. ST OK, this, these two [+ and - vertical components] are supposed to balance each other.	W	Implicit warrant using the second law.
77. ME Uh, huh.	Ak	
78. ST And this one [T sin 30] and this one [f cos α] are supposed to balance the 300 Newtons. The weight of these two.	W	Implicit warrant using the second law.
79. ME OK, now where's your angle for this normal force [f]? Is it the same as this one [α]?	W	*New Episode*.
80. ST Umm, no, it's a totally different angle. (CB/ME look shocked) I'm serious. This is exactly how he did it yesterday.	C B	Backing from class lecture.
81. ME OK, think, think, think.	En	Encourages the group
82. ST This one was called θ, and this one...	W B	Uses generally accepted notation and mimics the lecture.
83. ME Yeah.	Ak	
84. ST ...was called alpha.	W	Uses generally accepted notation and mimics the lecture.
85. ME OK.	Ak	
86. ST Oh, shit.	X	X = Omitted. Although said in a sense of futility, this could be seen as a skeptic statement.
87. ME Would it be 60 degrees?	RQCl	RQCl = Request for Clarification.
88. ST He never completed the whole problem yesterday. He just cut it out the whole entire time.	Cl B	
89. ME So we'll call it alpha, too.	C	Based on implicit backing of what the professor did.
90. TA So wait a second. It's probably a good idea, because trying to base it on just guesses...	I	I = TA Intervention. This was not omitted due to the relatively minor effect of the intervention.
91. ME We'll just call it alpha, then. That sounds good.	Cl	
92. ST Yeah.	Sp	

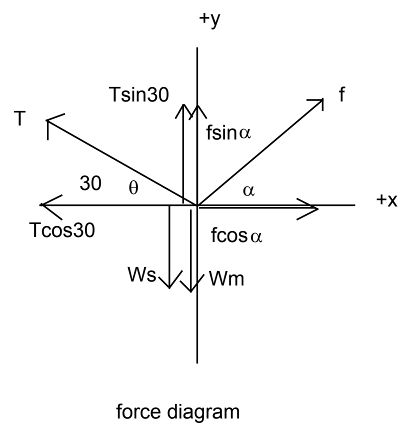
93. ME We've got thirty degrees and alpha. [ME labels these on their diagram.]	G	
94. ST Yeah.	Sp	Sp = Support
95. ME Or we could call it Bill.	En	En = Encouragement
96. CB Ha!	En	
97. ST Bill	En	
98. TA Bill, the angle.	En	
99. ME I don't...we don't have to be specific. Alpha sounds good to me.	Sp	

Table 3-14. Group 4D, Lines 75-99.

This group did not engage in any overt summarizing, consensus checking or skeptical questioning activities. This may be due to the lack of identifying the role of skeptic with a specific individual. However, their discussion proceeds from one thought to another in an orderly fashion. This is seen in their discussion of the free-body diagram where individual thoughts in the discussion of the forces are connected to one another (lines 18-22, Table 3-13, page 97). The discussion of where to *locate* the weight connects to the next thought about the existence of a torque *due to* this weight. In all of the previous examples, there are several references to the surface features of the problem, that is, the observable data. These data, such as the weight of the strut or mug, are used by the students to construct the free-body and force-vector diagram. While constant reference to these features may seem redundant, they actually are an important facet of their solution.

Although Group 4D made some fundamental errors in constructing their force-vector diagram, they equally shared in the solution of the problem. Their use of humor, which on the surface seems to alleviate tension, also serves to encourage the group and keep the solution progressing. Their grade on this problem was 6 points. (Although their force-vector diagram was in error, their plan and execution correctly translated the diagram they drew into two equations. An incorrect force-vector diagram correctly translated received more points than an incorrect translation of an incorrect diagram.)

Extension to The Remaining Groups

The procedure just described in detail for these four groups was next extended to include the remaining 10 groups. Several quantitative "data" and qualitative "descriptions" help to form a picture of each group. These data and descriptions are a form of triangulation, but not in the strict sense of using different data to explore the same hypothesis. Rather these measures and descriptions allow viewing the groups from slightly different perspectives. They also helped me to think about the issue of validity. Note again that the four basic "reference points" from which I made these descriptions are: (1) The videotapes and transcripts, (2) quantitative data from the video log sheets and course records, (3) written problem solutions, and (4) the subjective observations by myself, the transcription assistant, and my advisor.

I analyzed each remaining transcript in the manner just described. I examined the group solutions through the "Plan" because I discovered that often some important aspect of the physics surfaced during this portion of the solution. The most difficult aspect of the task was defining episodes. These principles were followed:

- New episodes begin with a new thought and/or a new speaker.

- Code about 15 to 20 episodes per group solution, if possible.
- Examine the solution through the "Plan" portion of problem-solving strategy.

When a single-factor ANOVA was run on the number of lines per episode for each of the 14 groups, a small significant difference was found ($F = 1.94$; $p = .03$, $F_{crit} = 1.76$). I ran this test to check whether or not my episode definition may have changed in time. While *statistically* significant, I decided this was not *meaningful* in terms of the definition of episodes. It rather reflects the slight difference between "talkative" (e.g., 2A and 5C, $\sigma > 1$) and "untalkative" (e.g., 3A, 6B, 7A, $\sigma < 1$) groups. Thus looking at *which* groups had a $\sigma > \pm 1$ convinced me that I had not significantly changed my episode delineation during the several months in which I did this.

Summary

The results of this initial analysis provided evidence that these groups are engaging in argument co-construction. The criteria I stated for argument co-construction were largely met in at least 13 of the 14 groups on a consistent basis.

Does this occur?	**Answer**
Claims are supported by Grounds, Warrants, and Backings	YES
Grounds, Warrants, and Backings appear in repeating patterns	YES
Group members listen to each other and discuss the *same* claim	YES
Claim-making role shifts among group members	YES

Table 3-15. Argument Co-Construction Criteria.

Moreover, the groups' discussions are episodic, that is, statements are not isolated from each other and there is a logical flow to the discussion. More compelling evidence for co-construction became clear later as I looked at other aspects of these groups. Since argument co-construction is occurring, it made sense to move ahead to the second research question and to look for patterns in the argument co-construction within a group.

QUESTION 2. ARE THERE SELF CONSISTENT ARGUMENT CO-CONSTRUCTION PATTERNS WITHIN A GROUP?

The basis of this question is the finding that the students in these groups are co-constructing an argument. It could also be stated as "Does a group adopt a particular, persistent manner in which they co-construct their argument?" This suggests looking for repeating patterns across several of their episodes. To determine a group's pattern of argument co-construction, I flowcharted all of a group's episodes that focused on the physics description. Then I looked for features common in all their episodes. These features then became the pattern for that group. As will be seen, there are discernible patterns. The following discussion will illustrate the flowchart process.

Episodes that dealt primarily with group functioning ("Who wants to be the recorder?") or tangential discussions ("Wasn't that last quiz something else!") were omitted from this analysis. In many cases, these kinds of statements are embedded in episodes that deal with the physics and these episodes were not *a priori* omitted. In some sessions, the teaching assistant interrupted the whole class or the group being taped. These episodes were omitted from the analysis if the intervention or interruption was a major part of the episode.

Episode Flowcharts

Many statements related to the steps of the problem-solving strategy. Although these appear to be procedural, they usually contain important physics. For example, Group 4A paid close attention to the strategy as is seen in the episode in Table 3-16 (p. 104). Their statements about the Target Variable and the Question being asked in the problem are integral parts of the problem-solving strategy (For a summary of the problem-solving strategy, refer to page 33 in Chapter 2). These steps are designed to help the group determine what variables they are to solve. Hence they do relate to the construction of an adequate physics description, and I decided they should not be excluded from the analysis.

The flowchart of this episode (Figure 3-1, page 105) contains a set of symbols, one for each statement type. Each symbol is numbered and the number is the same as a line number in the corresponding episode transcript. The statement abbreviations are the same as those in the transcripts and the speaker's initials are also included. The arrows indicate the "flow" of the argument. There are some important points to be made about the interpretation of the flowcharts. First, the lines indicate a connection with what preceeds or follows a given symbol. If the thought was left "dangling," the arrow would not terminate on another symbol. Second, if a statement refers to back to a prior, non-sequential statement, a dotted arrow is drawn to show the connection. That is, if the Support in line 36 referred back to the Claim in 31, a dotted arrow would connect those symbols.

Dialog	Coding	Comments
30. MK. So...what's our target [target variable]?	RQC	RQC = Request for Claim. The question arises because of the strategy. This is a problem solving claim. MK often makes claims in question form. She is the Recorder who keeps track of the variables.
31. MR. All the forces on the bar.	C	Directly answers RQ in 30.
32. RM. Sine and cosine. [talks over MR's statement above.]	W	Thinking aloud about vector components. Here the warrant is that vectors can be broken into components.
33. MR. Or, however you want to put that in the question [Question in the Focus step].	Sp	Sp = Support
34. Find all the unknown forces on the bar. [MK writes this as Equation 2 on the Solution Sheet.]	G	MK frequently talks aloud as she writes. These are grounds because they come from the problem statement.
35. MK. OK...that sound good?	Ck	Ck = Consensus Checking. Here Ck serves as a summary statement, could also be coded as Sm.
36. RM. Uh, huh.	Sp	
37. MK. Just so agreeable.	En	Encouragement is a form of light-hearted support.
38. MR. We already know two of the forces.	C	Implicit grounds. Here, the additional claim serves as a summary of the episode. It is a restatement of the grounds and modifies 31.

Table 3-16. Group 4A, Episode 5, lines 30-38.

Figure 3-2 (page 105) illustrates the symbols used in the flowcharts. Claims will generally appear on the left side of the flowchart. Grounds, Warrants, and Backings will appear on the right side. Statements of Support, Clarification, and Acknowledgment appear in the middle when they link Claims to the Grounds, Warrants, and Backings.

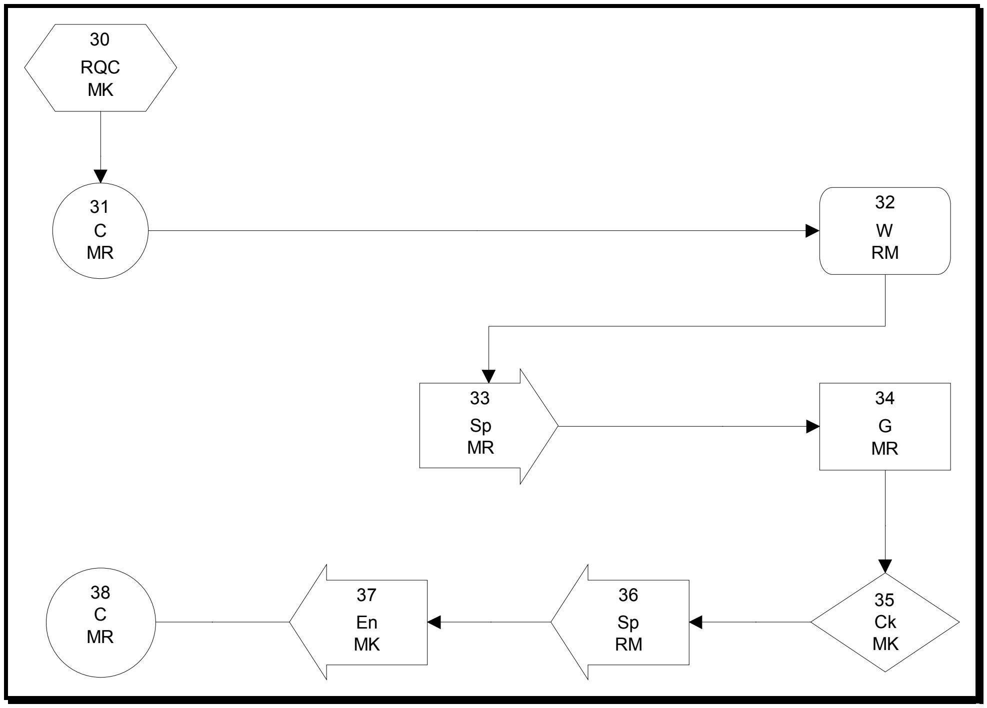


Figure 3-1. Group 4A, Episode 5, lines 30-38, Flowchart.

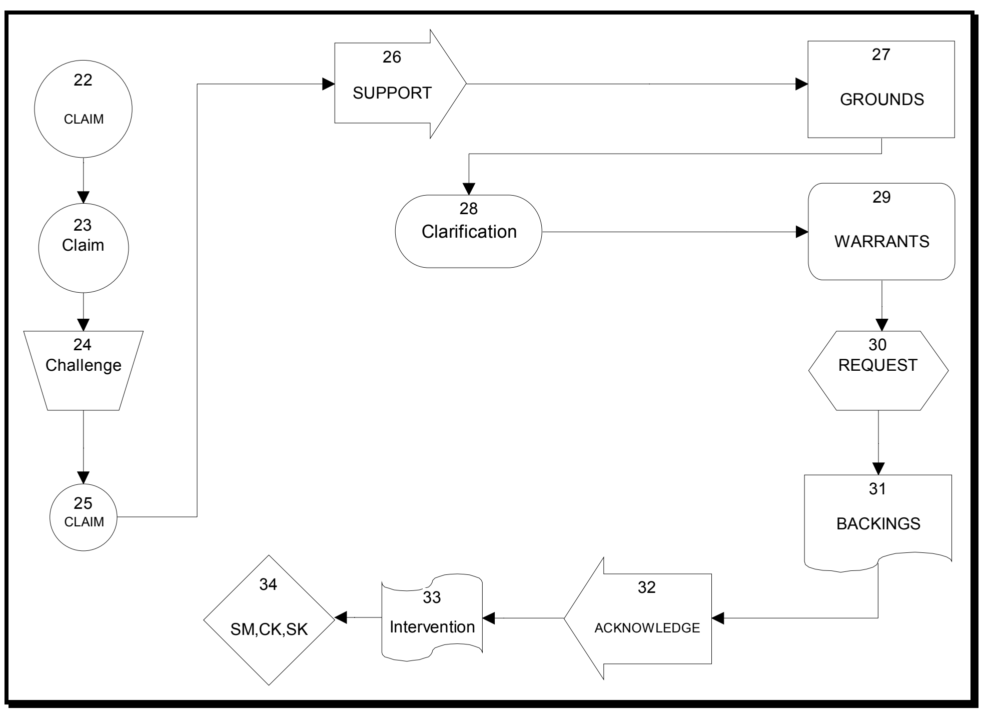


Figure 3-2. Key to Original Flowchart Symbols.

This episode flowcharting procedure was followed for all 14 groups, giving me a collection of approximately 120 flowcharts (out of 291 coded episodes). Some flowcharts were later combined or subdivided as further analysis indicated either a continuation or change in the thought. I excluded *a priori* any episodes in which the teaching assistant was a speaker in the group, or in which the teaching assistant interrupted the entire class with information on the problem. I also excluded episodes in which the students digressed to talk about everything from their grade on the last quiz to the weekend hockey games. In the end I had 112 flowcharts for the 14 groups. Then, armed with both episode transcripts and the flowcharts, I tried to look for repeating patterns within each groups episodes.

Prototype Flowcharts

To determine if a group had a self-consistent pattern of argument construction, I decided to determine if it was possible to characterize a group in terms of a "prototypical pattern." That is, on the *average*, what does this group do? When attempting to determine a "prototypical pattern" for a group, the focus was on their use of Claims, and their support for Claims with Grounds, Warrants and Backings. In most groups where there was a consistent use of such statements as Clarification or Support, those statements were considered to be secondarily important, but still diagramed. Few groups in this study used Skeptical or Summarizing statements, and so these statements tend to be prominent in the groups (2A, 4A, 5C) that use them more consistently.

Another important factor in determining the pattern and drawing the prototype was a subjective reading of the group's discussion. Early on in the research, before I ever drew a flowchart, I characterized each group with one short phrase and wrote a brief descriptive paragraph for each group (See Table 2-9, page 65). I readily acquired a feel for the personality of a group, the kinds of statements they prefer, and the order in which they use them. In a sense the transcripts, and the video tapes functioned much like an anthropologist's "informants." Table 3-17 summarizes the number of physics description episodes coded and flowcharted for each group. It was my intention for about eight to ten episodes to determine a prototype, but the case of five groups, less than eight were available and the reasons for this are noted in the table. I excluded episodes in which there was a lengthy off-task discussion or the teaching assistant intervened or interrupted the class. These kinds of discussions tended to occur at the beginning or end of the class period.

Group	Physics Description Episodes Coded	Episodes used to Determine Prototype	Comments
2A	12	8	
2B	16	10	
2D	15	8	Smaller episodes combined; digression
3A	12	8	
3B	12	10	
4A	16	11	
4B	17	11	
4C	15	6	Lengthy digressions.
4D	15	7	Poor tape quality; TA intervention.
5A	12	6	Rushed through Physics Description.
5B	8	6	Verbose but few claims.
5C	11	6	Digression; many Cl statements.
6B	15	8	Smaller episodes combined; digression
7A	17	8	Smaller episodes combined; digression

Table 3-17. Episodes Coded and Flowcharted.

Appendix D contains the episode flowcharts and corresponding transcripts for Group 4D. I will use this group as an example of the process of deciding if there is a typical pattern and then drawing the prototype. To draw the Group 4D prototype episode (Figure 3-3, page 109), the flowcharts were laid side by side and common features noted using the following procedure. Six episodes that contained numerous digressions or off-task chatter were omitted (Episodes 3-5 and 12-14, during which the Teaching Assistant interrupted the entire class or spoke individually to this group). Two episodes were later combined leaving a total of seven flowcharted episodes for Group 4D. Five of the remaining seven episodes began with a Claim, so that was the first symbol drawn on the prototype. There are an average of about two Claims per episode. When there is a second Claim it usually follows a Warrant. Thus, the second Claim symbol follows the Warrant symbol. This group preferred to support their Claims with Warrants, then Backings, and then Grounds. Warrants outnumber the Backings or Grounds by about two to one, but many of the Warrants are multiple Warrants by one person in one sentence. These longer sentences were split into smaller statements when the individual components all presented unique ideas. In other words group member ST, in particular, has a tendency to include multiple Grounds, Warrants, and Backings in one utterance. Hence, the prototype flowchart shows two Warrants followed by Backings and Grounds. The most common type of support statement was and Acknowledgment statement and thus that symbol links the Backing and the Grounds symbols.

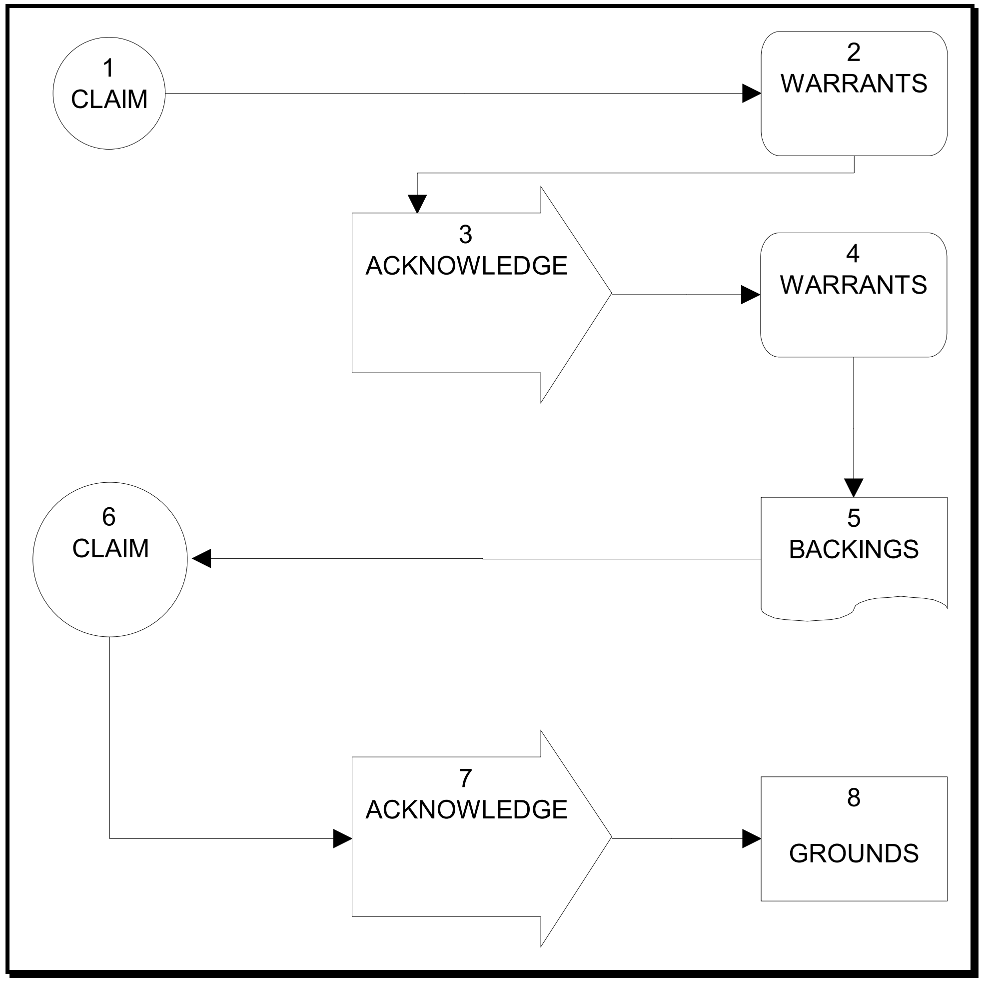


Figure 3-3. Group 4D Prototype Episode.

The flowcharting developed much like the episode coding. It took several attempts over many days to determine if 4A, 4B, 4C, and 4D had a self-consistent argument pattern, and if so to draw a prototype flowchart. After learning how to do this, the remaining ten groups were analyzed in just several hours of work. Although a group's prototype episode will not be found *verbatim* in any of the group's episodes, bits of it are in each. The prototype attempts to answer the question, "On the average, what does this group do?"

Multiple Claims in an Episode

When looking at the 14 prototype flowcharts, I discovered something perplexing. There were multiple claims in some prototypes. This is seen the in the prototype example from Group 4D (Figure 3-3, page 109). I went back to the transcripts and examined them with reference to the episode flowcharts. I found that episodes had multiple, additional claims that seemed to change the essence of the initial claim. In other words, these additional claims were elaborating the original claim. I realized I needed a better way to handle additional claims that would somehow discern differences between the various claims. Group 4B provides an excellent example of the problem (Table 3-18, page 111). The claims in 107, 111, 112, and 114 seemed to be slightly *modifying* what went before. Moreover, the claim in 113, has an inherent *challenge* within it. I had expected to find challenges (for example, line 119), but I could not determine how to handle the implicit challenge in 113. This challenge was imbedded in a claim.

A flowchart of this episode (Figure 3-4, page 112) did not reveal any direct clues. The flowchart does reveal a succession of claims, all slightly related, but still new claims. I gradually came to the realization that I was seeing two additional types of claims, one slightly *modifying* the prior claim, the other (e.g., line 113) giving a new, *alternate* idea.

With the idea of modifying and alternate claims in mind, I returned to all the fourteen groups and examined the transcripts and the flowcharts for every episode. I examined each additional claim in an episode as to its function within the episode. There were indeed two types of additional claims. Considering how they were used, I named them the Alternate Claim and the Modified Claim.

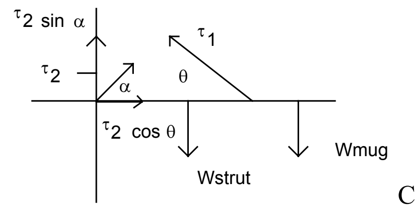
Dialog	Codin g	Comments
105. LP Now wait a second, we can check that on here. We'd be looking at it in...would that be sine? Yes. [places pen on force diagram and rotates the pen around an axis centered on the origin]	C W	*New Episode*. Excellent example of a "visual" warrant.  = Multiply τ by the sine.
106. JH Which way we going?	RQC	RQC = Request for Claim.
107. KJ Yeah, because if here's your angle, right?	C	Claim relates to complementary angles.
108. LP Yep.	Sp	
109. KJ Yeah...	Sp	
110. JH How'd you know the angle?	RQCl	[all look at the force diagram]
111. KJ Well, you'd use it, if you...well it's going to be the angle with the arm, isn't it?	C	Claim relates to complementary angles. [motions along the horizontal axis of the force diagram with his pen]
112. JH Well, it's [the angle] ninety degrees. You break it down.	C	Claim relates to complementary angles.
113. KJ The wall arm, that's ninety degrees, but not the force.	C	Additional Claim
114. JH It's going to be going clockwise, so t's going to be negative, right?	C	Additional Claim
115. KJ Yeah	Sp	
116. JH So then what's plus?	RQCl	
117. LP Plus...would be minus the weight of the mug.	Cl	
118. JH So what, 3?	RQCl	[begins writing equation 3]
119. LP Umm, no. It wouldn't be...	Ch	Ch = Challenge (albeit a weak one.)

Table 3-18. Group 4B, Episode 16, lines 105-119, Initial Coding.

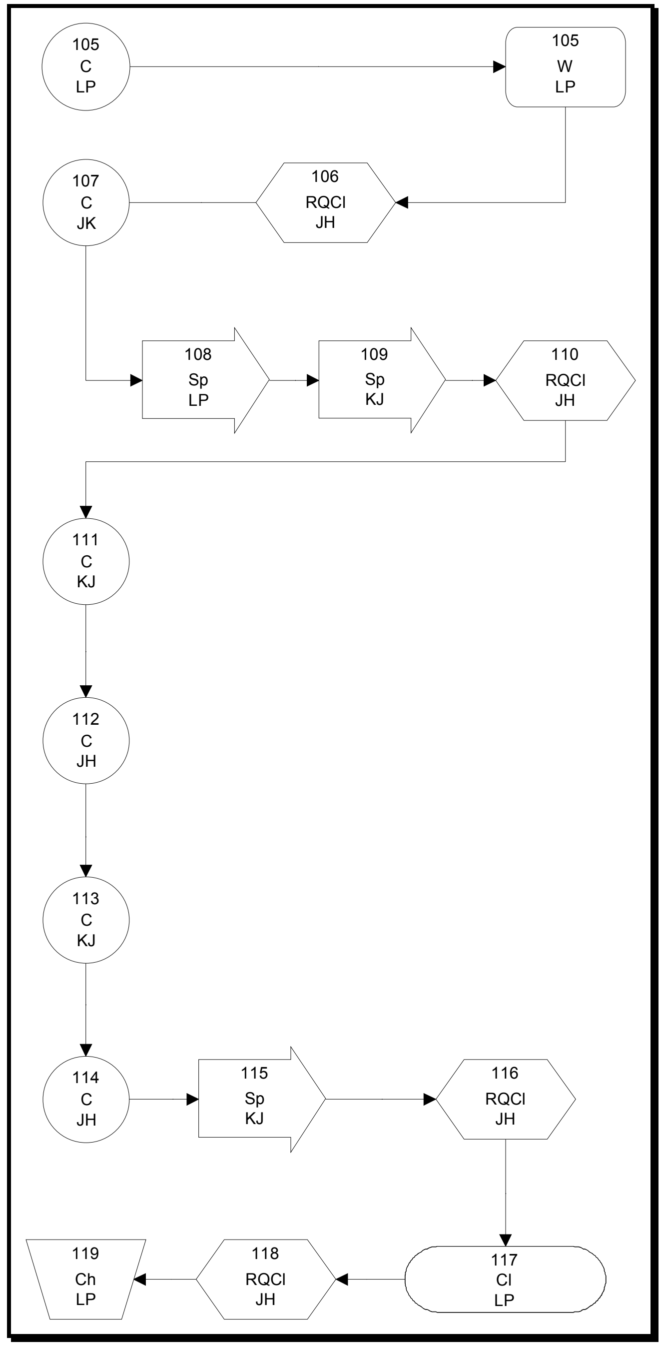


Figure 3-4. Group 4B, Episode 16, Original Flowchart

The Alternate Claim and Modified Claim have several distinctive features. Their characteristics, which will be discussed in more detail, are:

- An Alternate Claim follows a Claim or a Modified Claim and presents a contradictory or alternate idea to the initial claim. Either an explicit Challenge precedes an Alternate Claim, or a challenge is implicit within the Alternate Claim. Alternate Claims are sometimes stated as a question. Other verbal cues include "Perhaps we should consider..," "On the other hand..," "I think it's..."
- A Modified Claim follows a Claim or an Alternate Claim. A Modified Claim offers an additional, non-contradictory idea(s) to the initial claim, and serves to clarify, extend or elaborate upon the initial claim. A Modified Claim is usually stated in a non-confrontational manner compared to an Alternate Claim.

I also revised the flowchart symbology to reflect this new insight. In addition to symbols representing the Modified Claim and Alternate Claim, I added dotted lines to show the connection of the Modified Claim or Alternate Claim to the original Claim if the connected statements were not sequential. Figure 3-5 (page 114) illustrates the new symbology. In this key flowchart, the dotted line from the Support statement in 26 to the Challenge in 24 indicates the support was for the challenge. It is not uncommon to find these intervening statements. I did not draw a dotted line if a statement relates to the immediately preceding statement. Table 3-19 (page 114) summarizes the abbreviations used for the statement types. These appear in the flowcharts in the abbreviated form.

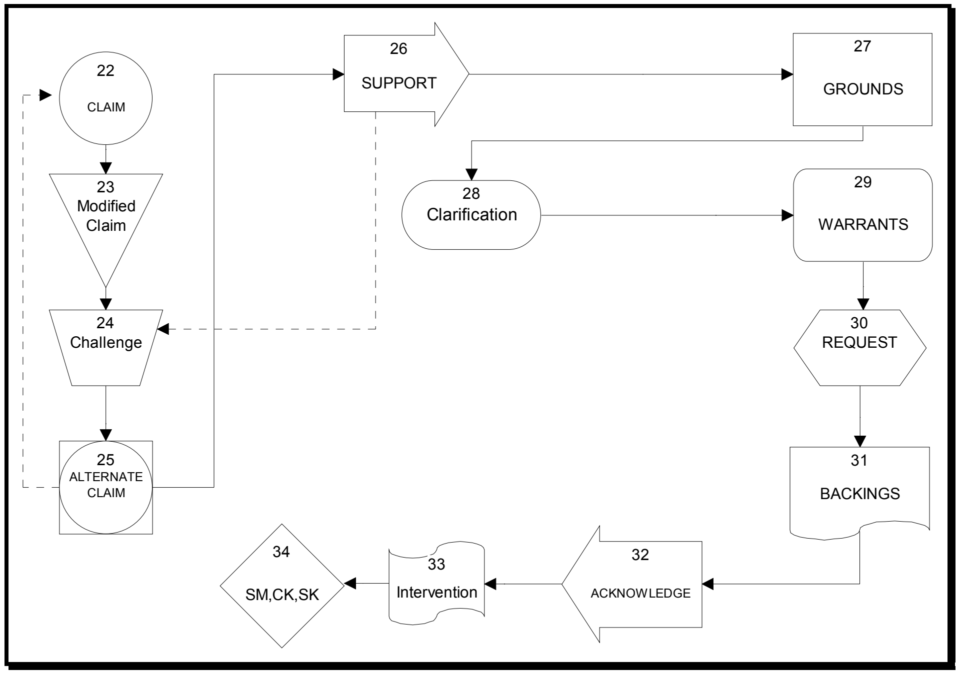


Figure 3-5. Key to Revised Flowchart Symbols.

Statement	Abbreviation
Claim	C
Modified Claim	MC
Alternate Claim	AC
Grounds	G
Warrant	W
Backing	B
Clarification	Cl
Support	Sp
Acknowledgment	Ak
Request	RQ
Challenge	Ch
Summarizing	Sm
Skeptic	Sk
Consensus Checking	Ck
TA Intervention	I

Table 3-19. Summary of Abbreviations in Flowcharts and Transcripts.

With these new statement codes in mind, I recoded, and rediagrammed the 14 groups' 112 episodes. Compared to Table 3-18 (page 111), Group 4B's episode takes on a new form with this revised schema, as illustrated in Table 3-21 (p. 116). Likewise the flowchart of this episode (Figure 3-6, page 117) better reveals the connections between the Modified Claims, Alternate Claims, and the original claims compared to the original flowchart, Figure 3-4 (page 112). The dotted lines helped me to visualize *who* was making the additional claims in response to the group member who made the original claim.

Statement Type	Definition	Verbal Cues
Challenge (Ch)	A challenge occurs when a group member requests proof for a statement or disagrees with a statement. A new claim usually follows a Challenge.	"No." "I don't think that's right," “Umm, no.” “No it ain't.”
Alternate Claim (AC)	An *Alternate Claim* follows a Claim or a Modified Claim and presents a contradictory idea to the initial claim. Either an explicit Challenge precedes an Alternate Claim, or a challenge is implicit within the Alternate Claim. Alternate Claims are sometimes stated as a question..	"Perhaps we should consider..." "On the other hand..." “I think it's...” “No, it should be...” “Or maybe...” “Well, wait...”
Modified Claim (MC)	A *Modified Claim* follows a Claim or an Alternate Claim. A Modified Claim offers an additional, non-contradictory idea(s) to the initial claim. The Modified Claim serves to clarify, extend or elaborate upon the initial claim. A Modified Claim is usually stated in a less “confrontational” manner than an Alternate Claim.	“Yeah... right?” “Well, it's...” “Well, if you... “Ok and then....”

Table 3-20. Modified and Alternate Claim Categories.

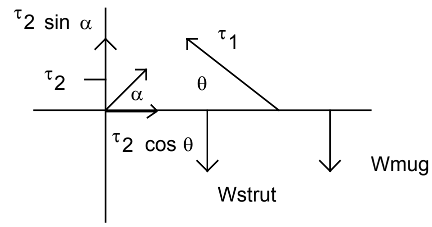
Dialog	Coding	Comments
105. LP Now wait a second, we can check that on here. We'd be looking at it in...would that be sine? Yes. [places pen on force diagram and rotates the pen around an axis centered on the origin]	C W	*New Episode*. Excellent example of a "visual" warrant.  C = Multiply τ by the sine.
106. JH Which way we going?	RQCl	RQCl = Request for Clarification
107. KJ Yeah, because if here's your angle, right?	MC	Modified Claim relates to complementary angles and elaborates on LP's original claim in 105 by specifying the angle.
108. LP Yep.	Sp	Sp = Support
109. KJ Yeah...	Sp	
110. JH How'd you know the angle? [all look at the force diagram]	RQCl	
111. KJ Well, you'd use it, if you...well it's going to be the angle with the arm, isn't it? [motions along the horizontal axis of the force diagram with his pen]	MC	Modified Claim relates to complementary angles. Namely, take the sine of the angle between the force and the lever "arm."
112. JH Well, it's [the angle] ninety degrees. You break it down.	MC	Modified Claim relates to complementary angles. "You break it down" is actually a procedural claim.
113. KJ The wall arm, that's ninety degrees, but not the force.	AC	Alternate Claim. The implicit challenge is "but not". The force is not acting at a 90° angle.
114. JH It's going to be going clockwise, so t's going to be negative, right?	MC	Modified Claim relating back to 112, and gives the direction of a "broken down" vector.
115. KJ Yeah	Sp	
116. JH So then what's plus?	RQCl	
117. LP Plus...would be minus the weight of the mug.	Cl	
118. JH So what, 3? [begins writing equation 3]	RQCl	
119. LP Umm, no. It wouldn't be...	Ch	This challenge is answered in the next episode.

Table 3-21. Group 4B, Episode 16, lines 105-119, Revised Coding.

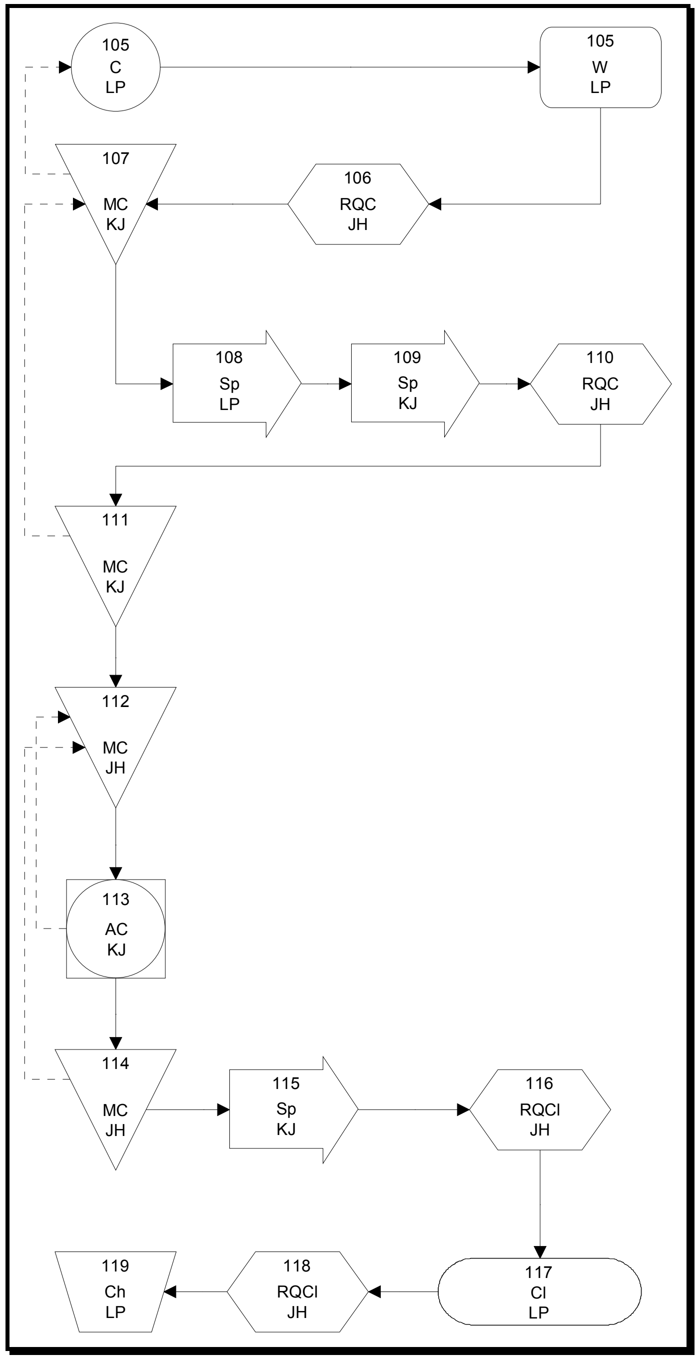


Figure 3-6. Group 4B, Episode 16, Re-Diagrammed.

Summary

These new definitions led to the refinement of the prototype patterns so that groups that used a large number of Modified Claims or Alternate Claims could be distinguished from those that did not. I edited each transcript, double-checking my classification of Claims, Modified Claims, and Alternate Claims. I then re-drew the prototype flowcharts for all 14 groups. Table 3-20 (page 115) summarizes the basic ideas of the Modified Claim and the Alternate Claim categories.

The process of defining the Modified Claims and Alternate Claims is typical of a qualitative case study research method. The important thing to note is that these new statement categories were not imposed on the data *a priori*, but rather grew out of the need to interpret the data, and were suggested by the data.

Does a Group Have a Self-Consistent Pattern of Argument Construction?

I found that 12 of the 14 groups exhibited a unique, *single* prototype pattern, and two of the groups exhibited a *dual* prototype pattern (Figure 3-7, page 118). These 16 prototype flowcharts are reproduced in Appendix D.

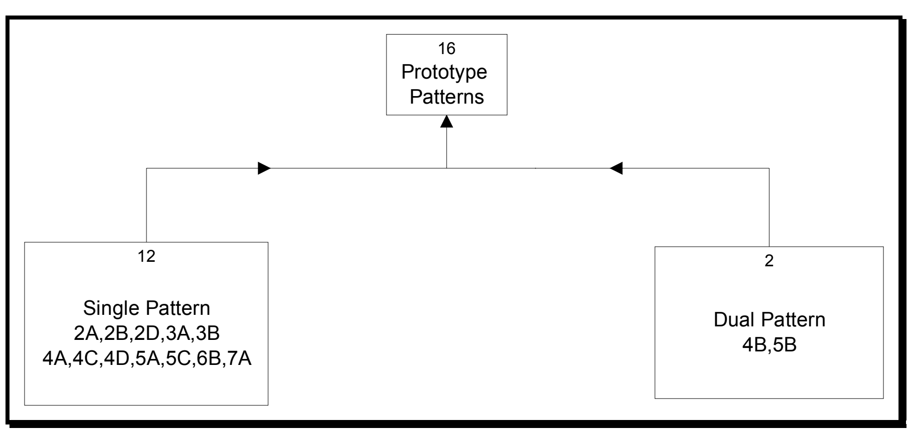


Figure 3-7. Prototype Patterns.

Group 4A, a single prototype group, had a very predictable pattern, and their pattern will be discussed later in this chapter. Figure 3-8 is their prototype flowchart. In one episode, they used a Modified Claim, but it was not typical of them. Group 4A was *so* predictable, that I could have drawn this prototype based on only a few of their episodes. Group 4A's most predictable feature is their end of episode summarization. In the prototype flowcharts, the statements are numbered sequentially, and the statement type is written out, instead of being abbreviated.

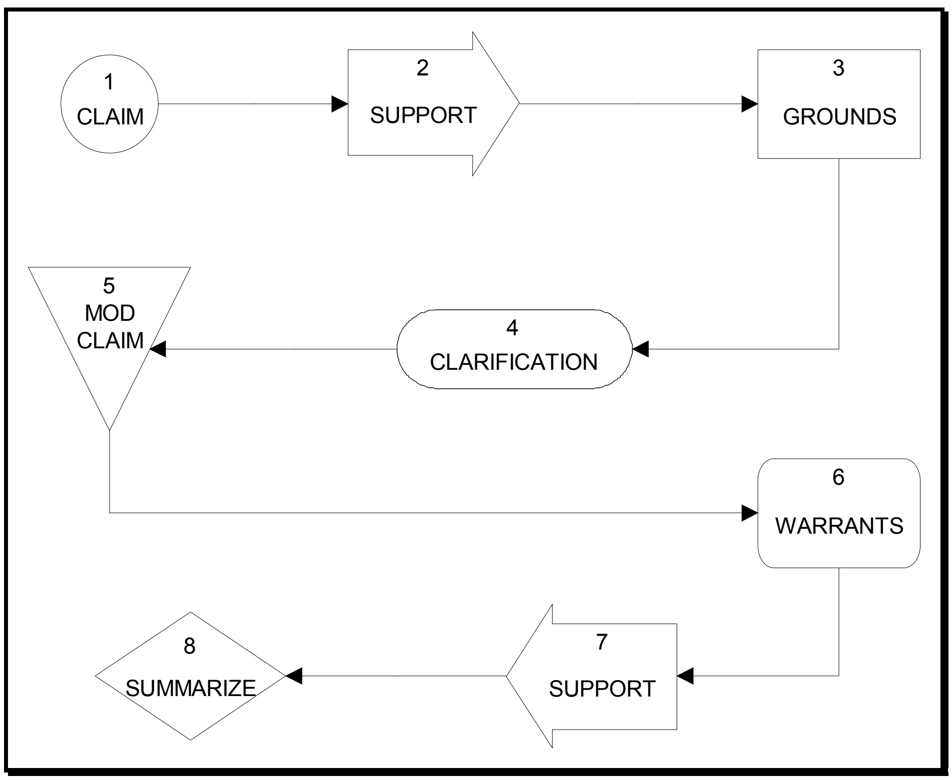


Figure 3-8. Group 4A Prototype Episode.

Group 4C, the "different" group, has a pattern in which their lack of co-construction is evident. I found the best way to draw their prototype (Figure 3-9) was with a line extending into nothing. This was typical of their discussion: Things seldom went anywhere. Hence, this prototype, like the group it represents, is a "non-example" of co-construction. Groups 4B and 5B each exhibited *two* patterns in how they elaborated upon the initial claim. Both groups had one pattern in which the claim was relatively unelaborated. For example, consider the two patterns for Group 4B. The major difference is that in one pattern (Figure 3-10, page 121), there is no elaboration of the claim with supporting statements. In the other (Figure 3-11, page 121) they use Grounds, Warrants, and Backings to support their claim. Their prototype patterns also will be discussed later.

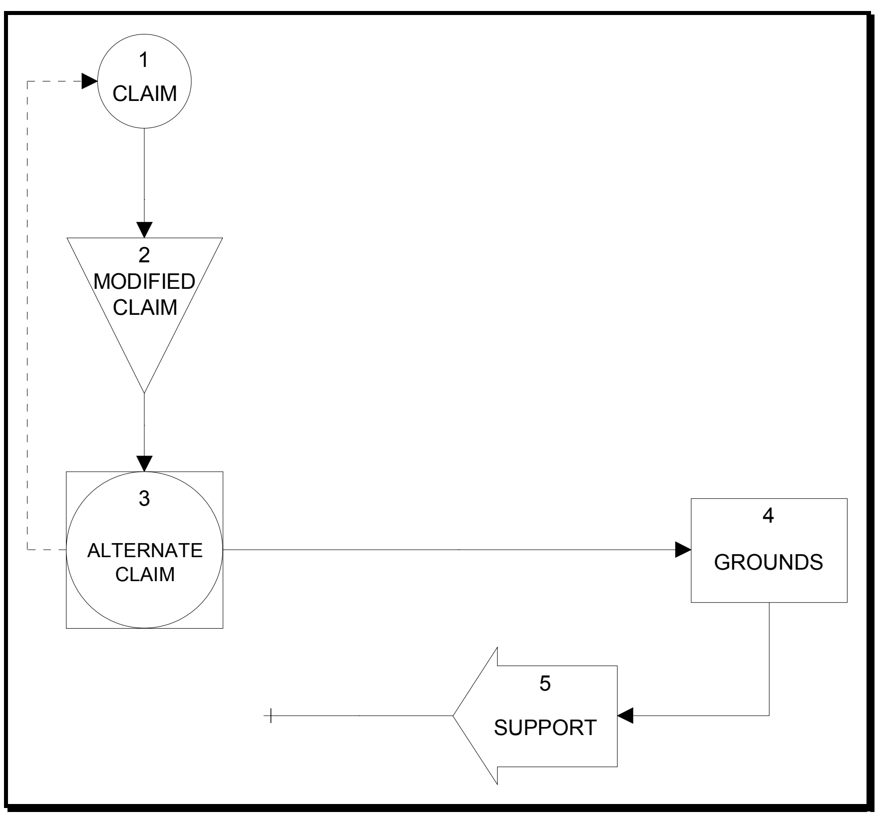


Figure 3-9. Group 4C, Prototype Episode.

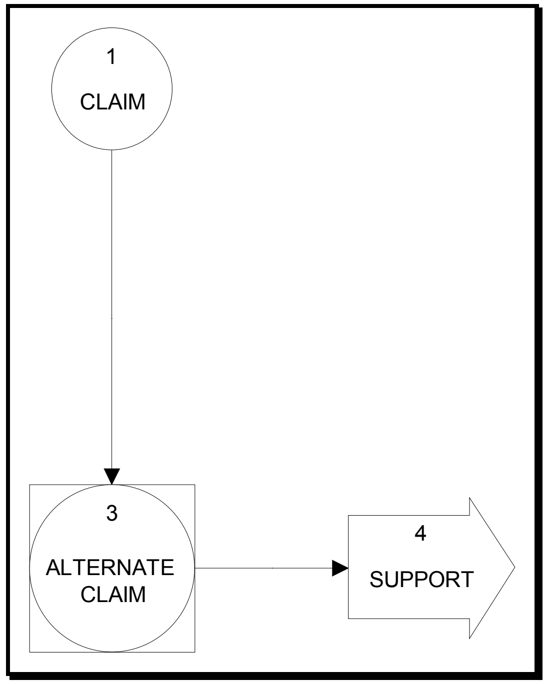


Figure 3-10. Group 4B Prototype Episode Type 1.

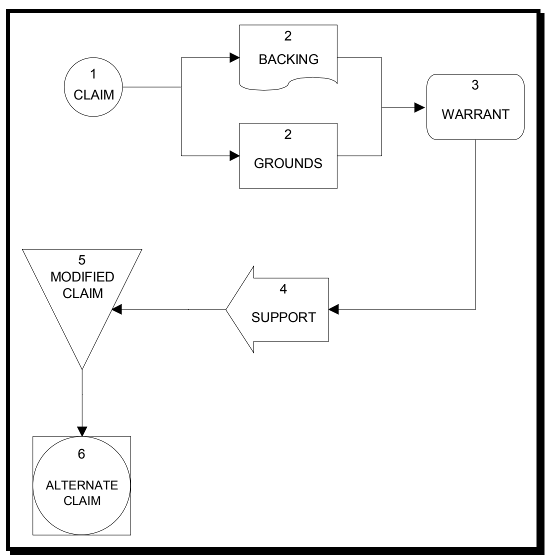


Figure 3-11. Group 4B Prototype Episode Type 2.

Co-Construction of the Argument Revisted

A major theme of this research is that the students in a cooperative problem-solving group are co-constructing the solution to the problem. There is preliminary evidence that this is occurring in at least 13 of these 14 groups: It is possible to use the Toulmin argument structure to analyze the discussion, the conversations proceed episodically, and the flowchart analysis shows connected discourse. Although in Group 4C, the individual episodes are somewhat coherent, their episodes typically do not connect logically to one another and thus their prototype flowchart shows an arrow leading to nothing (Figure 3-9, page 120). One of the things I noticed when drawing the flowcharts was that particular students made particular kinds of statements. For example, in Group 4D, member ST made all of the Modified Claims. To explore co-construction of the argument further, I examined the pattern of *who* is making the Alternate Claims and Modified Claims. Does the same person make the Modified or Alternate Claim as the original Claim, or is it someone different? Four patterns were noticed.

Who makes Claims Shifts among Members

The claim-making role shifts between students. That is, the maker of a Modified Claim is usually not the maker of the original claim as is seen Group 4B's Episode 16, Table 3-21 (page 116). Members JH and KJ make Modified Claims and Alternate Claims following LP's original Claim (see Table 3-26, page 128, Group 2D, for an additional example). However, when the Alternate or Modified claimant is the *same* person as the original claimant, other students had intervening supporting statements, as this example from Group 4A (Table 3-22, p. 123) illustrates:

Dialog	Coding	Comments
62. MK. OK, umm...so then do we have to include like the tension	C	Question can be rephrased as a statement.
63. and a weight here for the mug?	C	There are two claims made in one statement.
64. RM. No.	Sp	RM supports MK's Claim with a rhetorical "no." Sp = Support
65. MK. Or is it just a weight?	MC	MK makes a claim in question form.
66. MR. No, it's just the weight I think.	Sp	This is a rhetorical "no" and the statement agrees with MK's statement in 65.
67. RM. No, you don't need tension.	Sp	This is a rhetorical "no" and the statement with agrees with MK's statement in 65.
68. MR. I think the tension in this [i.e., the cable] comes from the weight. [Points to the picture.]	W	
69. It's negligible, as far as the cord's mass.	W	The Warrant is that the cord's mass can be ignored.
70. MK. OK, then...we just put weight-mug, right?	Sm	She follows here summarizing statement with a RQSp.
71. OK [goes with 70]	Sp	

Table 3-22. Group 4A, Episode 9, lines 62-71.

Active Members Make Claims

The making of claims is fairly uniformly distributed among the "active" students in a group. Students who make an overall high percentage of the statements, also tend to make most of the claims. Also, members who make original claims, tend to make Modified or Alternate Claims. Students who are "quiet" tend to make fewer claims. Table 3-23 (p. 125) illustrates these points. Only the flowcharted episodes are considered. The "Statements" column tallies the number of flowchart symbols for each member of the group. The percentage is the percent that number of statements is of the whole. It should be noted that the "Total Claims" are a part of the "Statements" column. That is, member TD in Group 2A, made 15 statements, six of which were claims. If statements and Claims were uniformly distributed, one would expect to see each student making 33% of the statements in a group of three, or 25% of the statements in a group of four. This is seldom the case. A *qualitative* analysis of the groups can explain the departures from this norm.

Although in Group 5C, member MP makes only 49% of the overall statements, she makes 77% of the Claims. This is because MP, a dominant member of the group, makes a lot of Claims, but she does not support them with other statements. Group 4A member DC was a very quiet student who rarely contributed Claims. He and member MK made statements supporting MP's Claims. Likewise, in Group 4D, student CB makes no claims. He missed class the day before this problem session and was poorly prepared. In Group 2D, member SU made 21% of the overall statements, but made no claims. Group 2D member SU is an Asian student, and there may be a cultural-based "deferring" to the other two non-Asian students. There was only one person (out of the 45 members, 40 unique individuals) in one group (out of the 14 groups) where a student, AW in Group 5A, made *only* Modified Claims or Alternate Claims, and no original Claims.

Six of the students appear in two different taping sessions, one from the first quarter (Physics 1041) and one from the second quarter (Physics 1042). Are students consistent in their group participation or do they agree to a group dynamic? As seen in Table 3-24 (page 126), these six students appear to have a fairly consistent degree of participation in terms of the percentage of total claims compared to total statements. Student KF in particular is very consistent by making no claims in either session. (The table is sorted by Member and then by the session and quarter in which they were taped.)

Group	Member	Statements	C	MC	AC	Total Claims
2A	TD	15 (25%)	5	0	1	6 (46%)
	CG	16 (27%)	1	0	0	1 (8%)
	DL	23 (39%)	2	1	3	6 (46%)
	JW	5 (8%)	0	0	0	0 (0%)
2B	PH	33 (39%)	3	0	4	7 (35%)
	MM	33 (39%)	5	2	3	10 (50%)
	AM	18 (21%)	1	1	1	3 (15%)
2D	KE	22 (31%)	3	1	0	4 (24%)
	LS	33 (47%)	5	6	2	13 (76%)
	SU	15 (21%)	0	0	0	0 (0%)
3A	SK	19 (33%)	4	1	1	6 (50%)
	MP	16 (28%)	2	0	0	2 (17%)
	GS	23 (40%)	1	2	1	4 (33%)
3B	JC	17 (27%)	3	5	0	8 (42%)
	KF	5 (8%)	0	0	0	0 (0%)
	PG	17 (27%)	0	1	1	2 (11%)
	CH	25 (39%)	6	3	0	9 (47%)
4A	MK	42 (42%)	6	2	0	8 (42%)
	RM	19 (19%)	1	0	0	1 (5%)
	MR	39 (39%)	4	5	1	10 (53%)
4B	JH	29 (28%)	4	2	1	7 (29%)
	KJ	35 (33%)	3	3	3	9 (38%)
	LP	41 (39%)	4	2	2	8 (37%)
4C	SV	22 (41%)	2	2	1	5 (36%)
	JV	19 (35%)	2	1	2	5 (36%)
	EW	13 (24%)	2	0	2	4 (28%)
4D	CB	9 (12%)	0	0	0	0 (0%)
	ME	31 (42%)	5	0	0	5 (45%)
	ST	34 (46%)	2	4	0	6 (55%)
5A	JC	16 (38%)	4	5	0	9 (60%)
	RS	15 (36%)	1	1	1	3 (20%)
	AW	11 (26%)	0	3	0	3 (10%)
5B	MC	20 (38%)	3	0	2	5 (28%)
	KE	22 (42%)	2	0	4	6 (33%)
	SW	10 (19%)	1	4	2	7 (39%)
5C	DC	2 (4%)	1	0	0	1 (8%)
	MP	23 (49%)	4	6	0	10 (77%)
	AR	22 (47%)	1	1	0	2 (15%)
6B	KF	1 (2%)	0	0	0	0 (0%)
	CH	29 (48%)	5	1	1	7 (58%)
	KJ	30 (50%)	2	2	1	5 (42%)
7A	PH	17 (29%)	1	2	0	3 (25%)
	TP	21 (36%)	4	1	0	5 (42%)
	TT	3 (5%)	0	0	0	0 (0%)
	PW	18 (31%)	2	2	0	4 (33%)

Table 3-23. Number of Statements and Claims by Group Members.

Group	Member	Statements	C	MC	AC	Total Claims
3B	CH	25 (39%)	6	3	0	9 (47%)
6B	CH	29 (48%)	5	1	1	7 (58%)
3B	JC	17 (27%)	3	5	0	8 (42%)
5A	JC	16 (38%)	4	5	0	9 (60%)
2D	KE	22 (31%)	3	1	0	4 (24%)
5B	KE	22 (42%)	2	0	4	6 (33%)
3B	KF	5 (8%)	0	0	0	0 (0%)
6B	KF	1 (2%)	0	0	0	0 (0%)
4B	KJ	35 (33%)	3	3	3	9 (38%)
6B	KJ	30 (50%)	2	2	1	5 (42%)
2B	PH	33 (39%)	3	0	4	7 (35%)
7A	PH	17 (29%)	1	2	0	3 (25%)

Table 3-24. Claims by Students Appearing in Two Sessions.

"Quiet" Students Do Contribute

What about the students who make *fewer* claims in proportion to their overall statements? Their contributions to the group frequently are a Request for some sort of support or Clarification. This frequently takes the form of skeptical questioning. No one illustrates this point better than member RM of Group 4A. An example (Table 3-25, p. 127) from their discussion shows how his question serves to initiate a clarification of the point MR and MK make about the location of the vectors on the free-body diagram. While his skepticism does not correct an obvious error, it does serve to *reinforce* the point MK and MR make about the location of the vectors. This is an important function when supporting claims.

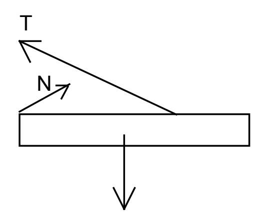
Dialog	Coding	Comments
108. MK. OK, so don't we draw this here...we draw tension here, right?	C	Relates to her recorder role, but is a physics claim about how and where one draws in the tension.
109. RM. Not...	Sk	Begins a Skeptical question
110. MK. Right?	RQSp	RQSp = Request for Support
111. RM. Not like that, do you?	Sk	Continues questions started in 109.
112. MR. Yeah, that's how he [professor] drew it, didn't he, on his force diagrams?	B	
113. MK. And then the normal right here. [Drawing as she speaks.]	W (MC)	The Claim is implicit in the drawing of the Table:  This modified Claim extends the idea started in 108.
114. RM. Oh, yeah.	Sp	He agrees with her.
115. MK. Right?	Ck	MK Checks for consensus before continuing.

Table 3-25. Group 4A, Episode 17, lines 108-115.

In Group 2D, group member SU, who makes no Claims, provides Grounds that support the Claims. A complete Physics Description *must* contain adequate, correct grounds. SU's contribution to this solution is not accomplished by Claims, but by carefully referring to the hard data of the problem statement.

Dialog	Coding	Comments
44. KE What else we gotta write up there? Oh, we gotta write the question.	RQC	"the question" refers to the first step of the problem-solving strategy. RQC = Request for Claim.
45. SU Yeah	Ak	Ak = Acknowledgment.
46. LS Question, what's the question? What is our question? We're trying to impress our little sister.	RQC	
47. SU Well, I can't Table...	Ak	This could be a RQCl.
48. LS How can we impress the little sister?	G	This question is based on the problem statement.

49. SU ...and your sister starts the train and concentrates just on the last car...and you measure that it goes 1.5 meters in the first 4 seconds.	G	He reads the statement and repeats the "grounds" given there.
50. LS Oh, down here.	Ak	
51. KE So we Tabled...we Tabled that we can calculate the tension. What is the tension?	C	
52. LS Oh, we want to know the tension of the strings.	MC	
53. KE Right.	Ak	
54. LS Okay.	Ak	
55. SU Between ...between car 1, I mean the last car and the second car.	G	He "self-corrects" his statement.
56. LS ...and finishing. Where?	RQCl	RQCl = Request for Clarification
57. SU Nah, I'm just asking.	Ak	

Table 3-26. Group 2D, Episode 7, lines 44-57.

In Group 5A, member AW fills a similar function to SU when he provides Warrants that supports the Claim of another student. His Modified Claim in line 48 (Table 3-26) is also a means to support the Claim that JC makes in 41 and modifies in 45. AW had not taken the pre-requisite course (Physics 1041). Interestingly enough, at the time of this problem, AW was ranked higher in the class compared to JC and RS. His reluctance to make original claims *may* reflect his poor preparation for this *particular* problem. His willingness, however, to make a few additional claims may have been stimulated by the ideas and contributions of the other students. That is, despite *possibly* poor preparation, he had something to contribute. Also, AW is the Recorder and his focus on writing down the solution may have lead to his lesser contribution of Claims.

Dialog	Coding	Comments
41. JC If we find GPE, can we find velocity after we have its value?	C	GPE = Gravitational Potential Energy
42. AW Because the initial kinetic energy will have to equal the final [kinetic energy].	W	
43. JC Gravitation[al energy].	W	JC adds to his warrant.
44. AW Gravitation[al energy.	W	Said simultaneously with 43.
45. JC OK, well that's...that's. So we find the GPE first, right?	MC	Slightly modifies 41.
46. RS But when it finished it's going to have to have Kinetic Energy and Potential Energy.	W	

47. JC No, we're going to have to work backwards. (mumbles)	C	Relates to the problem-solving strategy. Students were taught to work backwards from the target variable.
48. AW Our approach is conservation of energy?	MC	This clarifies the previous claims by relating it to the "approach" step of the strategy. Although said in question form, it is actually a statement.
49. JC Yeah.	Ak	Ak = Acknowledgment.
50. AW OK.	Ak	
51. RS Uh. huh.	Ak	
52. JC Use conservation of energy.	Sm	JC neatly summarizes the entire discussion.

Table 3-27. Group 5A, Episodes 7&8, lines 41-52.

In all three of these examples, students less involved in making claims nonetheless make important contributions. They are reluctant, for whatever reason, to make initial Claims and defer that part of the cooperative effort to other students. Their contribution to the group's solution is in the form of support for ideas, contribution of data (Grounds), skeptical questioning, or encouragement. This is an important finding in this study because it means that the students are indeed involved in co-constructing the solution, and the solution is not the work a single individual in the group. That is, ***all*** students in a cooperative problem-solving group contribute in some manner to solution of the problem.

Role of a Dominant Student

If there is a dominant student in the group, that person tends to make most of the claims, either original or Modified and Alternate. Groups 2D, 5A, and 5C can be classified as having a dominant student where one person made more than 60% of the total claims. It is important to note that this definition of dominance is in terms of the number of claims a student makes within the group. Another type of dominance I observed is what I would call "social" dominance. That certainly was the case in Group 4C, where SV effectively dominated the group and frequently made sequential claims. In this example from Group 4C, EW *tries* to make a claim, but JV and SV sidetrack the discussion. This group is my example of an absence of co-construction. It may be that the social interaction among the three students was a contributing factor to this.

Dialog	Code	Comments
63. EW OK, use Newton's second law... [writes this while JW and SV talk and look at their own papers.]	C	EW was the Recorder.
64. JV Don't we have to write down those things then?...umm, all the forces of torque equal, what are these? What's that?	AC RQCl	This is a claim related to the strategy. They exhibit what is almost an obsession with the details of the strategy. RQCl = Request for Clarification.
65. SV Tau?	Cl	
66. SV Tau equals L times.	MC	Modifies the AC in 64.
67. JV Oh, yeah, moment arm times...	W	They use very few warrants.
68. SV What is the other one, tension?	RQCl	
69. JV The force, whatever force it is, right?	MC	This could relate to either 63 or 64. It is not clear if JV is thinking of EW's statement about the Second Law, or SV's idea about torque. Since much of this group's conversation is between SV and JV, it probably is the latter.
70. SV So is it L times f?	RQCl	

Table 3-28. Group 4C, Episodes 7&8, lines 63-70.

Summary

The pattern of who makes the additional claims gave me a clearer insight into the co-construction of the argument as well as the role of the Alternate Claim. Two findings convinced me that these groups were co-constructing their solution: (1) The shifting of claim-making among students, and (2) the contribution of the "quiet" students. The Alternate Claim making is related to the original Claim. The Alternate Claim may result from an idea that emerges due to the clarification process following an original incorrect Claim. This may be the case in situations where the maker of the Alternate Claim is the not same as the original claimant. This alerted me to look at the relationship between initial Claim correctness and Alternate Claims. I will discuss this further in the next research question (Chapter 4). Another hypothesis is that the Alternate Claim is a statement of an idea that was not expressed initially when someone else beat the Alternate Claimant to secure the group's attention. This would also be the case when the maker of the Alternate Claimant is different from the original claimant.

SUMMARY

The theme of this chapter has been the patterns of argument co-construction *within* individual groups. I can now make four major claims related to the first two research questions.

First, students discussed the problem in an episodic manner and episodes were used as a unit of analysis. The group members' statements are not isolated from each other and there is a logical flow to the discussion.

Second, four criteria for argument co-construction were found in 13 of these 14 groups on a consistent basis, and in one group, 4C, only occasionally. These criteria are:

- Claims are supported by Grounds, Warrants, and Backings
- Grounds, Warrants, and Backings appear in repeating patterns
- Group members listen to each other and discuss the *same* claim
- Claim-making role shifts among group members

Statements of Support, Acknowledgment and Encouragement keep the conversation moving forward and allow students to "transfer" the conversation to another student.

Third, these 14 problem-solving groups appear to adopt not only a group "personality," but a group dynamic that leads to predictable, or at least repeating, patterns of argument co-construction. The differences in these patterns is evident in the manner the groups further explain, elaborate and defend their ideas. Twelve of the 14 groups had a single prototype pattern and two groups had dual patterns.

Fourth, additional Claims within a group's episodes can be accounted for by defining the Alternate Claim and Modified Claim.

- An Alternate Claim follows a Claim or a Modified Claim and presents a contradictory or alternate idea to the initial claim. Either an explicit Challenge precedes an Alternate Claim, or a challenge is implicit within the Alternate Claim. Alternate Claims are sometimes stated as a question. Other verbal cues include "Perhaps we should consider..," "On the other hand..," "I think it's..."
- A Modified Claim follows a Claim or an Alternate Claim. A Modified Claim offers an additional, non-contradictory idea(s) to the initial claim, and serves to clarify, extend or elaborate upon the initial claim. A Modified Claim is usually stated in a non-confrontational manner compared to an Alternate Claim.

These are the argument co-construction patterns *within* individual groups. The next step is to look at commonalities *between* the groups. In the next chapter, I will discuss how the groups are similar to each other. That analysis will particularly focus on the Alternate Claim and Modified Claim.

CHAPTER 4

PATTERNS BETWEEN GROUPS

Chapter Overview

The "answers" to the research questions are somewhat interactive. For example, in discussing the second question (Chapter 3), I came to some partial conclusions about the Modified Claims and Alternate Claims. A more comprehensive examination of the role of Modified Claims and Alternate Claims is given in this chapter which addresses Research Question 3. This chapter examines additional patterns common to all 14 groups. The emphasis in this chapter is on the groups' use of the Alternate Claims and Modified Claims. Although there are 16 prototype patterns of argument co-construction in the 14 groups, I will show there are several common features between those 16 patterns and the 14 groups.

It may be helpful to quickly review the definition of the episode, since it is the persistent feature of this analysis. An episode is "defined as one or more exchanges which comprise a completed verbal transaction between two or more speakers. A new episode is determined by a shift in what the speakers are talking about, which may be a new aspect, or part of a topic or a complete change of topic" (Sandefur and Bressler, 1971). Tables 2-4 (page 58) and 2-5 (page 59) summarize the statement types used in the episode coding. When the fourteen groups were analyzed, it was found that twelve of them could be characterized individually with a unique prototypical episode, and two groups exhibited two prototypical patterns. That is, I was able to reduce each of the groups to predictable patterns for a particular group.

Question 3. Are there similarities in the argument co-construction patterns between the fourteen groups?

To answer this question, I looked at various aspects of the group's argument construction, and thus this research question has several important sub-questions. First, since the heart of the Toulmin structure is the Claim, I closely examined the process of making a claim, specifically the order of events in an episode. Secondly, as has been noted, Modified and Alternate Claims are important statement categories, and thus I looked at how these additional claims elaborate the original claim. The discussion of Modified Claims and Alternate Claims includes several important subsections, including an analysis of the role of requests, as well as discussions of creative controversy and conflict avoidance. Finally, in the Toulmin argument structure, Ground, Warrants and Backings provide support for Claims, and I will illustrate how these are used to support the claims.

Question 3a. Do their argument constructions begin or end with a Claim?

In a strict Toulmin analysis of an argument, the Grounds, Warrants and Backings *lead to* the claim. Hence the first sorting of the groups' prototypes asked *where* in the process the claim occurs. Of the 16 patterns, only two patterns *lead to* the claim (Figure 4-1, page 135). Both groups 3B and 7A used supporting statements before and after their claim. Groups 3B and 7A were both groups of four. On the other hand, most groups (12 groups, 14 patterns) *begin* with the claim and then support it.

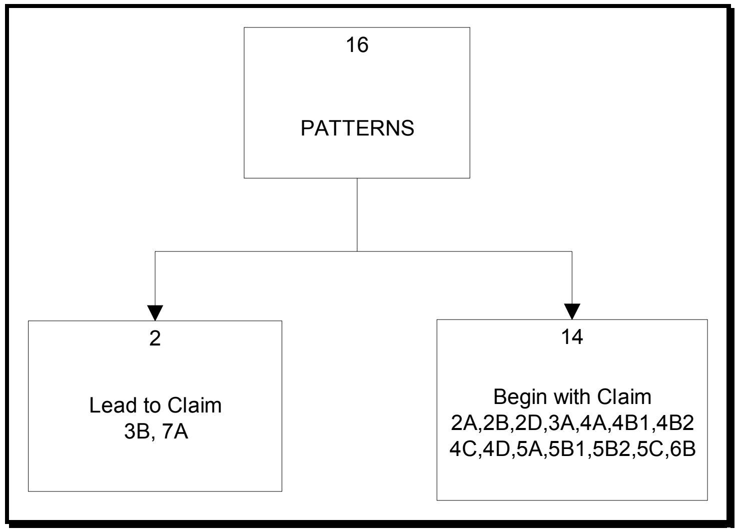


Figure 4-1. Groups Begin with Claims.

It should be noted this "beginning with the claim" may be in part due to the manner in which the episodes were defined. A new episode was defined to begin when a new thought occurs. In general, a claim introduces a new thought, and this new thought begins the new episode. I asked, "Is it *natural* for a group to begin with a claim?" Group 4A provided an insight into this question. Their episodes were very easy to code and define, in part because they usually *ended* with a summarizing statement. The *next* statement after summarizing statement was a new claim, and a new thought, and hence a new episode began.

Our prior research showed that groups of three worked better than groups of four for physics problem solving (Heller and Hollabaugh, 1992). Since both 3B and 7A are groups of four, perhaps claim making is inhibited, or slower to take shape, in larger groups. But, the *other* group of four (2A) did *not* follow this claim-last pattern. Group 2A had a better ability mix (LLMH) than Groups 3B or 7A (both LLLM). That may have caused an "interaction" between group size and ability mix. Even so, I am reluctant on the basis of only two "samples" to come to a general conclusion that claim making is inhibited in groups larger than three.

QUESTION 3B. WHAT ROLES DO MODIFIED CLAIMS AND ALTERNATE CLAIMS PLAY IN THE ARGUMENT CO-CONSTRUCTION PROCESS OF THESE GROUPS?

The original research question as stated in Chapter 1 (page 11) was: *What roles do challenges to the original claim play in the argument construction process of these groups?* Two observations of the groups' patterns prompted an adjustment of the question. First, it is apparent there are very few overt challenges. Second, the Modified Claims and Alternate Claims appear to fulfill the role of challenging and changing the original claims.

When examining the prototype flowcharts, it became apparent that some groups use Alternate Claims and some do not. As is shown in Figure 4-2, seven of the 16 patterns (5 groups) typically contained Alternate Claims, and nine of the 16 patterns (9 groups) do not. I will first discuss the five groups that use the Alternate Claims and then the nine groups that use few Alternate Claims, but do use Modified Claims.

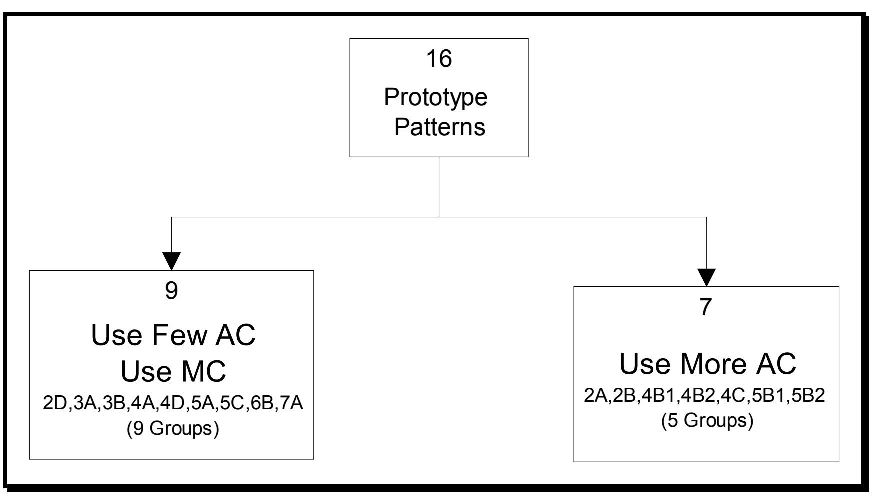


Figure 4-2. Alternate and Modified Claim Use.

Why do Some Groups Use Alternate Claims?

Turning to the five groups that do use Alternate Claims, I looked at the elaboration that leads up to the Alternate Claim and noticed a pattern (Figure 4-3). In two out of seven of the prototypes (4B2, 4C) a Modified Claim *precedes* the Alternate Claim. In five prototypes (2A, 2B, 4B1, 5B1, 5B2), there is little or no elaboration before the Alternate Claim, and no Modified Claim precedes the Alternate Claim.

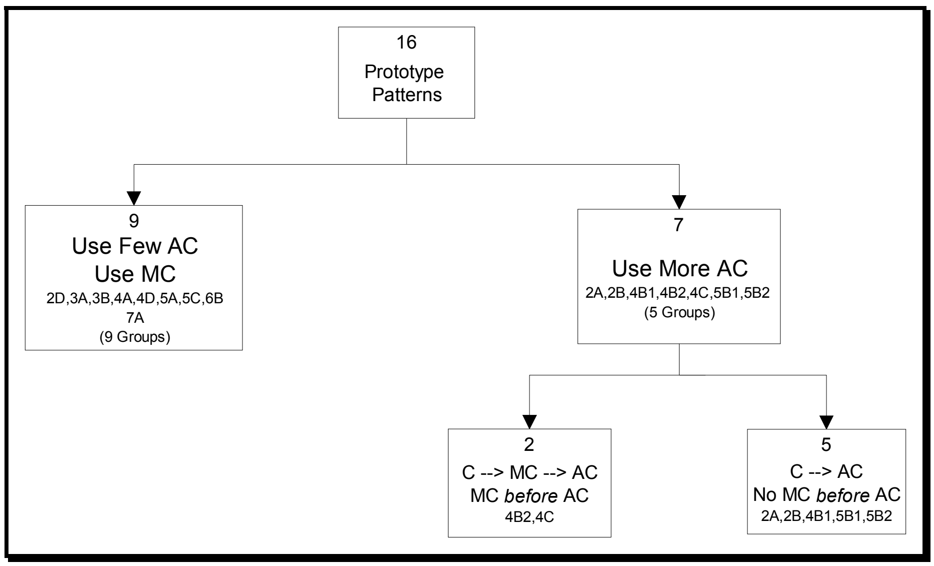


Figure 4-3. Elaboration of an Alternate Claim.

Consider first an example from Group 4C (Table 4-1, page 138) where student SV's Modified Claim (line 58) elicits a Challenge and Alternate Claim from EW. (Direct challenges are rare and the "No" in Line 59 could be interpreted as being a part of the Alternate Claim and not actually a separate challenge.) Although SV's Modified Claim is correct, EW is responding to here on the basis of what he said in 57. In the next example (Table 4-2, page 138) from Group 4B, one Alternate Claim immediately follows another (lines 24 and 25).

Dialog	Code	Comments
57. EW We want to find like f-x, f-y.	C	*New Episode*
58. SV And we have to use torque.	MC	This extends the Claim in 57.
59. EW No, we basically want to find tension...yeah, I know. That's the whole force diagram, right there.	Ch AC	Alternate claim immediately follows the Challenge. This could be coded as an AC, "No...find tension..." followed by an MC, "That's the whole force diagram..."
60. JV Do we have to use torques?	RQCl	RQCl = Request for Clarification
61. SV Yeah, that's statics.	W	They use few warrants.
62. JV OK, whatever you call it.	Sp	Sp = Support

Table 4-1. Group 4C, Episode 6, lines 57-62.

Dialog	Code	Comments
22B. JH It's negative [i.e., arithmetic sign of the term] and negative because they're both going down, or because it's [i.e., the sign itself] going clockwise.	G	[Included for clarification of what follows.]
23. LP It seems to me that we don't have the relationship to put together yet.	C	LP is concerned about the equation JH is writing. The basis of his question is 22B. LP claims "we don't know all the equations."
24. JH ...seems to me that we know all these values, though.	AC	"But we do know the values and hence we know the equations."
25. KJ We don't know our t's, though. We're going to end up solving for t.	AC	"But we don't know the target variables." These two Alternate Claims serve to correct the original Claim. *All* the values are not known.
26. JH OK, you got me...umm.	RQCl	This request is implicit.

Table 4-2. Group 4B, Episode 3, lines (22b)-26.

It seemed to me that the students were attempting to politely disagree with one another. This observations, plus my criteria for co-construction that groups resolve disagreements in a reasonable manner suggested to me that Alternate Claims and Modified Claims are forms of controversy. To understand this in the context of cooperative groups, I turned to the Johnson model of cooperative learning and the idea of the "creative controversy."

Creative Controversy

There are very few direct challenges in all of the analyzed episodes in all the 14 groups. In fact, the challenge symbol does not appear in *any* prototypical episode flowchart. That is, direct challenges are rare in these 14 groups. Part of the reason for this lies in the definition of Alternate Claim: A challenge is *implicit* within the Alternate Claim. What is the challenging aspect of the Alternate Claim in the argument co-construction process?

My hypothesis is that the Alternate Claim is a form of controversy or "creative conflict." The Alternate Claim affords a means of challenging an idea (claim) without directly challenging the individual stating the idea and hence it is an example of creative controversy (Johnson, Johnson, & Holubec, 1988; Johnson and Johnson, 1992). I found no example in which one student directly and overtly challenged or criticized another student for his or her opinion. There were disagreements over *ideas*, as is seen in the numerous examples of Alternate Claims, but the disagreements were handled with sensitivity to the other students and without direct personal confrontation.

The Johnson model of cooperation in groups proposes four decision-making processes (Johnson and Johnson, 1987; pp. 224-226):

> "*Controversy* exists when one student's ideas, information, conclusions, theories, and opinions are incompatible with those of another, and the two seek to reach an agreement."
>
> "...*debate* exists when group members argue for positions that are incompatible with one another and a winner is declared on the basis of who presented the best position."
>
> "*Concurrence-seeking* occurs when members of a decision-making group inhibit discussion to avoid any disagreements or arguments and emphasize agreement; there is a suppression of different conclusions, an emphasis on quick compromise, and a lack of disagreement with in a decision-making group"

> "*Individualistic* decision making occurs when isolated individuals independently decide on a course of action without and interaction or consultation with each other; each decision maker comes to his or her own decision."

For each of the four processes they identify six characteristic aspects of the process. Table 4-3 (page 141) summarizes the four decision-making processes by describing the six aspects of the process and the results (the last row in the table) (Johnson and Johnson, 1987, p.225; Johnson and Johnson, 1989, p.92).

It will be helpful to define some of the terms they use in this model. **Cognitive conflict** occurs when a student is presented with *seemingly* opposing viewpoints, ideas, concepts, or information. The conflict may occur because of the student's preconceptions or misconceptions and not necessarily because the input information is incorrect. **Epistemic** curiosity is curiosity about the meaning of the information and how it relates to other ideas. **Reconceptualization** is the process of reformulating an idea following the input of new information. **Cathexis** is the concentration of emotional energy on an idea under discussion. In some social interaction models, this is referred to as "ownership" (Johnson and Johnson, 1989).

Controversy	Debate	Concurrence-Seeking	Individualistic
Deriving conclusions by categorizing and organizing information and experiences	Deriving conclusions by categorizing and organizing information and experiences	Deriving conclusions by categorizing and organizing information and experiences	Deriving conclusions by categorizing and organizing information and experiences
Being challenged by opposing views	Being challenged by opposing views	Quick compromise to one view	Presence of only one view
Uncertainty about the correctness of own view; cognitive conflict	Uncertainty about the correctness of own view; cognitive conflict	High Certainty	High Certainty
High epistemic curiosity	Moderate epistemic curiosity	Absence of epistemic curiosity	No epistemic curiosity
Active reconceptualization and elaboration of position and rationale	Active reconceptualization and elaboration of position and rationale	Active restatement of original position	No oral statement of position
High Reconceptualization	Moderate Reconceptualization	No Reconceptualization	No Reconceptualization
High productivity High positive cathexis	Moderate productivity Moderate positive cathexis	Low productivity Low positive cathexis	Low productivity Low positive cathexis

Table 4-3. Comparison of Four Decision-Making Processes in the Johnson Model.

	Controversy		**Debate**		**Concurrence-Seeking**		**Individualistic**	
	Johnson Model	*This Research*	*Johnson Model*	*This Research*	*Johnson Model*	*This Research*	*Johnson Model*	*This Research*
Positive Goal Interdependence	YES	YES	NO	(N/A)	YES	(N/A)	NO	NO
Resource Interdependence	YES	YES	YES	(N/A)	NO	(N/A)	NO	NO
Negative Goal Interdependence	NO	NO	YES	(N/A)	NO	(N/A)	NO	NO
Conflict	YES	YES	YES	(N/A)	NO	(N/A)	NO	**COVERT**

Table 4-4. Comparison with Johnson Model Processes.

The Johnson model also examines the mix of cooperative and competitive elements within the decision-making process. *Positive Goal Interdependence* is the common goal students have in solving the problem. *Resource Interdependence* is the sharing of ideas, experiences, and opinions. *Negative Goal Interdependence* is when students have differing goals in solving the problem. *Conflict* occurs when students have differing ideas and attempt by one of the four processes to resolve the conflict. In the manner I am using the terms, *controversy*, *constructive controversy*, and *creative conflict* are synonymous terms. In asking how the groups follow these models, it is necessary to ascertain if these elements are present or missing. Table 4-4 (page 142) summarizes these elements and compares the model with the results of this study.

Looking at the 14 groups in this study, the *Controversy* model is the most predominate with 13 of the 14 groups following this model. The primary clues they were following the controversy model were their goal and resource interdependence. The *Debate* and *Concurrence-Seeking* models are totally absent. Group 4C followed the *Individualistic* decision making process. Examples will help to elaborate this point.

Individualistic Model of Decision Making

Group 4C follows the *Individualistic* decision making process when two students talk while the other works. Their rapid-fire style made not only for difficult coding, but also for very unequal participation. In the episode shown in Table 4-5 (p. 145), EW writes on one paper, while SV and JV have a one-on-one conversation with each other. The isolation of EW is even more noticeable when viewing the videotape.

Dialog	Code	Comments
63. EW OK, use Newton's second law... [writes this while JV and SV talk and look at their own papers.]	C	New Episode
64. JV Don't we have to write down those things then?...umm, all the forces of torque equal, what are these? What's that?	AC RQCl	This is a claim related to the strategy. They exhibit what is almost an obsession with the details of the strategy. RQCl = Request for Clarification
65. SV Tau?	Cl	
66. SV Tau equals L times.	MC	Modifies the AC in 64.
67. JV Oh, yeah, moment arm times...	W	They use very few warrants.
68. SV What is the other one, tension?	RQCl	
69. JV The force, whatever force it is, right?	MC	This could relate to either 63 or 64. It is not clear if JV is thinking of EW's statement about the Second Law, or SV's idea about torque. Since much of this group's conversation is between SV and JV, it probably is the latter.
70. SV So is it L times f?	RQCl	

Table 4-5. Group 4C, Episode 7&8, Lines 63-70.

Two factors seem to have shaped this group's dynamic. First, the seating arrangement inhibited face-to-face interaction (see page 88). Second, member SV effectively socially dominated the group with her forceful style. These two factors resulted in a very dysfunctional group. There is no *direct* creative conflict occurring in this group. All challenges are essentially covert. Their individualistic decision making process is further evidence of their lack of consistent co-construction.

Controversy Model of Decision Making

The Johnson model of controversy suggests a process that repeats until the group reaches a decision (Johnson, Johnson, and Smith, 1991; Johnson and Johnson, 1987). The cyclic nature of the process is seen in Figure 4-4 (p.146), Process of Controversy (Johnson, Johnson, and Smith, 1991; p. 7:7, reproduced with permission). Several aspects of this diagram relate directly to what the students in these groups do, and there are behaviors I would expect to see based on the model. When the students are "categorizing, organizing, and deriving conclusions from present information and experiences," they are co-constructing an argument. The "active representing and elaborating of position and rationale" and "being challenged by opposing views" requires the presentation of Grounds, Warrants, and Backings to support Claims. When students in these groups are "experiencing conceptual conflict, uncertainty and disequilibrium", they undertake an "active search for more information and [they seek] understanding [of] opposing positions and rationale." As they do this, the use of Modified Claims and Alternate Claims leads to the "incorporation of opponents' information and reasoning" and their "attitude and position change" as they make the "transition to higher stages of cognitive reasoning." Specific examples will illustrate this process.

Group 4B usually had a Modified Claim *and* Alternate Claim in every episode. Consider this segment in which they discuss the vector components (Table 4-6, p. 147). There is movement from Claim (line 105) to Modified Claim (lines 107, 111, 112) to Alternate Claim (line 113). This process closely parallels the controversy decision-making model (Figure 4-4). Note that multiple Modified Claims and the Alternate Claim suggest the forward movement and reconceptualization process of the Johnson model.

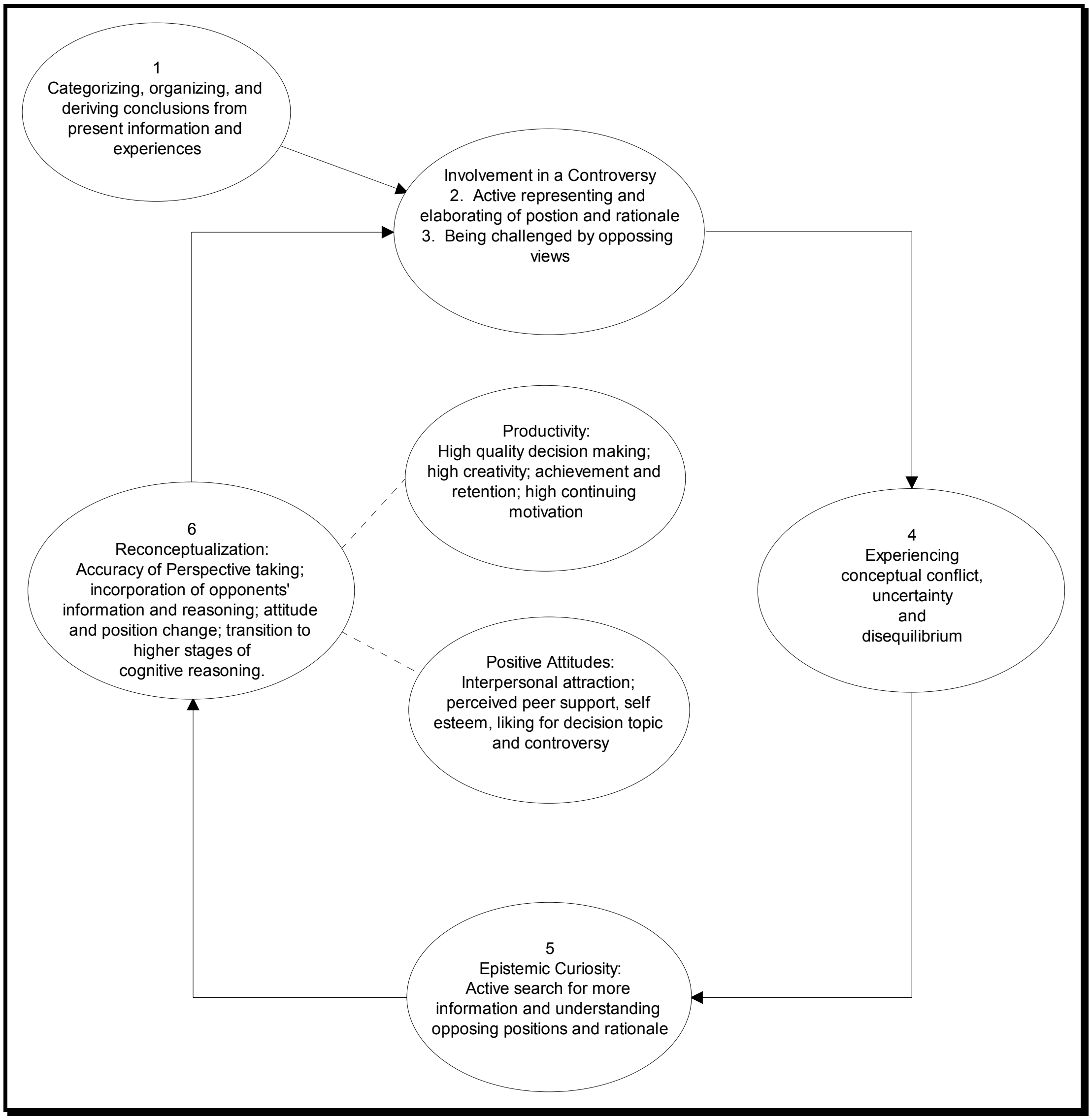


Figure 4-4. Process of Controversy.

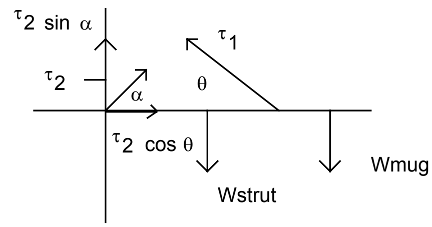
Dialog	Coding	Comments
105. LP Now wait a second, we can check that on here. We'd be looking at it in...would that be sine? Yes. [places pen on force diagram and rotates the pen around an axis centered on the origin]	C W	*New Episode*. Excellent example of a "visual" warrant.  C = Multiply τ by the sine.
106. JH Which way we going?	RQCl	RQCl = Request for Clarification
107. KJ Yeah, because if here's your angle, right?	MC	Modified Claim relates to complementary angles and elaborates on LP's original claim in 105 by specifying the angle.
108. LP Yep.	Sp	Sp = Support
109. KJ Yeah...	Sp	
110. JH How'd you know the angle? [all look at the force diagram]	RQCl	
111. KJ Well, you'd use it, if you...well it's going to be the angle with the arm, isn't it? [motions along the horizontal axis of the force diagram with his pen]	MC	Modified Claim relates to complementary angles. Namely, take the sine of the angle between the force and the lever "arm."
112. JH Well, it's [the angle] ninety degrees. You break it down.	MC	Modified Claim relates to complementary angles. "You break it down" is actually a procedural claim.
113. KJ The wall arm, that's ninety degrees, but not the force.	AC	Alternate Claim. The implicit challenge is "but not". The force is not acting at a 90° angle.
114. JH It's going to be going clockwise, so t's going to be negative, right?	MC	Modified Claim relating back to 112, and gives the direction of a "broken down" vector.
115. KJ Yeah	Sp	
116. JH So then what's plus?	RQCl	
117. LP Plus...would be minus the weight of the mug.	Cl	This series of Sp and Cl statements maintain the forward movement.
118. JH So what, 3? [begins writing equation 3]	RQCl	
119. LP Umm, no. It wouldn't be...	Ch	This challenge is answered in the next episode.

Table 4-6. Group 4B, Episode 16, lines 105-119.

The lone challenge (line 119) actually is answered in the *next* episode (Table 4-7, p. 148). Clearly although there is a challenge, the challenge is hardly argumentative. In this case, the Consensus Checking in line 125 functions to gain agreement to the

Alternate Claim in 122. These two episodes could be combined into one "meta-episode" since the second episode (17) continues the thought in the prior episode (16).

Dialog	Coding	Comments
120. JH Well, wait. The mug doesn't matter, because that's where our origin is. [erases something in equation 3]	C	Claim that answers the challenge in 119.
121. LP No it [origin] ain't.	Ch	Challenges 120.
122. KJ No, it's [origin] at the angle [α].	AC	Alternate Claim to 120.
123. JH Where do we put our origin? Oh, OK...	RQCl	RQCl = Request for Clarification
123B. LP It [?] would be times one.	Cl	Cryptic
124. KJ Yeah.	Sp	Sp = Support
125. JH Sure now?	Ck	Ck = Consensus Checking.
126. KJ Yeah	Sp	

Table 4-7. Group 4B, Episode 17, lines 120-126.

At first, I thought Group 4A, operated with the *concurrence-seeking* model. Member MK, who was the recorder and undeclared group leader, typically summarized or checked for consensus (i.e., "concurrence") at each major step. She does have high certainty about her position as she states her claims, as is seen in this example (Table 4-8, p. 150). However, in the Johnson model, Resource Interdependence is *not* a characteristic element of the *Concurrence-Seeking* model. While it is not totally clear from Episode 7, Group 4A did indeed share ideas, experiences, and opinions. Actually, RM, the quiet member of the group, frequently added important ideas. His participation is better seen in the episode in Table 4-9 (p. 150). While RM does not present any *additional* ideas, he does *support* MK's claim, an equally important contribution. An overall reading of Group 4A does suggest they *are* resource interdependent. Moreover, the fact this group uses numerous Warrants suggests there is a moderate amount of epistemic curiosity (i.e., curiosity about the meaning of the information and how it relates to other ideas). They also exhibit high productivity and high positive cathexis (the concentration of emotional energy on an idea under discussion). In fact, a subjective observation of this group's videotape suggests they had the *highest* positive cathexis of the 14 groups. Finally, their summarizing, which I mistook for a concurrence model, *may* be a means to reconceptualize their ideas. Hence, they do follow the *controversy* model.

I made similar observations about the remaining 11 groups. What seems to be most prominent is the cyclic nature of the controversy decision-making process. That is, there is a pattern. This idea led me to look at the similarities in the controversy decision-making process and the argument co-construction process I observed in this study. Table 4-10 (page 151) compares the Johnson model with a summary of the argument construction process involving the additional Modified and Alternate Claims. While I would not argue for a one-to-one correspondence, there are some parallels. This table verbally summarizes what I observed in these groups in reference to Figure 4-4 (page 146).

Dialog	Coding	Comments
43. MK. We'll need to draw the bar. [Draws bar.]	C	*New Episode*. This is a claim related to the problem solving strategy: i.e., it is necessary to draw the bar to show the forces acting. She supports her own claim when she draws the bar.
44. And this is a weird force.	W	These three G & W's all comprise one statement. They are separated out because of brief pauses separating them.
45. We have a weight going.	G	This is G because it is evident from the picture.
46. We have tension this way, right? [draws T vector]	W RQSp	This is W because that there is a tension caused by the weight is a principle of physics. The tension is in the cable. "right?" is an RQSp.
47. RM / MR. Yeah	Sp	Sp = Support
48. MK. So we label that t?	Sm	This is a summary statement not a question.

Table 4-8. Group 4A, Episode 7, Lines 43-48.

Dialog	Coding	Comments
62. MK. OK, umm...so then do we have to include like the tension	C	Question can be rephrased as a statement.
63. and a weight here for the mug?	C	There are two claims made in one statement.
64. RM. No.	Sp	He supports her C with a rhetorical "no." Sp = Support.
65. MK. Or is it just a weight?	MC	MK makes a claim in question form.
66. MR. No, it's just the weight I think.	Sp	This is a rhetorical "no" and the statement with agrees with MK's statement in 65.
67. RM. No, you don't need tension.	Sp	This is a rhetorical "no" and the statement with agrees with MK's statement in 65.
68. MR. I think the tension in this [i.e., the cable] comes from the weight. [Points to the picture.]	W	
69. It's negligible, as far as the cord's mass.	W	The Warrant is that the cord's mass can be ignored.
70. MK. OK, then...we just put weight-mug, right?	Sm	She follows here summarizing statement with a Sp.
71. OK [goes with 70]	Sp	

Table 4-9. Group 4A, Episode 9, Lines 62-71.

What decision makers do in a controversy... *(Johnson Model)*	**What students do in argument construction...** *(This Research)*
1. Categorize and organize their present information and experiences so that they derive a conclusion.	*Claims* present ideas. *Grounds*, *warrants*, and *backings* provide “information and experiences”.
2. Realize that others have a different conclusion and that their conclusions are being challenged and contested.	*Requests* for *Clarification* lead to elaboration. Some *Skeptical* questioning may ensue.
3. Become uncertain about the correctness of their conclusion and experience and internal state of conceptual conflict or disequilibrium.	Additional elaboration provides “more information, new experiences, improved reasoning, and a more adequate cognitive perspective.”
4. Actively search for more information, new experiences, improved reasoning, and a more adequate cognitive perspective to resolve their uncertainty. This include listening to and attempting to understand opponents’ conclusions and supporting rationale.	*Grounds*, *warrants* and *backings* provide the “supporting rationale.” A *Modified Claim* is a gradual movement towards acknowledging the “conceptual conflict.” An *Alternate Claim* represents a new “position and reasoning.”
5. Actively represent their position and reasoning to opposing group members, thereby engaging in considerable cognitive rehearsal of their position and rationale.	Group members make *Support* and *Acknowledgment* statements. Additional *Grounds*, *warrants* and *backings* provide more “supporting rationale”.
6. Reconceptualize their position (aided by accurate understanding of opposing perspectives; incorporation of opposing information and reasoning, attitude and position change; and use of higher level reasoning strategies).	The new idea, expressed through a *Modified Claim* or *Alternate Claim*, is accepted through *Summarizing* or *Consensus Checking* that verbalizes the “incorporation of opposing information and reasoning, attitude and position change”.

Table 4-10. Creative Conflict Parallels.

Conflict Avoidance

To understand more fully the role Alternate Claims play in creative conflict, the issue of conflict avoidance must be addressed. In physics, destructive interference of light waves leads to dark patterns on a viewing screen, and constructive interference of light waves causes a bright pattern. "Evidence supports the argument that a cooperative context aids constructive controversy" (Johnson and Tjosvold, 1989, p. 57). Creative activity occurs when controversy or conflict in a group is constructive, and the outcome is greater than any individual contribution. In general, the students in this study engaged in constructive controversy (with Group 4C being the notable exception). The degree of constructiveness, however, was largely dependent on the composition of the group:

> Whether there are positive or negative consequences depends on the conditions under which controversy occurs and the way in which it is managed. These conditions and procedures include: (1) the goal structure within which the controversy occurs, (2) the heterogeneity of decision-makers, (3) the amount of relevant information distributed among decision-makers, (4) the ability of decision-makers to disagree with each other without creating defensiveness, and (5) the perspective taking skills of the decision-makers (Johnson and Tjosvold, 1989, p. 56).

Lack of these factors may help explain less adequate physics descriptions.

Prior research showed a general reluctance of students in a physics problem-solving group to make overt challenges or to disagree with each other (Heller and Hollabaugh, 1992). (We have dubbed this "Minnesota niceness," and it may in part be culturally conditioned. Other college faculty in Minnesota have noticed this phenomena.)

To look for open conflict in these groups, I would turn to Group 4C. In an interaction between members SV and EW (Table 3-7, p. 85, Group 4C, Lines 35-54), SV says, "Write down we want to find out unknown forces on the strut. On the strut, unknown forces...find them!" If member EW wanted to confront SV in open conflict, he *could* have said, "Shut up, I know what I'm doing!" Instead he responds, "What are the unknown forces on the board? OK, so we have..." That is, direct conflict is avoided. If EW was upset with SV's attitude, he does not give any verbal or non-verbal cues that this is the case. Why does any group in this study avoid conflict?

The reluctance of one group member to challenge another group member is conflict avoidance. Johnson and Tjosvold (1989, pp. 47-48) give three reasons for conflict avoidance:

> [First] "There is insufficient knowledge and understanding of the procedures involved in controversy and the advantages and potentially constructive outcomes that can result from disagreements..."
>
> "The second reason is that most organizational personnel seem to lack the interpersonal skills and competencies needed to stimulate controversy and ensure that it is managed constructively."
>
> "Thirdly, the discussion of conflicting ideas may not be a standard and common practice within decision-making and problem-solving situations due to fear and anxiety most people seem to fear in conflict situations. A general feeling in our society is that conflicts are bad and should be avoided, and consequently many people believe that an effective organization is one in which there are no conflicts among members."

The avoidance of conflict has been discussed at great lengths in the social psychology literature (cf. Deutsch, 1965; 1973). The overwhelming impression is that people generally do whatever is necessary to avoid direct conflict, particularly when the goal of a group of people is cooperation and they are in a classroom setting. When I discussed conflict avoidance with a colleague who teaches interpersonal communication, he mentioned the interesting idea that the more *cohesive* a group, the greater the tendency to engage in "conflict" (Gaskill, 1995; Barker, Wahlers, & Watson, 1995). I do not believe these groups were particularly cohesive, and in fact may have experienced more forces of disruption than of cohesion. As I mentioned earlier, the two week residence time in a particular group may not be adequate for good cohesion.

This lack of cohesion can be explained in the context of these 14 groups. Structuring academic controversies is an integral part of learning to be effective in a cooperative learning group (Johnson, Johnson and Smith, 1990). In an ideal situation, students would experience group activities that build the skills, both interpersonal and problem solving, necessary for effective, constructive controversy. Students in this course were *not* taught these skills. Thus, when constructive controversy occurs in these groups, it is somehow instinctual or may even arise as a part of the problem-solving strategy and the group roles, which encourage skepticism and critical questioning.

It also may be that these groups avoided conflict because they lacked one or more of the five characteristics of the Johnson model. The attention to the details of structuring these groups fell by the wayside as the teaching assistants attempted to balance their teaching duties with their own academic work. Of the 14 groups, three were groups of four, not three members. The performance heterogeneity of the groups was not balanced in 9 of the 14 groups. There was a gender imbalance in 9 of the 14 groups. As seen in the transcripts, fixed furniture greatly inhibited face-to-face interaction in Group 4C. Typically, groups left the room after finishing the problem, without engaging in any group processing. These "structural defects" would all inhibit group cohesion and hence tend to inhibit direct conflict. However, this may also be serendipitous.

Summary

The tendency of these problem-solving groups to avoid direct conflict may help explain the roles of the Modified Claim and Alternate Claim. The isolated Modified Claim may be a lower level of creative controversy. When the Modified Claim leads to an Alternate Claim, the Modified Claim is a first step in the creative controversy process. The Alternate Claim, with the inherent challenge, is a more obvious form of creative controversy. It allows students to disagree with one another without being critical of one another. That is, the Alternate Claim is a crucial step in the process of argument co-construction. This suggests the making of Modified and Alternate Claims are not ends in themselves, but *steps* in a *process* of argument construction. They are a high-level form of elaboration. But, conflict avoidance may only be a part of the reason for using Alternate Claims instead of direct challenges. To further explore the reasons for using Alternate Claims, I turned to the groups that *do not* use them.

Why Do Some Groups Not Use Alternate Claims?

It is apparent from Figure 4-2 (page 136) that seven of the prototype patterns contain Alternate Claims and nine do not typically contain Alternate Claims. In other words, five of the fourteen groups use Alternate Claims and the other nine groups typically do not use Alternate Claims, but do use Modified Claims. In the previous sections *Why do Some Groups Use Alternate Claims?* and *Creative Controversy*, I suggested the Alternate Claim and Modified Claim are a form of creative controversy. The view of the Modified Claim in that discussion is that the Modified Claim is a step leading to the Alternate Claim. However, there are Modified Claims that stand isolated from Alternate Claims. Thus, another way to phrase the theme of this section is, "Why are there Modified Claims without Alternate Claims?" The answer appears to lie in the quality, that is the degree of correctness, of the original claim.

Consider this scenario: A student makes a Claim. Two or more other students hear that Claim. One or more of the hearers may *interpret* the Claim to be correct, ambiguous or "fuzzy" in some aspect, or incorrect. Based on their interpretation, these other students may propose a Modified Claim or an Alternate Claim. One could hypothesize that the prompt for the Modified Claim or Alternate Claim resides in the quality of the original Claim. There are four possibilities. First, original Claims that are correct and completely clear should not need to be modified and they should be accepted by the rest of the group and perhaps followed by Grounds, Warrants, and Backings. Second, original Claims that are correct, but perhaps incomplete or ambiguous ("fuzzy"), should be followed by a Modified Claim that brings clarity to the original Claim. Third, original Claims that are very ambiguous should be followed by a Modified Claim, or in an extreme case by and Alternate Claim. The Alternate Claim would follow in a case where the original Claim is misunderstood by the hearer(s). Fourth, and finally, original Claims that are totally incorrect should be followed by Alternate Claims that provide the correction to the initial Claim. In all four cases Grounds, Warrants, and Backings should also appear in the episode.

To test this hypothesis relating Claim correctness to the use of Modified Claims and Alternate Claims, I re-analyzed the Claims, Modified Claims, and Alternate Claims of all 14 groups. I rated the original Claims as essentially correct or slightly unclear (+1), very ambiguous or "fuzzy" (0), or totally incorrect (-1). I also tabulated the type of claim (Modified Claim or Alternate Claim) that follows the original claim. If a Claim was followed by an Alternate Claim or an Alternate Claim *and* a Modified Claim, I counted that as an Alternate Claim following the Claim. If the original Claim was followed *only* by a Modified Claim, then that was counted as a Modified Claim following.

I "summed across groups" and tabulated the episodes in which initial Claims that were followed only by a Modified Claim or by an Alternate Claim (and possibly a Modified Claim as well). The results of this tabulation are shown in Table 4-11.

Type/Number of Initial Claims	***Only* Modified Claim Follows**	**Alternate Claim Follows**
Correct (28)	21	7
"Fuzzy" (46)	30	16
Incorrect (21)	6	15
Total	57	38

Table 4-11. Modified Claim and Alternate Claim Use vs. Claim Quality.

These results support the hypothesis that the groups' use of Modified Claims and Alternate Claims is related to the degree of correctness or quality of the original Claim. Modified Claims and Grounds, Warrants, and Backings tend to follow and clarify mostly correct initial Claims (21/28 or 75%). Modified Claims follow and slightly "tweak" an ambiguous initial Claim (30/46 or 65%). Sometimes Alternate Claims follow an ambiguous initial Claim (16/46 or 35%). Alternate Claims follow incorrect initial Claims (15/21 or 71%).

Based on these results, I hypothesized further about why some groups consistently use Alternate Claims and some rarely do: Groups that have a consistent use of Alternate Claims should also have more incorrect original claims. To test this hypothesis, I determined an overall Claim quality rating for each group by averaging the correctness rating for each group's set of original Claims. An average closer to 1.0 would indicate a majority of correct Claims. A number near 0.0 would indicate either mostly ambiguous Claims or an even mix of correct and incorrect. A number near -1.0 would indicate mostly incorrect claims. In Table 4-12 (page 160), Claim Quality is compared with the groups' use of Modified Claims and Alternate Claims. Instead of sorting the table by group, or if they use or do not use Alternate Claims, I sorted them by the "Claim Quality." The MC and AC entries were determined by what the group typically does. Furthermore, I divided the 14 groups in to three subgroups: The top five, the middle four, and the bottom five in terms of claim quality. An interesting pattern emerges from this ordering.

The top five groups in terms of Claim quality (7A, 4A, 3B, 3A, 5C) use only Modified Claims. Groups 7A and 4A, which have the same claim quality use Modified Claims to extend and elaborate ideas in an original correct Claim (For example, Group 4A, Table 4-17, p. 166). Of the five groups (4B, 2B, 5B, 5A, 2A) that have the lowest Claim quality, four of these groups use Alternate Claims after incorrect initial claims (For example, Group 4B, Table 4-15, page 164). The middle four groups, 2D, 6B, 4C, and 4D were more difficult to interpret. Group 4C was most difficult to classify because this group again exhibited their frenetic behavior by having no persistent pattern of how Alternate Claims followed Claims.

There are some other observations about these three groupings shown in Table 4-12 (p. 160). First, it is not surprising to find Groups 3A and 7A using only Modified Claims. Their argument construction generally leads to a Claim. The Modified Claims they use *immediately* follow the original Claim and serve to slightly clarify the original

Claim. It is interesting to hypothesize that if their Claims were less correct, their episodes would have extended far beyond the original Claim and would contain more Modified Claims and perhaps Alternate Claims. I probably would not have then found their arguments *ending* with a Claim, but rather found their episodes *beginning* with a Claim and followed by elaboration.

Second, it is interesting that groups 3B and 7A are both groups of four and typically do not use Alternate Claims. It may be that the challenging aspect of an Alternate Claim is inhibited in a problem-solving group larger than three. This hypothesis is consistent with prior cooperative group problem-solving research (Heller and Hollabaugh, 1992). However, Group 2A, another group of four, typically does use Alternate Claims and I can not generalize this hypothesis on the basis of two out of three groups. This possible inhibiting of challenges in argument co-construction in groups of four, however, warrants further investigation.

Group	Claim Quality	Correct followed by	"Fuzzy" followed by	Incorrect followed by	Use AC	Gender Mix	Perf. Mix
7A	.83	MC	MC		NO	MMFF	LLLM
4A	.82	MC			NO	MFF	MMH
3B	.63	MC	MC		NO	MMMF	LLLM
3A	.38		MC		NO	MFF	LMH
5C	.33		MC		NO	MMF	LMM
2D	.29	MC	MC		NO	MMF	LMH
6B	.26		MC		NO	MFF	MMM
4C	.17		MC	AC	YES	MMF	LMM
4D	.14		MC		NO	MMF	LLH
4B	.09		MC	AC	YES	MMF	LMH
2B	-.11		MC	AC	YES	MMF	LMH
5A	-.33		MC	MC	NO	MMF	LMH
5B	-.33			AC	YES	MFF	LMM
2A	-.78			AC	YES	MMFF	LLMH

Table 4-12. Claim Quality

Third, I determined the presence of a "dominant" student in each group by looking at Table 3-23 (page 125). Three Groups (2D, 5A, and 5C) of the fourteen had a student who made the large majority (≥60%) of the claims. These "dominant" students appear in each third of the claim quality ranking (although Group 5C and 2D are essentially identical). That suggests that the presence or absence of a dominant student in the group doesn't appear to *directly* influence *quality* of the original Claims. However, if the groups are sorted by the "Use AC" column, then dominant students are not found in groups that use Alternate Claims. This finding suggests that the making of Alternate Claims *may* be inhibited in a group with a dominant student. It is important, however, to note that the working definition of "dominant" is based on the overall percentage of claims a student makes. Three factors may contribute to the number of claims a student makes: The group members personalities, their social interaction and their knowledge of physics. I did not find any pattern between the students' overall class performance (Low, Medium, High) and whether or not they were dominant in the groups. Groups 2D and 5A were balanced (LMH) and Group 5C had a slight imbalance (LMM). In this context, dominance therefore seems to be a personality factor. Group 4C, which had a "socially dominant" member follows this pattern as well. The use of Alternate Claims (usually by SV) after correct Claims (usually by EW) seems to be based more on how these students interacted with each other and not on Claim quality. This may also reflect their lack of co-construction.

This finding means that lower quality initial Claims tend to lead to Alternate Claims, whereas higher quality initial Claims tend to lead to Modified Claims. Thus, the

Alternate Claim provides a group with a means to rectify incorrect Claims. This, I believe, is a part of creative controversy: A student disagrees with another student who makes an initially incorrect Claim. The Alternate Claim allows for verbalization of the disagreement and correction of the Claim. The Modified Claim, on the other hand, allows a group to fill in the details of an initially correct claim or to clarify a "fuzzy" initial claim.

In Table 4-13, the use of Alternate Claims and Modified Claims is sorted by course quarter (1041 and 1042). Most of the groups that used Alternate Claims were in the first quarter of the sequence. Three groups (4B, 2B, and 2A) of the four with the lowest claim quality were first quarter groups. Only Group 5B is from the second quarter, and they are responsible for the solo entry in the lower right quadrant of the table. I can hypothesize that with time, students make more correct claims as they understand the physics better.

	1041 9 Groups (64%)	**1042 5 Groups (36%)**
Use no Alternate Claims 9 Groups (64%)	5 Groups (56%)	4 Groups (80%)
Use Alternate Claims 5 Groups (36%)	4 Groups (44%)	1 Groups (20%)

Table 4-13. Alternate Claim Use by Course Quarter.

The Role of Requests

A very common statement type in this whole study is the Request. I wondered: *Are the Modified Claims and Alternate Claims spontaneous, or does a request initiate them?* I found that the answers to Requests may clarify a statement ("Meters?" "Yes, meters.") or may actually elicit an additional Modified Claim, Grounds, Warrants, and Backings, or other support statements. Table 4-14 summarizes the results of Requests in the 14 groups. The single phrase "What?" was interpreted as a request for clarification, whereas "What force is acting?" was interpreted as a request for a claim.

Result of Request	Frequency
Claim (C)	23 %
Modified Claim (MC)	16 %
Grounds, Warrants, and Backings (GWB)	16 %
Clarification (Cl)	29 %
Other Support (Sp, Ak, En)	16%

Table 4-14. Results of Requests

Noticeably absent from Table 4-14 is the Alternate Claim. The students do not request another student to present a contradictory idea. This absence may be due to the general tendency towards conflict avoidance in these groups. That is, the Alternate Claims are spontaneous and unsolicited. Two examples will illustrate this point. In both of these cases, the Alternate Claims were not directly solicited or requested. In Group 4B (Table 4-15, p. 164) two members, LP and KJ, disagree with member JH over the location of their origin of coordinates. JH's initial Claim is incorrect and the result is the spontaneous Challenge and then Alternate Claim in line 122.

Dialog	Coding	Comments
120. JH Well, wait. The mug doesn't matter, because that's where our origin is. [erases something in equation 3]	C	Claim that answers the challenge in 119.
121. LP No it [origin] ain't.	Ch	Challenges 120.
122. KJ No, it's [origin] at the angle [α].	AC	Alternate Claim to 120.
123. JH Where do we put our origin? Oh, OK	RQCl	RQCl = Request for Clarification
123B. LP It [?] would be times one.	Cl	Cryptic
124. KJ Yeah.	Sp	Sp = Support
125. JH Sure now?	Ck	Ck = Consensus Checking.
126. KJ Yeah	Sp	

Table 4-15. Group 4B, Episode 17, lines 120-126.

In a second example, Group 5B (Table 4-16) continually confuses the relationship between gravitational potential energy, kinetic energy, and escape velocity (See Appendix B for a statement of Problem 5). Group member KE wanted the velocity of the space probe to be zero when it reaches its designated altitude. Group member MC disagreed with him (line 42) and the challenge causes him to modify his original claim. But his Modified Claim is also in error, and member MC continues to correct the error. Eventually he sees the problem and changes his mind.

Dialog	Coding	Comments
41. KE Kilometers per second. If it's going that fast when it's launched. Right when it's free of our gravitational pull, it'll be going zero. So it'll just leave.	C	His Claim is that the space probe will have zero velocity when it achieves its designated altitude.
42. MC OK, so but...I don't think this [space probe] is going to leave [i.e., escape], is it?	AC	MC disagrees the idea expressed in 41.
43. KE So then, actually kinetic energy goes to zero.	MC	Modifies Claim in 41.
44. MC I don't think [the kinetic energy goes to zero].	Ch	
45. KE This [velocity] isn't [zero], so this [space probe] will still have kinetic energy.	AC	This is an Alternate Claim to his original Claim.
46. MC OK.	Ak	MC Acknowledges his new claim.
47. KE Oh, perfect.	Ak	He accepts the support in 46.

Table 4-16. Group 5B, Episode 6, Lines 41-47.

From Table 4-14 it is clear that most requests (29%) lead to Clarification. Somtimes (16%) a Modified Claim is the result of the Reqeust. Group 4A is an excellent example of how requested clarification statements (Grounds, Warrants, and Backings) and Modified Claims elaborate an idea. The members of this group often continue one another's thoughts with a clarifying phrase following a Request. In Table 4-17, line 50, member MR clarifies the Warrant, although the Warrant was not requested. Compare this to lines 55-59, which illustrate the clarification of a Ground in response to a Request. When member MR says "The weight of the bar," she clarifies MK's "What?" in line 56. She then elaborates the original Claim member RM made in line 49 by specifying the location of the "weight right here." What is equally interesting is the Request in line 56 leads not only to the Modified Claim in line 58, but supporting Backings and Grounds in lines 58 and 59. This is a example of how a requested Modified Claim clarifies the meaning of the initial Claim.

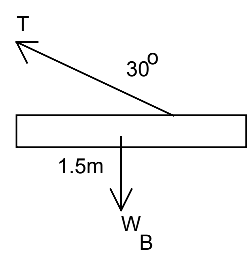
Dialog	Code	Comments
49. RM. You have a weight right here. [Points to where W_B goes on diagram.]	C W	The Claim is the location of the weight. The warrant is the pointing to the diagram.
50. MR. The bar weight.	Cl	
51. In the middle.	W	
52. RM. Yeah, goes in the middle.	Sp	Supports the previous warrant.
53. MR. That always goes in the center.	Sp	Supports the previous warrant.
54. MK. OK, so this is weight bar. [labels diagram while talking.]	Sm	This is a good example of the Recorder summarizing before continuing.
55. MR. That should be at one end, 1.5 meters.	G	
56. MK. What?	RQCl	RQCl = Request for Clarification
57. MR. The weight of the bar.	Cl	This clarifies the "what?"
58. They always do it from the center. We always do it from the center. We're going to have to know how far over it is. [Indicating labels for the distances.]	MC B RQG	This modifies the claim in 49 because it elaborates on the location of the weight. The backing is based on what "they," i.e., the book and professor do.
59. So it's always at 1.5.	G	"Always at 1.5" implies it is always in the middle, i.e., at the center of mass. She provides the Grounds.
60. MK. Oh, OK [Draws and labels the 1.5 meters.]	Sp	
61. MR. Meters.	Cl	This is an example of using a clarifying statement to complete a thought.

Table 4-17. Group 4A, Episode 8, lines 49-61.

Summary

There are four general claims I can now make concerning the role of Modified Claims and Alternate Claims in argument co-construction.

1. The Alternate Claim
    - generally occurs in a "controversy" model of decision-making,
    - is a higher form of creative conflict,
    - generally corrects original claims that are wrong or "fuzzy",
    - and allows students in problem-solving groups to disagree while avoiding direct conflict.

2. The Modified Claim
    - can elicit another Modified Claim or Alternate Claim; it can serve as a bridge or link to the Alternate Claim,
    - may prompt the ideas that cause the maker of the Alternate Claim to state the Alternate Claim,
    - is a lower-level form of creative conflict when it stands in isolation of an Alternate Claim
    - and refines, clarifies or elaborates original claims that are slightly "fuzzy" or incomplete.

3. All Claims are steps in a "reconceptualization" process.
    - Within episodes, the claim-making role shifts between students, that is the Modified Claimant and the Alternate Claimant are not the same as the original Claimant.
    - The claim-making role is fairly uniformly distributed among the active students in a group. Usually all students make claims.
    - When there is a dominant student, he or she tends to make most of the claims.
    - All students in the group are involved in the argument co-construction, that is, even the "quiet" students contribute.

4. Although groups engage in both types additional claims, they tend to have a typical controversy pattern which uses either Alternate Claims or Modified Claims. This pattern is related to the correctness of the original claim.

The grounds for this finding are:

- Direct challenges are rare.
- 13 of the 14 groups followed a Controversy Model of Decision Making. (Warrant: Johnson Model, Table 4-10, p. 151)
- 9 of the 13 groups following the Controversy Model did not use Alternate Claims but do use Modified Claims. 7 of these 9 groups have a higher initial Claim quality. Modified Claims are requested in these groups.
- 5 of the 13 groups following the Controversy Model use Alternate Claims. These 5 groups have a lower initial Claim quality. Alternate Claims are never requested in any group.
- At least one Modified Claim and one Alternate Claim are found in every group. (Table 3-23, page 125)

To summarize, when a Modified Claim stands in isolation from any Alternate Claim, it seems to fulfill a refinement role, what a physicist might call a "tweaking" of the original claim. Again, the very definition of the Modified Claim may be partially responsible for this "tweaking" function: A Modified Claim presents a variation on the prior claim, but does not present a totally new idea. This also seems to be the function when the Modified Claim appears in an episode with an Alternate Claim. Alternate Claims are more likely when the original Claim is somehow erroneous. The presence or absence of a dominant student in a group does not seem to directly influence quality of the original Claim, but the making of Alternate Claims *may* be inhibited in a group with a dominant student

QUESTION 3C. DO THE GROUPS HAVE A PREFERENTIAL MEANS TO SUPPORT ARGUMENT CONSTRUCTION?

The previous discussion of Question 3b on the Modified Claims and Alternate Claims lead to the conclusion that these are a fundamental part of the argument co-construction process. Yet, these types of statements are insufficient by themselves. Argument co-construction also needs substance that connects the co-construction to the statement of the problem as well as the laws and principles of physics. This is the function of the Grounds, Warrants and Backings.

Figure 4-5 (page 171) shows the sorting the 16 argument co-construction patterns into categories based upon the use of the basic Toulmin categories. Whether or not there are additional claims, the groups preferred to use Grounds and Warrants to support their claims. Of the 16 patterns, five predominantly exhibit Grounds and Warrants, and seven show the use of Grounds, Warrants, and occasional Backings. And, Group 4C, of course, tended to not have any further elaboration following the additional claims.

Overemphasis on the surface features of a problem could lead to a heavy use of Grounds. The opposite of this, reliance mainly on Warrants and Backings, leads to an interesting situation where the physics is not adequately described in the context of the *particular* problem. Important bits of data are omitted and the solution becomes flawed. For example, this is seen in Group 3A. This group attempted to model their solution after other problems they have seen in the textbook, the professor has done in class, or problems the Teaching Assistant has done in recitation. Compared to all 14 groups, they had a much higher use of Backings ($z = 2.12$) and a much lower use of Grounds ($z = -1.12$). Their physics description was initially weak because they did not have an adequate “picture” of the problem. What ultimately “saved” Group 3A, and earned them 10 points on the problem, was following the problem solving strategy in a fairly precise manner. An example shown in Table 4-18 is from early in their solution, and ultimately they did draw upon some “data” in the problem. It might be that this initial discussion about other problems they have seen led them to the inclusion of proper Grounds. Even so, they relied very heavily on modeling their solution after other examples.

Groups like 3A that use many Backings tend to have some lack of physics knowledge, due to inadequate preparation, missing class, or other factors such as lacking the pre-requiste course. When these groups use Backings, they show a hierarchical preference to model their solution after first the professor, then the textbook, then the teaching assistant. Table 3-12 (page 96) illustrates how Group 4D sought intervention from the teaching assistant. One member of Group 4D had missed class the day before the group problem. In general I found that groups that use many Backings are “in trouble” or lack self-confidence. Groups, such as 4A, that use fewer Backings ($z = -0.45$) seem to be very confident they can solve the problem.

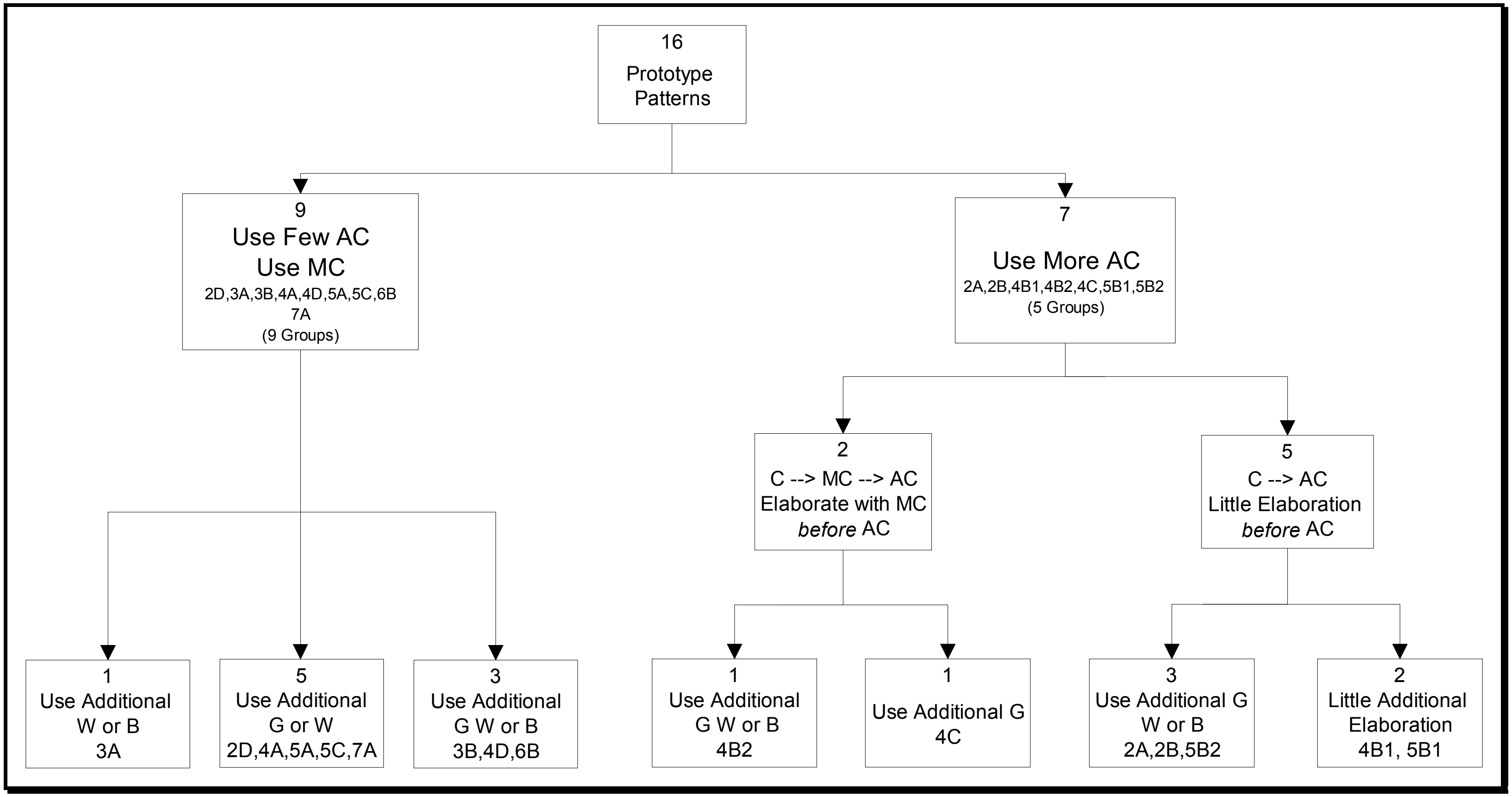


Figure 4-5. Elaboration of Claims.

Dialog	Code	Comments
5. MP This would be tension.	C	New Episode
6. GS We'll need one on "a" one on "w" and we'll need a force diagram for the knot.	W	W = need for a force diagram
7. SK We do? [Each looks at their own paper.]	RQCl	RQCl = Request for Clarification. Asks for clarification of the Warrant.
8. GS I think so, does that make sense?	Sp RQCl	Supports his own warrant.
9. SK Umm	Ak	Ak = Acknowledgment.
10. MP What'd you say?	RQCl	
11. GS That we'd need a diagram for the knot there. [points to picture]	Cl	Clarifies 8.
12. SK Do we? [pause]	RQSp	SK is still uncertain. RQSp = Request for Support.
13. MP I don't, well do we...I don't remember ever doing that...didn't we just do it for...	B	Incomplete thought refers to something that was done in class. (We = the class)
14. GS I'm assuming that the problem is we've got...maybe I'm seeing the picture wrong, but we've got this rope here attached to the wall [points to picture., others watch] and then attached to the book and we're pulling that weight.	G	Grounds from the picture supplied with the problem statement.
15. SK So like yeah, this was like straight across here [looking at her own copy of the problem], and then they put the weight on so it goes down.	B	The "they" could refer to the book, the professor, or something the T.A. did in a previous problem.
16. GS And right at the knot there's tension down, tension that way and tension up that way ...it's like the pictures he [i.e., T.A.] drew where we had the three weights. Think of what he [i.e., T.A.] just drew on the board. [Gestures towards the board.]	W B	W = directions of the tensions B = What the T.A. did on the blackboard.
17. MP OK		

Table 4-18. Group 3A, Episode 2-3, Lines 5-17.

The two groups that had dual argument patterns, 4B and 5B, both use Alternate Claims, but in slightly different ways. When Group 4B uses a Modified Claim preceding an Alternate Claim, there is additional elaboration in the form of Grounds, Warrants, and Backings. However, when there is *no* Modified Claim preceding an Alternate Claim, there are *no* additional Grounds, Warrants, and Backings. It seems as if the Modified Claim elicits the Grounds, Warrants, and Backings. Perhaps the more "tentative" nature of the Modified Claim made necessary these support statements.

Group 5B, on other hand, typically used no Modified Claims, and sometimes their Alternate Claims were elaborated and sometimes they were not. In other words, I cannot accurately characterize Group 5B's use of supporting statements. This lack of elaboration and support may account for a persistent misuse of the terms orbital velocity and escape velocity.

Summary

Based on this analysis of Grounds, Warrants, and Backings, I can now claim these groups are supporting their argument co-construction with statements that would be expected in a Toulmin argument structure.

The grounds for this claim are:

- 7 of 16 patterns contain additional Grounds, Warrants and Backings.
- 5 of 16 patterns contain Grounds and Warrants.
- 1 pattern contains mostly Warrants and Backings.
- 3 patterns contain little additional elaboration or support.
- Groups that use Backings tend to prefer the professor.

SUMMARY

In this chapter I explored the similarities in the argument co-construction between these 14 problem-solving groups. Chapter Five will discuss the implications of these findings for present and future research and practice in science education. The emphasis was on the use of the Modified Claims and Alternate Claims, the role of requests, as well as creative controversy and conflict avoidance. Since the Toulmin structure includes Grounds, Warrants, and Backings, I also examined how groups use these types of statements. There are three major findings.

First, most of the patterns (14 of 16 patterns, 12 of the 14 groups) *begin* with a claim. This is different from a strict Toulmin argument pattern where the claim is the *end* result of the argument construction.

Second, the Alternate Claim and Modified Claim were discussed in Chapter Three in the context of the need to account for additional claims within an episode. In this chapter, the discussion looked more closely at the role these claims played in the argument co-construction process. There are four major claims I can make about the Alternate Claim and Modified Claim.

1. The Alternate Claim
    - generally occurs in a "controversy" model of decision-making,
    - is a higher form of creative conflict,
    - generally corrects original claims that are wrong or "fuzzy",
    - and allows students in problem-solving groups to disagree while avoiding direct conflict.

2. The Modified Claim
    - can elicit another Modified Claim or Alternate Claim; it can serve as a bridge or link to the Alternate Claim,
    - may prompt the ideas that cause the maker of the Alternate Claim to state the Alternate Claim,
    - is a lower-level form of creative conflict when it stands in isolation of an Alternate Claim
    - and refines, clarifies or elaborates original claims that are slightly "fuzzy" or incomplete.

3. All Claims are steps in a “reconceptualization” process.

- Within episodes, the claim-making role shifts between students, that is the Modified Claimant and the Alternate Claimant are not the same as the original Claimant.
- The claim-making role is fairly uniformly distributed among the active students in a group. Usually all students make claims.
- When there is a dominant student, he or she tends to make most of the claims.
- All students in the group are involved in the argument co-construction, that is, even the “quiet” students contribute.

4. Although groups engage in both types additional claims, they tend to have a typical controversy pattern which uses either Alternate Claims or Modified Claims. This pattern is related to the correctness of the original claim.

The grounds for this finding are:

- Direct challenges are rare.
- 13 of the 14 groups followed a Controversy Model of Decision Making. (Warrant: Johnson Model, Table 4-10, p. 151)
- 9 of the 13 groups following the Controversy Model did not use Alternate Claims but do use Modified Claims. 7 of these 9 groups have a higher initial Claim quality. Modified Claims are requested in these groups.
- 5 of the 13 groups following the Controversy Model use Alternate Claims. These 5 groups have a lower initial Claim quality. Alternate Claims are never requested in any group.
- At least one Modified Claim and one Alternate Claim are found in every group. (Table 3-23, page 125)

Because all students are involved in the claim-making process, co-construction of the argument is occurring. That is, the solution to the problem is a *group* solution and not the product of the best individual in the group. This supports prior research (Heller, Keith, and Anderson, 1992). The Modified Claim can be spontaneous or be offered in response to a request for clarification. A lack of group cohesion and conflict avoidance may inhibit direct challenges.

Finally, the Modified Claim and Alternate Claim are one means of supporting a Claim. Grounds, Warrants, Backings provide “color” and base the problem on the stated parameters and the principles of physics. Most groups use Grounds, Warrants, and occasional Backings to support their arguments. Lack of adequate Grounds leads to an inadequately described problem, and a reliance on Backings for support. Groups that use Backings tend to prefer the professor over the teaching assistant or textbook.

CHAPTER 5

DISCUSSION OF RESULTS

RESEARCH SUMMARY

This chapter will briefly summarize the research setting and procedures and then discuss the meaning of the results. The purpose of this research was to undertake a systematic "fine-grained examination" of what students actually do in cooperative problem-solving groups. The research explored the process of argument co-construction, using Stephen Toulmin's argument structure, in fourteen cooperative problem-solving groups while they completed their qualitative analysis of physics problems. The physics courses used for this study were the algebra-based, introductory two-quarter sequence Physics 1041 and 1042, taught winter and spring quarters 1991, at the University of Minnesota.

Students were taught a problem solving strategy (Heller and Hollabaugh, 1992). They were expected to use this five-step strategy in the recitation period when solving a complex problem as a cooperative group. The students were introduced to the four roles of Manager, Recorder, Skeptic and Engergizer. It was *intended* that there would be a heterogeneous mix within a group in terms of the students' performance in the class (high, medium, low). Also, it was *intended* that there would be all groups of three, and no groups where the number of men was greater than the number of women. However, the teaching assistants only occasionally followed this plan. In reality, of the 14 groups in this study, there were 11 groups of three, only four of these groups met the gender criteria, and of these four, only one met the ability composition criteria.

Students in a group worked a "practice" problem one week, and then worked a problem for a grade the following week. Students were then reassigned to new groups for another two-week period. During each of the two quarters, there were four graded problems, offering eight data collection opportunities. Only six of these problems were used in this study.

The data collection and analysis consisted of these procedures:

- Videotaping 14 groups solving six physics problems ("raw" data).
- Transcribing the videotapes.
- Editing the transcripts with annotations to written solutions and the videotapes.
- Identifying the Toulmin statements of Claims, Grounds, Warrants, and Backings.
- Identifying new statement categories based on the cooperative group roles and the problem-solving strategy.
- Characterizing each group qualitatively and their written solutions quantitatively.

This "processed" material comprised the "data" in this research. In order to answer the research questions, another analysis tool was invented, the flowchart.

In order to determine the patterns of argument construction, I flowcharted all of a group's episodes that focused on the physics description. The flowchart of each episode contains a set of symbols, one for each statement type. Each symbol contains the transcript statement number, statement type, and speaker. Then I characterized a group in terms of a "prototypical pattern". That is, on the *average*, what does this group do? When attempting to determine a "prototypical pattern" for a group, the focus was on their use of Claims, and their support for Claims with Grounds, Warrants and Backings. I discovered there were multiple claims in the prototypes. I found that episodes had multiple, additional claims that seemed to change the essence of the initial claim and elaborated the original claim. Based on how they were used, I named them the Alternate Claim and the Modified Claim.

I will now make major "claims" related to the research questions. Just as these 14 groups preferred, I will state the claim and then follow it with grounds, warrants and backings, and modified claims. The theme of Chapter Three was the search for self-consistent the patterns of argument co-construction *within* individual groups.

Claim 1. Thirteen of these fourteen problem-solving groups engaged in argument co-construction as they completed a physics description of a problem. There are two findings that support this. First, students discussed the problem in an episodic manner and episodes were used as a unit of analysis. The group members' statements are not isolated from each other and there is a logical flow to the discussion. Very few episodes contained statements that did not relate to previous statements by other group members. Second, four criteria for argument co-construction were found in 13 of these 14 groups on a consistent basis, and in the other group, 4C, only occassionally. These criteria are:

- Claims are supported by Grounds, Warrants, and Backings
- Grounds, Warrants, and Backings appear in repeating patterns
- Group members listen to each other and discuss the *same* claim
- Claim-making role shifts among group members

Statements of Support, Acknowledgment and Encouragement keep the conversation moving forward and allow students to "transfer" the conversation to another student.

Claim 2. There are self consistent argument co-construction patterns within a group. Two findings support this claim. First, these 14 problem-solving groups appear to adopt a group dynamic that leads to predictable, or at least repeating, patterns of argument co-construction. The differences in these patterns is evident in the manner the Groups further explain, elaborate and defend their ideas. Twelve of the 14 groups had a single prototype pattern and two groups had dual patterns.

Second, additional Claims within a group's episodes can be accounted for by defining the Alternate Claim and Modified Claim.

- An Alternate Claim follows a Claim or a Modified Claim and presents a contradictory or alternate idea to the initial claim. Either an explicit Challenge precedes an Alternate Claim, or a challenge is implicit within the Alternate Claim. Alternate Claims are sometimes stated as a question. Other verbal cues include "Perhaps we should consider..," "On the other hand..," "I think it's..."
- A Modified Claim follows a Claim or an Alternate Claim. A Modified Claim offers an additional, non-contradictory idea(s) to the initial claim, and serves to clarify, extend or elaborate upon the initial claim. A Modified Claim is usually stated in a non-confrontational manner compared to an Alternate Claim.

All groups contain at least one Alternate Claim and one Modified Claim somewhere in their analyzed episodes. The claim-making role shifts among the students. This also supports the claim of co-construction of an argument.

Chapter Four explored the similarities in the argument co-construction *between* these 14 problem-solving groups. The emphasis was on the use of the Modified Claims and Alternate Claims, the role of requests, as well as creative controversy and conflict avoidance. Since the Toulmin structure includes Grounds, Warrants, and Backings, I also examined how groups use these types of statements. The general claim in this chapter is: *Claim 3. There are similarities in the argument co-construction patterns between the fourteen groups.* Three subsequent modified claims support and clarify this initial claim.

Claim 3a. The groups' argument co-constructions usually begin with a Claim. Most of the patterns (14 of 16 patterns, 12 of the 14 groups) *begin* with a claim. This is different from a strict Toulmin argument pattern where the claim is the *end* result of the argument construction.

Claim 3b. Modified Claims and Alternate Claims play a direct role in the argument co-construction process of these groups and allow groups to engage in creative controversy and to correct initially incorrect or ambiguous claims. The Alternate Claim and Modified Claim were discussed in Chapter Three in the context of the need to account for additional claims within an episode. In Chapter Four, the discussion looked more closely at the role these claims played in the argument co-construction process. There are four major findings about the Alternate Claim and Modified Claim.

1. The Alternate Claim
    - generally occurs in a "controversy" model of decision-making,
    - is a higher form of creative conflict,
    - generally corrects original claims that are wrong or "fuzzy",
    - and allows students in problem-solving groups to disagree while avoiding direct conflict.
2. The Modified Claim
    - can elicit another Modified Claim or Alternate Claim; it can serve as a bridge or link to the Alternate Claim,
    - may prompt the ideas that cause the maker of the Alternate Claim to state the Alternate Claim,
    - is a lower-level form of creative conflict when it stands in isolation of an Alternate Claim
    - and refines, clarifies or elaborates original claims that are slightly "fuzzy" or incomplete.
3. All Claims are steps in a "reconceptualization" process.
    - Within episodes, the claim-making role shifts between students, that is the Modified Claimant and the Alternate Claimant are not the same as the original Claimant.
    - The claim-making role is fairly uniformly distributed among the active students in a group. Usually all students make claims.
    - When there is a dominant student, he or she tends to make most of the claims.
    - All students in the group are involved in the argument co-construction, that is, even the "quiet" students contribute.

4. Although groups engage in both types additional claims, they tend to have a typical controversy pattern which uses either Alternate Claims or Modified Claims. This pattern is related to the correctness of the original claim. The grounds for this finding are:

- Direct challenges are rare.
- 13 of the 14 groups followed a Controversy Model of Decision Making. (Warrant: Johnson Model, Table 4-10, p. 151)
- 9 of the 13 groups following the Controversy Model did not use Alternate Claims but do use Modified Claims. 7 of these 9 groups have a higher initial Claim quality. Modified Claims are requested in these groups.
- 5 of the 13 groups following the Controversy Model use Alternate Claims. These 5 groups have a lower initial Claim quality. Alternate Claims are never requested in any group.
- At least one Modified Claim and one Alternate Claim are found in every group. (Table 3-23, page 125)

Because all students are involved in the claim-making process, co-construction of the argument is occurring. That is, the solution to the problem is a *group* solution and not the product of the best individual in the group. This supports prior research (Heller, Keith, and Anderson, 1992). The Modified Claim can be spontaneous or be offered in response to a request for clarification. A lack of group cohesion and conflict avoidance may inhibit direct challenges.

Claim 3c. The groups have a preferential means to support claims made in argument construction (e.g., Grounds, Warrants, Backings). Grounds, Warrants, Backings provide “color” and base the problem on the stated parameters and the principles of physics. Most groups use Grounds, Warrants, and occasional Backings to support their arguments. Lack of adequate Grounds leads to an inadequately described problem, and a reliance on Backings for support. Groups that use Backings tend to prefer the professor over the teaching assistant or textbook.

Reliability, Validity, and Generalizability Revisited

It is important to address again the reliability, validity and generalizability of this study now that the results are known. The fundamental issue can be simply summarized: Are the results what a reasonable person would conclude from this data, and would expect to conclude in another situation from similar data?

While there are limited "triangulation" sources in the strict sense of the concept's usage in qualitative research, there are several "reference points" from which my conclusions were drawn. Figure 1-2 (page 23) can now be made more specific. The primary sources for this study are the videotapes. These led to the coded transcripts. The transcripts gave birth to the flowcharts. Together they form the primary data.

The written solutions to the problems are related to the video, and help to clarify what the students were discussing. These are a separate type of data and due to their written form could be objectively evaluated.

Descriptive data relating to the size, gender and performance mix of the group, as well as quantitative test scores enabled some "statistical" characterization of the groups. It is important to see this data as *descriptive* and not normative. That is, this data helps to describe the members of a group individually and their group as a whole. One of the most useful pieces of data of this type were the self-disclosure statements such as "I missed class yesterday." While these statements come from the videos, they really are self-descriptions of the groups.

Finally there are the subjective comments that I, the transcription assistant, and my dissertation advisor made upon viewing the tapes or reading the transcripts. At first glance, all fourteen transcripts look a lot alike. Immediate differences are noted upon comparing different problem sessions. Within one problem session, repeated readings of each group lead me to be able to "feel" what the group was like.

All of these four reference points enabled me to answer the research questions and come to the conclusions I did. Although the videos were the primary source, I do not believe it would have been possible to eliminate one reference point over another. Like the points of a compass, they help to locate the results in a broader picture. A visual representation of these four cardinal directions is depicted in Figure 5-1.

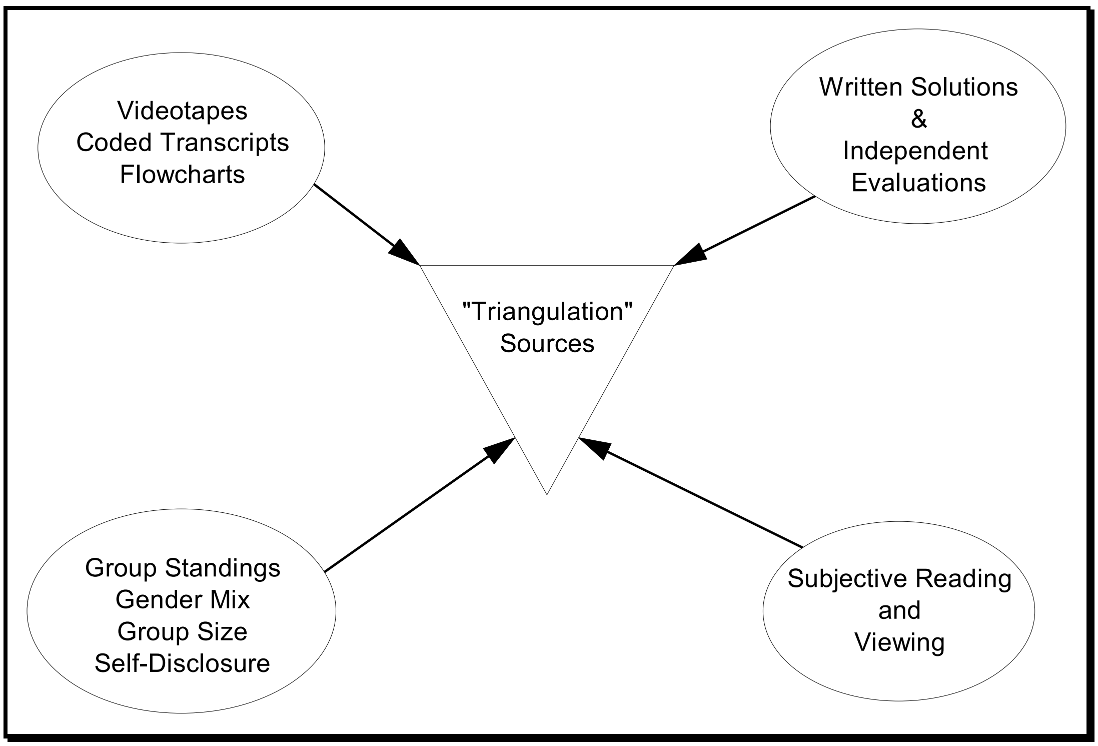


Figure 5-1. Reference Points

Joseph Maxwell (1992) offers a useful typology for understanding validity. His goal is to provide a checklist of "threats" to validity. He identifies these categories of validity useful in qualitative studies: Descriptive, interpretive, theoretical, generalizability. The categories reformulate the traditional validity, reliability, generalizability categories which actually come from quantitative research. Maxwell's categories can be useful in analyzing the validity of this study.

Descriptive Validity

Descriptive validity asks if the account of the research is factually accurate. For example, are the transcripts an accurate rendering of the original videotapes? In an attempt to be descriptively valid, I checked the transcripts against the video, not once, but several times. If an interpretive questions arose, I found the episode on the video and carefully watched it while making annotations. Moreover, the transcripts themselves were repeated edited. Where important, I noted the antecedents of pronouns so the reader would know to what "it" refers. The written solutions were the source of drawings incorporated in the annotated transcripts. It was important to reproduce their drawings as accurately as possible. In many cases I watched the video repeatedly to see exactly what they were drawing at a given instant. My comments about Group 4C's seating was based on observing their seating arrangement on the video as well as my own personal observation of the group when they were solving the problem. The use of a *video* source as opposed to an *audio* source for the basic data is the primary guarantor of descriptive validity in this study.

Other descriptive aspects of the data are also accurate. The quiz grades for the students in these two courses were obtained directly from the department's master spreadsheet containing the grades. The few statistical analyses in this research were made with generally accepted methods with an Excel™ Spreadsheet. A simple check of the video log sheet revealed the gender of the students, and this was cross checked with the video itself.

Interpretive Validity

There is subjectivity in this research. Interpretive validity asks if what is interpreted from the observations is true to the data. That is, what is the meaning of the observations and does it reflect what the participants (i.e., the students in the groups) actually did? Maxwell notes, "Like descriptive validity, then, interpretive validity, while not atheoretical, refers to aspects of accounts for which the terms of the account are not themselves problematic. *Interpretive accounts are grounded in the language of the people studied and rely as much as possible on their own words and concepts*" (Maxwell, 1992; p. 289; emphasis added). The guarantor of interpretive validity in this study is the manner in which the interpretation developed. There was an interactive process. For example, the flowcharts refer to the transcripts, and indeed one must read the transcript of an episode to understand the flowchart.

Likewise, there was an iteration process. I view the progress through this research as a helix. There is constant forward movement but I continually returned to the same groups or the same ideas. For example, the four groups in session four formed the basis of the coding system. When I was satisfied with the coding, the system was extended to the other 10 groups. Flowcharts were drawn for Groups 4A, 4B, 4C, 4D. When I was satisfied with the results, I extended the flowcharting to the other 10 groups. Then I faced the question of what to do with the additional claims in an episode. After identifying the Alternate Claims and Modified Claims in the four groups, I went back to the remaining 10 groups. They were recoded to account for the Alternate Claims and Modified Claims. Next, the revised flowcharts were drawn for Groups 4A, 4B, 4C, 4D, and then for the remaining groups. In other words, instead of plowing boldly ahead, I made sure at *each* step that what I was doing made sense to me and fairly represented the data. In addition, I had to convince Dr. Heller that what I was doing made sense. An analogy to this process might be the pilot testing of curriculum materials. After testing, revisions are made prior to releasing the materials to the larger audience. I believe this is a constructivist way of doing research: The process is a part of the product, and meaning is constructed out of what is evident, reasonable, and logical. Even subjective evaluations were are part of this process. We were able to assign highly subjective monikers to groups ("bad", "good", "confused", "dysfunctional") and know which group we were discussing by its pejorative name. Finally, the independent evaluation of the *written* solutions supplied another interpretive reality check.

One major interpretive concern was that somehow my coding of the statements or drawings of the flowcharts changed between the beginning and the end of the study. First of all, it is important to note the order in which the sessions were coded: 4, 2, 3, 5, 6, and 7. I saw no "chronological" pattern to such measures as lines per episode. I have already addressed the issue of whether or not the students who appear in more than one group were consistent in their claim making (Table 3-24, page 126). They are relatively consistent.

As a final example of interpretive validity, consider the very use of the Toulmin categories and the additional defined categories. Alternate Claims and Modified Claims are interpretive but also related to the Toulmin category of the Claim. Likewise categories like Consensus Checking grew out of the cooperative groups and the problem-solving strategy. That is, these additional statement types are not atheoretical, to use Maxwell's term.

Theoretical Validity

Theoretical validity ask if the account of the research is valid in terms of the theory of what is happening in these groups. "...the issue is the legitimacy of the application of a given concept or theory to established facts, or indeed whether any agreement can be reached about what the facts are" (Maxwell, 1992; p. 293). There are two issues in this specific research: Is the use of Toulmin's argument structure valid, and do students co-construct a problem solution? One might even ask if constructivism itself is a valid world-view. The theoretical starting point of this research was that Toulmin *is* valid and that students *do* co-construct a solution. For nearly 40 years, Toulmin's argument structure has been use in rhetoric, debate, and logic. Although many have "argued" with some of his ideas, the fundamental assertion that a formal argument structure contains Claims, Grounds, Warrants, and Backings is generally accepted. That acceptance is supported by the number of people and disciplines that have used it. Likewise, there is a vast body of research literature on constructivism in science. It is a view of science learning that is commonplace. In both cases, I believe these theoretical frameworks have stood the test of time *because they work*. That is a bit like theories in physics. Those that survive do so because they are able to describe existing phenomena and predict new behavior.

Generalizability Validity

This type of validity asks if the account can be extended to other persons, times, or settings. What generalizability really asks is if this account can be used to make sense of other situations and settings. Qualitative studies are not usually replicated, but the extension to other settings is important to consider. I will more directly address the issue of generalizability in my discussion of suggestions for future research and suggestions for curriculum and instruction.

SIGNIFICANCE OF THE RESEARCH

This was not the first research to use the episode as a unit of analysis. However, as far as I know, it is the first to use episodes in a qualitative case study of cooperative group problem solving. The episode is a valid unit of analysis because a group co-constructs an argument by conversing, and conversations consists of *multiple* statements and sentences. Thus, it was better, in this case, to use episodes instead of just counting statement types. The use of this technique is further warranted because using episodes revealed important patterns. Even so, the episodes are composed of statements and it was important to carefully classify individual statements. One could see the statements as a micro-context and the episode as a mini-context.

I also feel confident that beginning with the Toulmin categories yielded rich insights. As I found, students in a problem-solving group do not strictly follow the Toulmin argument structure and thus, other statement types must be considered. In addition, their patterns do not always lead to the claim. Even so, the Toulmin structure is a valid and useful analysis tool for studying the *process* of cooperative group problem solving. Part of the usefulness is the manner in which the additional statement types complement the Toulmin statements.

Students in a problem-solving group are engaged in *co-constructing* an argument. That means the product, i.e., the problem solution, is a group product and not the work of an individual. This is a finding in this study that supports previous research. We frequently hear the criticism of cooperative group problem solving, especially from physics professors, that the best student in the group solves the problem. I believe, post research, that this is *not* the case. Even the least involved student contributed some idea that lead to the solution. I might even argue in the case of Group 4D that ST's insistence that there is no normal force lead to a much better understanding of the forces acting on the sign. In Group 4A, RM who was very quiet, frequently asked the skeptical questions or requested clarification because he did *not* understand.

The ensuing discussions led to all three students understanding better. It may even be the questions of the *least* "capable" student that leads to the problem solution. This has implication for how we teach problem solving and how we structure cooperative groups.

Students in a problem-solving group use Modified and Alternate Claims. These additional claims are a means for students to engage in "creative controversy" in order to elaborate claims, correct and clarify initial claims, and to co-construct a problem solution. One of the fundamental tenets of cooperative learning is that when a group member asks a "why" question, someone will have to "explain, elaborate or defend" an idea (Brown and Palincsar, 1989, p. 395). Thus, the use of Alternate Claims and Modified Claims lead me to the conclusion these claims are a means of engaging in the cooperative task of explaining, elaborating and defending ideas. Furthermore, since creative controversy was not explicitly taught to these students, it is interesting that several of the groups none the less practiced it spontaneously. One might ask how much more they would engage in controversy if the groups were more cohesive and if conflict management skills were explicitly taught.

Finally, I believe this research shows that a qualitative case study approach is useful in understanding the nature of cooperative group problem solving. When I started this research I did not know what a systematic "fine-grained examination" of the argument co-construction process even looked like, let alone how I would go about it. Now, I am not only sure of what it looks like, but I believe this is a good example of how to do it. I have attempted to be very clear in my assumptions, methods, and techniques. It should be possible for someone to extend or translate the general approach to another context.

SUGGESTIONS FOR FUTURE QUALITATIVE AND QUANTITATIVE RESEARCH

Two important questions in any research are those of generalizability and repeatability. The very nature of a qualitative study makes broad generalizations tenuous and repetition difficult. It may be, however, possible to generalize or repeat the study in *similar contexts*. Such a context would be a course where the instructor and teaching assistants knew the basics of cooperative group problem solving but do not strictly follow all the structuring and management guidelines. However, I must agree unequivocally with Schofield that I have no desire "to engage in the relatively unexciting task of conducting a study designed specifically to replicate a previous one" (Schofield, 1990, p. 203). What I believe to be more fruitful is to *translate* or *extend* the study to similar contexts. The similar context would be a college physics course, either calculus-based or algebra-based, in which the Johnson model of cooperative learning was employed. Three possible studies come to mind.

First and foremost, it is our hypothesis that the problem-solving strategy seems to give these students a means to "talk physics." Given some of the less than desirable composition aspects of these groups (number, gender and performance mix), it is amazing to me as a physics teacher that they did as well as they did on these problems. Since the problem-solving strategy is itself a "construction" and provides an outline of the problem solution, the strategy may be partially responsible for the argument co-construction patterns. An interesting study would compare two courses using cooperative learning that are alike except for the use and non-use of the specific problem-solving strategy. One could compare the argument co-construction structures of groups in the two courses.

It would be possible to "control" for some of the "variables." Because much of what I found is intimately a part of the problem-solving strategy we use at the University of Minnesota and at Normandale Community College, it would be important to use the same strategy, or a very similar one. As I noted, the group management was not ideal. I would attempt to maintain stricter control over group composition, following the size, gender, and performance mix guidelines from our prior research (Heller and Hollabaugh, 1992). I believe it would be useful to have a larger number of groups solving the *same* problem. Ten groups (five from the course using the strategy, five from the non-using course) would be ideal, but perhaps not practical due to the costs of video equipment and operators. Using more groups solving the *same* problem helps control the “variable” of the problem itself. Although this is a concept from quantitative research, I believe it is useful to think about this “variable”. Although I didn’t find any qualitative “variability” associated with the problem type (e.g., dynamics or energy conservation), I think it would be better to “control” for it than to ignore it.

Second, if group cohesion indeed fosters creative controversy, then there should be more creative controversy in a more cohesive group. A way to test this idea would be to videotape two sets of groups. The first set of groups (preferably 10 in number) would be from early in the first term of a two-quarter or two-semester sequence course. These groups would be taped solving a problem in the second week of the groups’ existence. Then, near the end of the second term, groups could be formulated and kept the same for about three weeks. During the third week, the groups could solve a problem. It is almost always the case that by the end of the second term of a course, there are no more “new” combination of members in a cooperative group. Everyone has worked with everyone else by that time. Cohesion should be higher than at the beginning. In such a situation, I would expect to see more controversy and more spontaneous Alternate Claims in response to incorrect Claims.

Another means to foster group cohesion would be to specifically teach creative controversy skills. Providing this instruction should lead to more cohesion and hence more Alternate Claims. A means to test this would be to give a group problem, teach controversy skills, an then give another problem. More Alternate Claims should appear. One could even run this as a controlled, quantitative experiment where a control group did not receive instruction in creative controversy.

Third, I did not address the issue of conceptual change. Looking for misconceptions was not the purpose of this research. There are examples of incorrect usage of physics terminology by these groups. The comment of Brown and Palincsar (1989) about the necessity in the group to "explain, elaborate or defend" an idea is actually made in the context of their theorizing about what promotes *conceptual change*. If I wanted to look for evidence of conceptual change, I would select groups from early in an academic term when concepts like Newton's Laws of Motion are still a bit unclear and confusing to students. I'd probably give an inclined plane problem and see if that old common misconception of "the force making it go up the plane" surfaces and is corrected by the group process. Based on my experience as a teacher, out of ten groups, some are sure to get it right and some are sure to persist in the misconception.

Curriculum and Instruction Concerns

Although this research had a specific research goal, and very definite research questions, the ultimate goal of research in science education is to improve teaching and learning. I have several suggestions to make concerning the use of cooperative groups in physics problem solving. Some of these suggestions are based on results that support previous research and some are based on this contribution to science education.

Suggestions Supported by This Research

- Because the groups' Backings show a preference to model their solution after the professor, modeling the problem-solving strategy in class can be an effective means of fostering physics problem-solving skills. However, the instructor must be cautious that he or she models the "right stuff." For example, being consistent and thorough when drawing free-body diagrams is very important.
- Groups should be explicitly taught creative controversy skills. Because there is a prototype pattern (Group 4B, Type 1) in which there is *no* Modified Claim preceding an Alternate Claim and there are *no* additional Grounds, Warrants, and Backings supporting the Claim, it would be important to teach students to support all claims with Grounds, Warrants, and Backings.
- Co-construction should be promoted. This might be done by paying very close attention to group participation. Students might then participate more equally and fully in the group. An instructor could monitor groups as they work and intercede to draw in a "quiet" student. It also might be helpful to rotate roles mid-problem. In many of these 14 groups, the Recorder bore the major task of consensus checking. Rotating this role to another student might bring in other ideas. I would recommend this *only* as a technique to encourage equal participation and not recommend its universal use. Even though all students contribute, it can be important to encourage the student who feels his or her contribution is insignificant.
- Skeptical questioning and consensus checking should be overtly built into any problem solving strategy. An instuctor could promote this by asking to see intermediate steps before the group moves along. All the problems in this study were quantitative with numerical answers. My own experience, coupled with the importance of skeptical questioning and consensus checking in this study, suggests giving problems with algebraic answers might foster this in cooperative problem-solving groups.

Suggestions Supported by Previous Research and This Research

- Groups should be carefully managed in terms of gender, performance, and number of members. This agrees with prior research. I believe some of the dysfunction observed in some of these groups (e.g., 4C) could be avoided if the instructor becomes acquainted with the students personalities and intervenes in dysfunctional groups.
- Group processing, according to the Johnson model, improves group functioning. This should be a part of all problem-solving groups in order to foster group cohesion and functioning.
- The explicit problem-solving strategy seems to have helped these groups. Teaching problem solving should be an integral part of all physics courses at all levels of instruction.

Epilogue

In Chapter 1, I said we already know that cooperative physics problem-solving groups co-construct a superior problem solution that is not merely the work of the best individual in the group. What is was not known is *how* this occurs. That is, what was *not* well-understood is the sequence of behaviors and actions that lead to a superior product. Based on my research, the sequence of behaviors and actions are now better understood.

I began this dissertation with seven principles about good college instruction. Cooperative group problem solving is an example of those seven principles in action. This dissertation research has endeavored to be a good example of a qualitative case study approach to understanding the inner workings of these groups as they seek with their instructors to understand and appreciate the physical world. Like the 400 kg of lunar rock samples that yielded rich theories and new questions, these fourteen cooperative problem-solving groups have spawned more questions and shown new areas for research in physics education.

BIBLIOGRAPHY

Edmund J. Amidon and John B. Hough, eds. (1967), *Interaction Analysis: Theory, Research and Application*, Reading, Massachusetts: Addison-Wesley.

Larry L. Barker, Kathy J. Wahlers, Kittie W. Watson (1995), *Groups in Process*, 5th Edition, Boston: Allyn and Bacon.

Erwin P. Bettinghaus (1966), Structure and Argument, in *Perspectives on Argumentation*, Gerald R. Miller, ed., Chicago: Scott, Foresman and Company.

Wayne Brockriede and Douglas Ehninger (1960), Toulmin on Argument: An Interpretation and Application, *Quarterly Journal of Speech,* February, 1960, pp. 44-53.

Ann L. Brown and Annemarie S. Palincsar (1989), Guided, Cooperative Learning and Individual Knowledge Acquisition, *Knowing, Learning, and Instruction*, Lauren B. Resnick, ed., pp. 393-451, Hillsdale: Erlbaum Associates.

Brant R. Burleson (1979), On the Analysis and Criticism of Arguments: Some Theoretical and Methodological Considerations, *Journal of the American Forensic Association*, Vol. 15, Winter, 1979, pp. 137-147.

M. T. H. Chi, P. J. Feltovich, & Robert Glaser (1981), Categorization and Representation of Physics Problems by Experts and Novices, *Cognitive Science*, Vol. 5, pp. 121-152

Arthur W. Chickering and Zelda F. Gamson (1987), Seven Principles for Good Practice in Undergraduate Education, *American Association for Higher Education Bulletin*, March, 1987, pp. 3-7.

Louis Cohen and Lawrence Manion (1995), *Research Methods in Education*, Fourth Edition, New York: Routledge.

John W. Creswell (1994), *Research Design: Qualitative and Quantitative Approaches*, Thousand Oaks, California: Sage Publications, Inc.

Sara Delamont and David Hamilton (1984), Revisiting Classroom Research: A Continuing Cautionary Tale, in *Readings on Interaction in the Classroom*, Sara Delamont, ed., New York: Methuen, pp. 3-38.

Morton Deutsch (1973), *The Resolution of Conflict*, New Haven: Yale University Press.

Morton Deutsch (1965), *Theories in Social Psychology*, New York: Basic Books, Inc.

H. C. Dreyfus and S. E. Dreyfus (1986), Five Steps from Novice to Expert, in *Mind Over Machine*, New York: The Free Press, pp. 16-51.

Robert G. Fuller (1982), Solving Physics Problems-- How Do We Do It?, *Physics Today*, September, 1982, pp. 43-47, New York: American Institute of Physics.

Rex Gaskill (1995), Personal Communication, Normandale Community College.

Ronald N. Giere (1984), *Understanding Scientific Reasoning*, New York: Holt, Rinehart and Winston.

J. P. Goetz and M. D. LeCompte (1984), *Ethnography and Qualitative Design in Education Research*, Orlando: Academic Press.

Christina Gustafsson (1977), *Classroom Interaction: A Study of Pedagogical Roles in the Teaching Process*, Stockholm: MAP Gruppen.

Joan I. Heller and Frederick J. Reif (1984), Prescribing Effective Human Problem Solving Processes: Problem Descriptions in Physics, *Cognition and Instruction*, Vol. 1, No. 2, pp. 177-216, Hillsdale, New Jersey, Lawrence Erlbaum Associates.

Patricia Heller, Ronald Keith, and Scott Anderson (1992), Teaching Problem Solving Through Cooperative Grouping. Part 1: Group Versus Individual Problem Solving, *American Journal of Physics*, Vol. 60, No. 7, pp. 627-636.

Patricia Heller and Mark Hollabaugh (1992), Teaching Problem Solving Through Cooperative Grouping. Part 2: Designing Problems and Structuring Groups, *American Journal of Physics,* Vol. 60, No. 7, pp. 637-644.

Mark Hollabaugh (1993), *Cooperative Group Physics Problem Solving*, Invited Talk at Winter Meeting (New Orleans) of the American Association of Physics Teachers, January, 1993, *AAPT Announcer*, Vol. 22, December, 1992, p. 47.

B. Humphrey, Roger T. Johnson, and David W. Johnson (1982), Effects of Cooperative, Competitive, and Individualistic Learning on Students' Achievement in Science Class, *Journal of Research in Science Teaching*, pp. 351-356.

David W. Johnson and Frank P. Johnson (1987), *Joining Together*, Third Edition, Englewood Cliffs: Prentice-Hall.

David W. Johnson, and Roger T. Johnson, (1989), *Cooperation and Competition: Theory and Research*, Edina, Minnesota: Interaction Book Company.

David W. Johnson, and Roger T. Johnson, (1992), *Creative Controversy: Intellectual Challenge in the Classroom,* Edina, Minnesota: Interaction Book Company.

David W. Johnson, Roger T. Johnson and Karl A. Smith (1991), *Active Learning: Cooperation in the College Classroom*, Edina, Minnesota: Interaction Book Company.

David W. Johnson, Roger T. Johnson and Karl A. Smith (1991b), *Cooperative Learning: Increasing College Faculty Instructional Productivity*, ASHE-ERIC Higher Education Report No. 4, Washington, DC.: The George Washington University School of Education and Human Development.

Roger T. Johnson and David W. Johnson (1986), Action Research: Cooperative Learning in the Science Classroom, *Science and Children*, October, 1986, pp. 31-32.

Roger T. Johnson and David W. Johnson (1988), Cooperative Learning and the Gifted Science Student, in *Gifted Young in Science*, Paul F. Brandwein and A. Harry Passow, eds., Washington, DC: National Science Teachers Association, pp. 321-330.

Roger T. Johnson, David W. Johnson, and E. J. Holubec (1988), *Cooperation In The Classroom*, Edina, Minnesota: Interaction Book Company.

Jill H. Larkin (1979), Processing Information for Effective Problem Solving, *Engineering Education*, December, 1979, pp. 285-287.

J. Larkin, J. McDermott, D. P. Simon and H. Simon (1980), Expert and Novice Performance in Solving Physics Problems, *Science*, Vol. 208, pp. 1335-1342

Joseph A. Maxwell (1992), Understanding and Validity in Qualitative Research, *Harvard Education Review*, Vol. 62, No. 3, Fall, 1992, pp. 279-300.

Glen E. Mills (1968), *Reason in Controversy: On General Argumentation*, Second Edition, Boston: Allyn and Bacon.

Raymond S. Nickerson, David N. Perkins, and Edward E. Smith (1985), Schoenfeld's Heuristic Instruction, in *The Teaching of Thinking*, Hillsdale: L. Erlbaum Associates,. (pp. 195-200)

V. Paley (1981), *Wally's Stories*, Cambridge, Massachusetts: Harvard University Press.

C. Pontecorvo (1985), *Discussing for Reasoning: The Role of Argument in Knowledge Construction*, Paper presented at the European Association for Research on Learning and Instruction, Leuven, Belgium.

Richard D. Rieke and Malcom O. Sillars (1975), *Argumentation and the Decision Making Process*, New York: Wiley.

J.T. Sandefur and Alex A. Bressler (1971), Classroom Observation Systems in Preparing School Personnel, in *Interaction Analysis: Selected Papers*, Washington: Association of Teacher Educators, ERIC SP 004 979.

Alan H. Schoenfeld (1985), *Mathematical Problem Solving*, New York: Academic Press.

Alan H. Schoenfeld (1989), Teaching Mathematical Thinking and Problem Solving, in *Toward the Thinking Curriculum: Current Cognitive Research*, Lauren B. Resnick, ed., Washington: ASCD.

Janet Ward Schofield (1990), Increasing the Generalizability of Qualitative Research, in *Qualitative Inquiry in Education*, Elliot W. Eisner and Alan Peshkin, eds., New York: Teachers College, Columbia University.

Herbert A. Simon and Allen Newell (1970), Human Problem Solving: The State of the Theory in 1970, *American Psychologist*, pp. 145-159

Craig R. Smith and David M. Hunsaker (1972), *The Bases of Argument: Ideas in Conflict*, Indianapolis: Bobbs-Merrill Company.

Karl A. Smith (1985), Cooperative Learning Groups, in *Strategies for Active Teaching and Learning in University Classrooms*, S. Schomberg, ed., Minneapolis: University of Minnesota Press, pp. 18-26.

Karl A. Smith (1989), The Craft of Teaching. Cooperative Learning: An Active Learning Strategy, *IEEE Frontiers in Education Conference Proceedings*, pp. 188-192.

B. Othanel Smith and Milton O. Meux (1970), *A Study of the Logic of Teaching*, Urbana: University of Illinois Press.

B. Othanel Smith, Milton Meux, Jerrold Commbs, Graham Nuthall, Robert Precians (1967), *A Study of the Strategies of Teaching*, Urbana: University of Illinois.

Robert E. Stake (1988), Case Study Methods in Education Research, in *Complementary Methods for Research in Education*, Richard M. Jaeger, ed., Washington: AERA.

Gene Stanford and Albert E. Roark (1974), *Human Interaction in Education*, Boston: Allyn and Bacon, Inc.

Anselm L. Strauss (1987), *Qualitative Analysis for Social Scientists*, Cambridge: Cambridge University Press.

Kenneth Tobin (1990), Research on Science Laboratory Activities: In Pursuit of Better Questions and Answers to Improve Learning, *School Science and Mathematics*, Vol. 90, No. 5, pp. 403-418.

Kenneth Tobin, Deborah J. Tippins, and Alejandro José Gallard (1994), Research on Instructional Strategies for Teaching Science, in *Handbook of Research on Science Teaching and Learning*, Dorothy L. Gabel, ed., New York: Macmillan, pp. 45-93.

Wayne N. Thompson (1971), *Modern Argumentation and Debate*, New York: Harper and Row.

Stephen Toulmin (1958, 1990), *The Uses of Argument*, Cambridge: Cambridge University Press.

Stephen Toulmin and June Goodfield (1961), *The Fabric of the Heavens*, New York: Harper and Row.

Stephen Toulmin, Richard Rieke, and Allan Janik (1984), *An Introduction to Reasoning*, New York : Macmillan.

Jimmie D. Trent (1968), Toulmin Model of an Argument, *Quarterly Journal of Speech*, October, 1968; pp. 252-259.

Alan Van Heuvelen (1986), *Physics: A General Introduction*, 2nd Edition, Boston: Little, Brown, and Company.

Charles Arthur Willard (1976), On the Utility of Descriptive Diagrams for the Analysis and Criticism of Arguments, *Communications Monographs*, Vol. 43, November, 1976, pp. 308-319.

Harry F. Wolcott (1990), On Seeking-- and Rejecting-- Validity in Qualitative Research, in *Qualitative Inquiry in Education*, Elliot W. Eisner and Alan Peshkin, eds., New York: Teachers College, Columbia University.

APPENDIX A

GLOSSARY

Just like physics research, research in cooperative learning and problem solving has specific terminology that may have a different meaning in this context. For that reason, a brief glossary is provided of those terms and concepts that recur frequently in this dissertation. Throughout the text of the dissertation, words defined in this glossary will appear in **boldfaced** font the first time the term is introduced. The reader may wish to refer back to this section when encountering subsequent uses of theses terms. Although some terms may have different meanings in other contexts, these are the operational definitions for this research.

Action research: A research model in social psychology in which theory and practice interact. Theory informs practice and practice informs theory. Kurt Lewin was the principal advocate of this model.

Active learning: Any learning strategy that actively involves students in their own learning process. Cooperative learning is one active learning strategy. Typically, students in a lecture hall are not engaged in active learning.

Argument Construction: The process of "building" an hypothesis by using a set of heuristics or other normative rules. Co-construction occurs when two or more people collaborate on the argument construction.

Case study: A qualitative research method in which the researcher explores a single entity, process, or phenomenon, and uses a variety of data collection tools including qualitative descriptions and records (e.g., video or audio tapes).

Cathexis: Concentration of emotional energy on an object or idea.

Cognitive conflict occurs when a student is presented with *seemingly* opposing viewpoints, ideas, concepts, or information.

Collaborative Skills: One of the five elements of cooperative learning. Collaborative skills encourages leadership, trust, communication, conflict-management, and decision-making.

Cooperative learning: An active learning strategy that assigns students to work groups.

Episode: A unit of analysis consisting of a conceptually unified series of statements by a members of a group.

Epistemic: Of, relating to, or involving knowledge; cognitive.

Expert: An advanced problem solver, typically a physics professor or graduate student. Experts use higher order skills in solving problems and look more at a problem's conceptual basis as opposed to the novice.

Face-to-face Interaction: One of the five elements of cooperative learning. Face-to-face Interaction promotes students' support for one another to learn. It is necessary to have a classroom where students can physically face each other.

Force-vector Diagram: A diagram that follows the drawing of a free-body diagram and shows all the forces acting at a point or on an object. The vectors are usually resolved into components on a Cartesian coordinate system.

Free-body diagram: A diagram showing all the forces acting on an isolated body. Free-body diagrams are essential to solving any physics problem involving forces and interactions.

Group Processing: One of the five elements of cooperative learning. Group Processing involves an evaluation by the participants of their group: What they did well and what they could do better the next time to improve the functioning of the group.

Heuristic: A usually speculative formulation serving as a guide in the investigation or solution of a problem; an educational method in which learning takes place through discoveries that result from investigations made by the student; a problem-solving technique in which the most appropriate solution of several found by alternative methods is selected at successive stages of a program or strategy for use in the next step of the program or strategy.

Individual Accountability: One of the five elements of cooperative learning. Individual Accountability requires the instructor to assess each person's performance by asking questions randomly of individuals and giving examinations.

Information processing model: A model of human reasoning and problem solving that likens the mind to a computer that processes inputs and outputs.

Interaction: Any verbal, written, or non-verbal exchange between any two people in a group.

Joint construction: Students jointly create an argument or a problem solution, for example, by systematically arranging ideas or concepts.

Novice: A beginning problem solver who focused on surface features of a problem and frequently utilizes a formulaic approach to problem solving.

Physics Description: A qualitative analysis of a physics problem that involves translating a literal picture into a diagram which gives only the essential information for a mathematical solution; defining a symbol for every important physics variable on the diagram; drawing a coordinate system; drawing motion diagrams, specifying the objects' velocity and acceleration at definite positions and times, drawing idealized, **free-body**, and force diagrams; when using conservation principles, drawing "before", "transfer", and "after" diagrams to show how the system changes; giving the value for each physics variable labeled on the diagram, or specifying that it is unknown; declaring a **target variable**; listing mathematical expressions which use the principles, relationships and constraints to relate the physics variables from the diagrams.

Positive Interdependence: One of the five elements of cooperative learning. Positive interdependence links students together so that their success in a course is dependent on one another. Group members work together, striving for consensus on goals, problem solving strategies and answers.

Reconceptualization: The process of reformulating an idea following the input of new information.

Target variable: The unknown variable quantity in a problem.

Toulmin's Argument Structure: An assertion of fact is a **claim**, that is, a statement of something as a fact or an assertion of truth. **Grounds** (or **data**) are the particulars of a situation that support the **claim**... In many argumentative contexts, one never makes explicit just how the grounds support the claim. A **warrant** is a general rule connecting particular grounds to their implications. A warrant requires support, such support is called a **backing**. The appropriate backing for a warrant differs from field to field. **Modality** refers to qualifiers that may be present such as "chances are." **Rebuttal** refers not to the response of an adversary, but to something the arguer may include and acknowledge: exceptional conditions under which the usually sound warrant does not hold.

Triangulation: A research technique that uses two or more data collection methods to study some phenomena or process. The term originates in navigation where two bearings are used to locate one's position.

APPENDIX B

THE SIX PROBLEMS

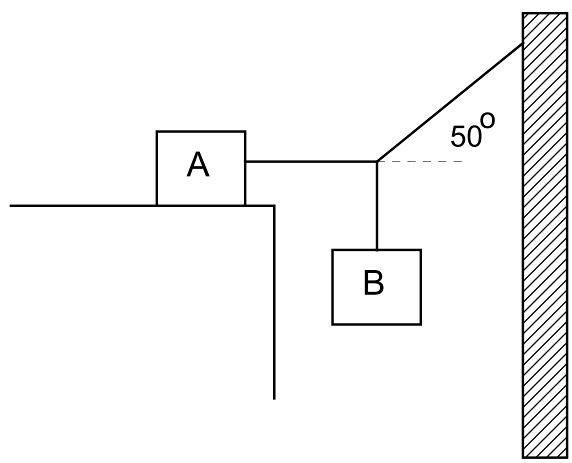
This Appendix contains the six problems solved by the 14 groups. Figure 2-3 is reproduced here for easy reference to the principal ideas of the problems.

Problem	Problem Title	Problem Goal	Applicable Physics
2	Toy Train	Finding the tension in strings connecting the cars of a toy train.	Newton's Second and Third Laws, Free-body diagrams.
3	Equilibrium	Finding the maximum weight for which a system will remain in equilibrium.	Newton's Second and Third Laws, Free-body diagrams, Frictional forces.
4	At the Gasthaus	Finding the forces acting on a suspended sign.	Newton's Second and Third Laws, Free-body diagrams, Torque.
5	Space Cannon, Inc.	Finding the launch velocity necessary to place a probe in orbit at an altitude of 900 km.	Conservation of Energy, gravitational potential energy.
6	Fahrenheit 451	Finding the temperature change in a container of water on a heater.	Conservation of Energy, temperature conversions, calorimetry.
7	A Quick Lift	Finding the time and cost for an elevator trip.	Conservation of Energy, power, Ohm's Law

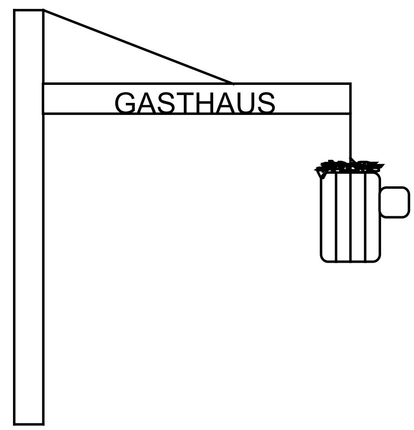
Figure 2-3. CHARACTERISTICS OF PROBLEMS

Problem 2, Toy Train: A small toy train consists of one locomotive and three cars. The car behind the locomotive and the lst car have a mass of 100 grams each, while tghe car in the middle is larger and has a mass of 250 grams. When you unpack the train the information sheet says that the locomotive will pull with a constant force. To impress your little sister (who is still in high school) with your new knowledge of physics, you claim to be able to calculate the tension in each of the three cables connecting the four parts of the train by making the following measurements: The locomotive is 10 cm long while the other cars are all 8 cm long. As your sister starts the trainb, you concentrate just on the last car and you measure that it moves 1.5 meters during the first 4 seconds. All the this motion is along a straight stretch at the beginning of the track. [Kinematics equations are then given as useful information.]

Problem 3, Equilibrium: Here is most of a problem conception [i.e., focus; in an earlier version of the problem-solving strategy, the focus step was referred to as the Problem Conception.]. Please do a physics description and execute it. Mass of block A = 10 kg, coefficient of static friction between table and block, 0.30. Question: What is the maximum weight, W, for which the system will just remain in equilibrium? [An outline of the problem-solving strategy is then given.]



Problem 4, At the Gasthaus: Above the entrance door of an old German "GASTHAUS" hangs a sign. A 200 N metal beer mug hangs at the end of a 3 meter long strut that is attached to the wall by a hinge. The weight of the strut is 100 N. A support cable is attached to the strut at a point 2 meters from the wall and makes a 30° angle with the strut. Find all the forces acting on the strut. Useful information: $\sum F = 0$ and $\sum \tau = 0$. [The following diagram was also given.]



Problem 5, Space Cannon, Inc.: You have been invited by your new employer, Space Cannon, Inc., to work on a new space launch facility: Instead of using big rockets to carry payloads aloft, small probes are to be shot into space using gigantic cannons. First, you are asked to figure out how fast a small particle detector must leave the cannon barrel to be placed in orbit 900 km above the earth. After that, your employer wants to know the minimum initial speed of the same device would be launched to the planet Mars. To make your jobv a little easier, you are allowed to neglect air friction.

Problem 6, Fahrenheit 451: A few years ago, the movie, *Fahrenheit 451* starring Oscar Werner, was shown on TV. If a physicist had made the movie, the title probably would have been *Celsius X* or *Kelvin Y*. What are X and Y? Please derive your answer carefully uisng the information below:

$$212\ °F = 100\ °C = 373\ K$$
$$32\ °F = 0\ °C = 273\ K$$

What is absolute zero on the Fahrenheit scale? Problem: Now suppose you are given a burner that transfers 80% of the heat form the gburning object to whatever is in the reservoir on top of the burner. If burning one page of a book releases one calorie of heat, how much will the temperature of 180 grams of water rise if you burn the book *Fahrenheit 451* (about 500 pages) in your burner? 1 cal = 4.18 joules; C_{water} = 1 cal/g -°C.

Problem 7, A Quick Lift: You are working with a company that has the contract to design a new, 700-foot high, 50-story office building in Minneapolis. Your boss suddenly bursts into your office. She has been talking with an engineer who told her that when the elevator is operating at maximum speed, it would take the 6500-lb loaded elevator one minute to rise 20 stories. She thinks this is too long a time for these busy executives to spend in an elevator after returning from lunch at the Minneapolis Athletic Club. She wants you to buy a bigger power supply for the elevator. You look up the specifications for the new supply and find that it is the same as the old one except that it operates at twice the voltage. Your boss's assistant argues that the operating expenses of the new power supply will be much more than the old one. Your boss wants you to determine if this is correct. You estimate that while the elevator runs at maximum speed, the whole system, including the power supply, is 60% efficient. The cost of electricity is \$0.06 per kilowatt hour (commercial rate).

APPENDIX C

DETERMINING A PROTOTYPE EPISODE

This Appendix contains the flowcharts and corresponding transcripts for Group 4D. To draw the Group 4D prototype episode, the flowcharts were laid side by side and common features noted using the following procedure. Episodes that contained numerous digressions or off-task chatter were omitted (Episodes 3-5 and 12-14, during which the Teaching Assistant interrupted the entire class or spoke individually to this group). For Group 4D, five of the remaining seven episodes began with a Claim, so that was the first symbol drawn on the prototype. This group preferred to support their Claims with Warrants, then Backings, and then Ground. Hence, the prototype flowchart shows Warrants and Backings followed by Grounds. This group uses an exceptionally large number of Warrants, but many of them are multiple Warrants by one person in one sentence. These longer sentences were split into smaller statements when the individual components all presented unique ideas. In other words ST, in particular, has a tendency to include multiple Grounds, Warrants, and Backings in one utterance. The most common type of support statement was an Acknowledgment statement and thus that symbol links the Backing and the Grounds symbols. While it is true Group 4D uses a *few* Modified Claims (Episodes 6 and 9), ST states them all. Modified Claims and Alternate Claims are *not* typical of this group. The Group 4D episodes in this appendix are in chronological order. The flowchart follows each transcript excerpt. Group 4D's prototype is reproduced in Appendix D.

11. CB OK, what it says. It says that the uniform strut is 100 Newtons. Oh, wait, wait...that the beer mug is 200 Newtons. Could we say that this [tension] is, then?	G	Data from the problem statement.
12. ME The tension in here is 200 Newtons.	W	The 200 N is an implicit G, repeating 11. That this G gives rise to a tension is a W.
13. ST (unintelligible)		
14. DB 200 Newtons, OK. And, uhh...	Ak	
15. ST There's a tension here, this one.	R	
16. ME Yep. So this weight should be coming down directly here, about midway. Right here.	C	Physics claim. This is a good example where G and W lead to a C.

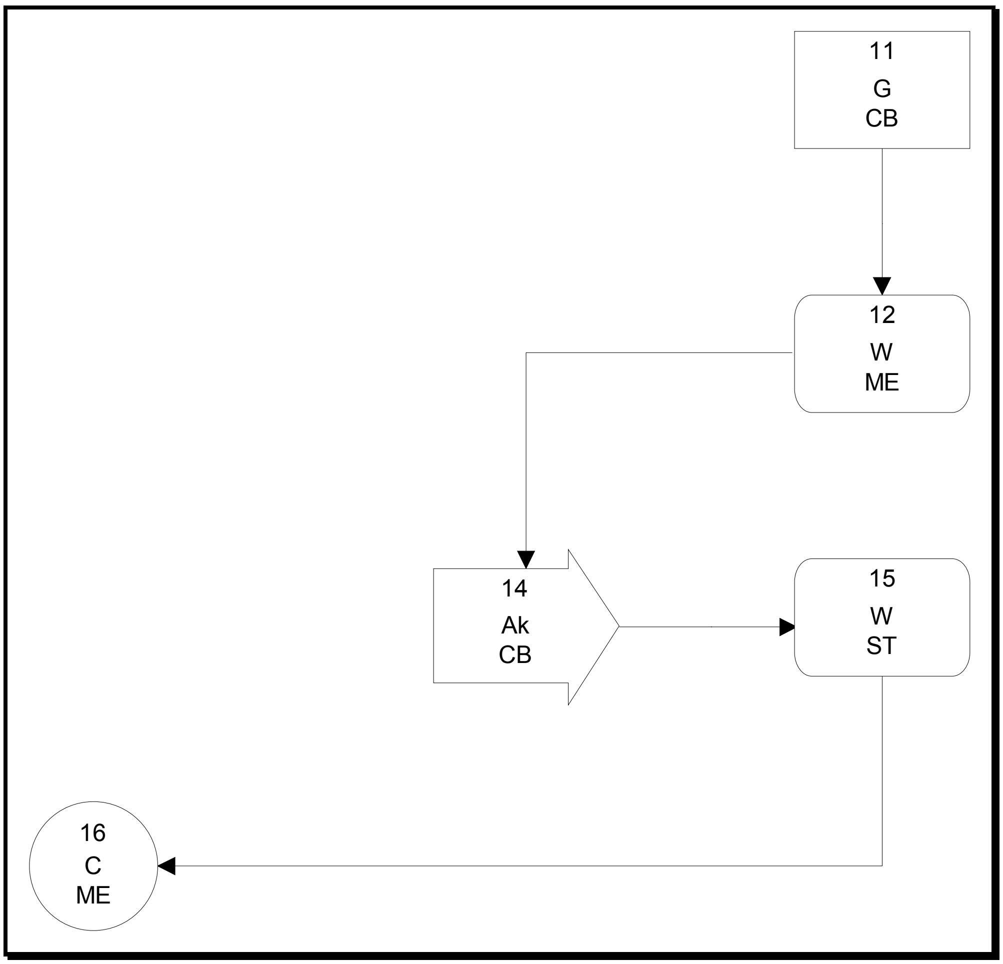


Figure C-1. Group 4D, Episode 2, lines 11-16

36. ME Do we have another tension here? Yes, we do.	C	
37. ST Beer mug. This is connected to this. This is an angle, 30 degrees. And let's see, one of these is 2 meters...2 meters...	G G	
37B. OK...then we, the question is...what are all of the unknown forces exerted on the strut.	MC	
38. ME Is there going to be, uhh, friction force?	RQC	
38B. (ST shakes head)	MC	Implicit Claim.
38C. (ME) Nope. Is there going to be a normal force?	Ak RQC	
39. ST Nope.	MC	
40. ME You sure?	RQSp	
41. ST I'm positive.	Sp	
42. ME What about the wall?	MC	There's a force from the Wall is her C in statement form
43. ST I remember it from yesterday. No, because this is hinged, it can move. That's what he said yesterday, it doesn't...	W B	
44. ME The normal force.	Ak	
45. ST There's, uh, uhh.	Ak	
46. ME OK.	Ak	

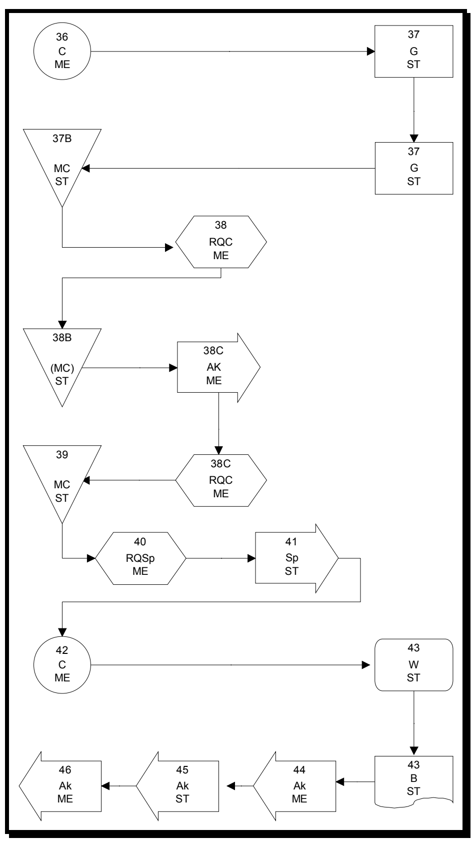


Figure C-2. Group 4D, Episode 6, lines 36-46

57. ST He had...OK, there was a tension. He had a tension going here.	C B	
58. ME Uh, huh.	Ak	
59. ST And it was broke into two parts like this.	B W	(Implicit backing)
60. ME Uh, huh. Sure.	Ak	
61. ST And then he said there was another one that was either going up or down. There was another force exerting because it had to balance this force. There was no force.	B W	ST frequently uses a B as a preface to a W.

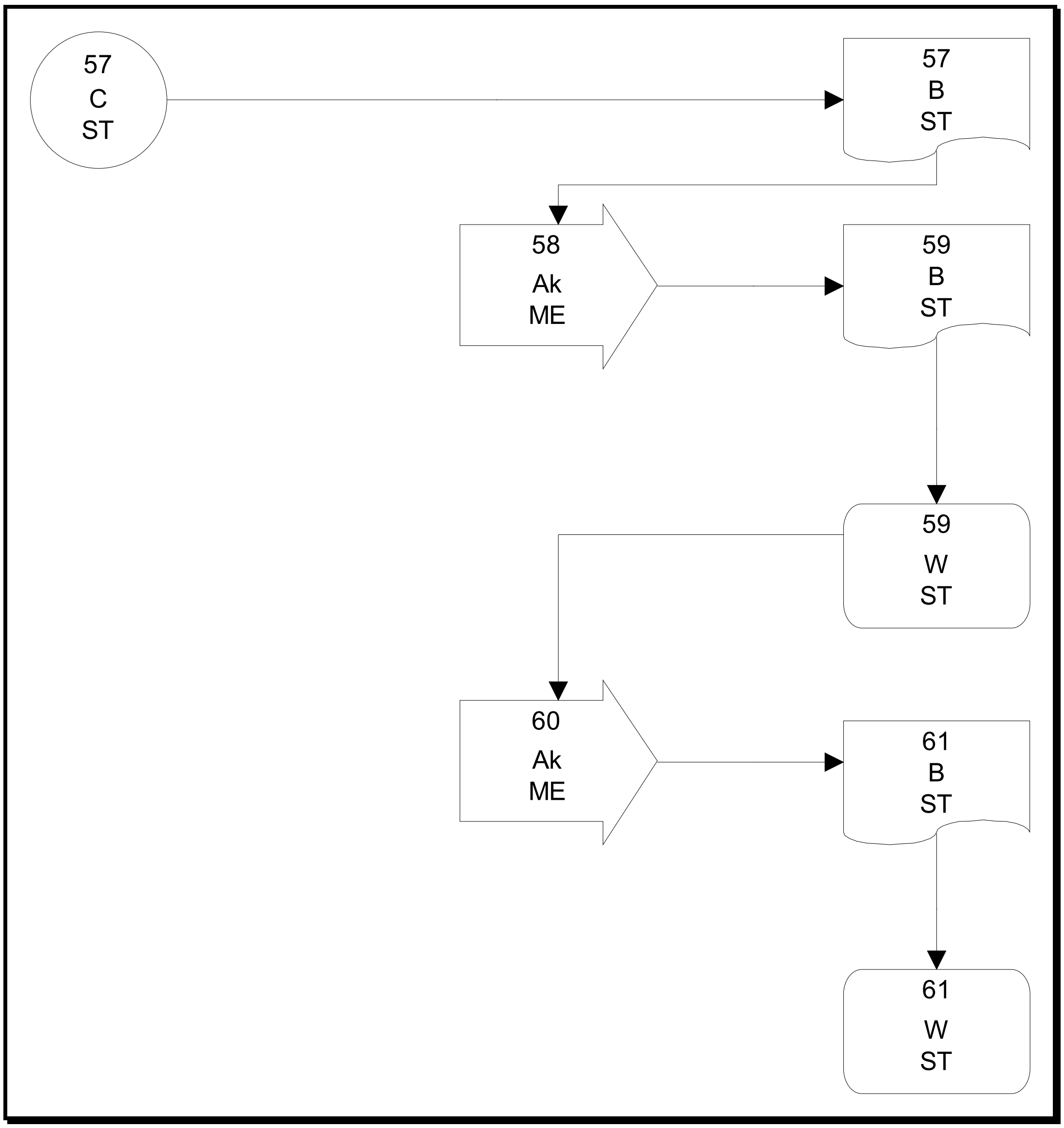


Figure C-3. Group 4D, Episode 8, lines 57-61

62. ME Yeah, it [the tension] would have to balance this component, right?	C	ME frequently states her claims in question form.
63. ST Uh, huh. Yeah.	Ak	
64. ME Acting on the wall.	W	
65. ST So there's one going this way and one going this way.	MC	Modifies 62.
66. ME Whoa, what the heck was that?	RQCl	
67. ST Because, to break it into the, into the...	Cl	
68. CB Components?	Cl	
69. ST Components, yeah.	Sp	
70. ME The normal force.	W	
71. CB So where does this one come from? [points at diagram]	RQCl	
72. ST This is another force that the wall is acting on, this. So it balances, so it stays there.	MC	Modifies 62.
73. ME Yep, so it doesn't go crashing through, crashing through the wall.	W	
74. ST Yeah, so it doesn't go through the wall or, if it's not...going out this way.	W	

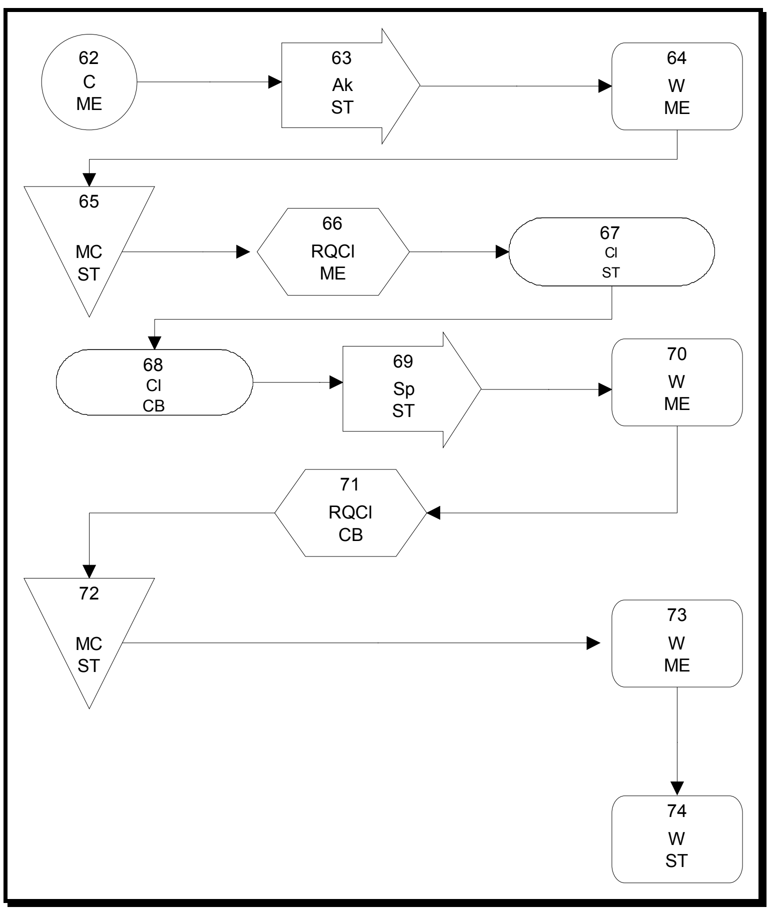


Figure C-4. Group 4D, Episode 9, lines 62-74

75. ME But they're in equilibrium. So really, the only component we're interested in is this one. This one is balanced, that one's balanced.	W C	Claim - one component Warrant - Equilibrium means they are balanced.
76. ST OK, this, these two are supposed to balance each other.	W	Implicit warrant using the second law.
77. ME Uh, huh.	Ak	
78. ST And this one and this one are supposed to balance the 300 Newtons. The weight of these two.	W G	Implicit warrant using the second law. G = 300 Newtons (200+100)

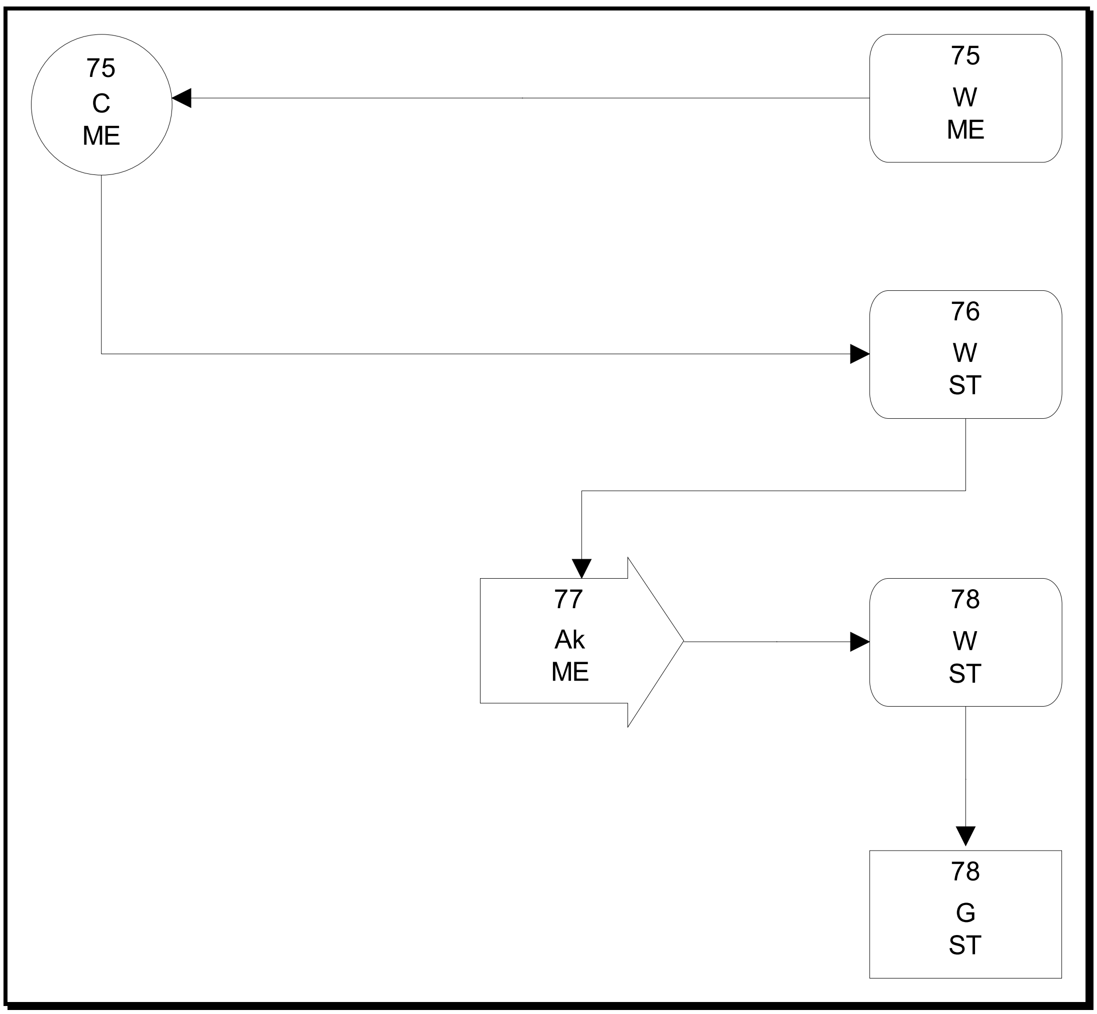


Figure C-5. Group 4D, Episode 10, lines 75-78

79. ME OK, now where's your angle for this normal force? Is it the same as this one?	W	
80. ST Umm, no, it's a totally different angle. [CB/ME look shocked] I'm serious. This is exactly how he did it yesterday.	C B	Backing from class lecture.
81. ME OK, think, think, think.	En	Encourages the group
82. ST This one was called theta, and this one...	W B	Uses generally accepted notation and mimics the lecture.
83. ME Yeah.	Ak	
84. ST ...was called alpha.	W	Uses generally accepted notation and mimics the lecture.
85. ME OK.	Ak	
86. ST Oh, shit.	X	Although said in a sense of futility, this could be seen as a skeptic statement. (Omitted)
87. ME Would it be 60 degrees?	RQCl	
88. ST He never completed the whole problem yesterday. He just cut it out the whole entire time.	Cl B	

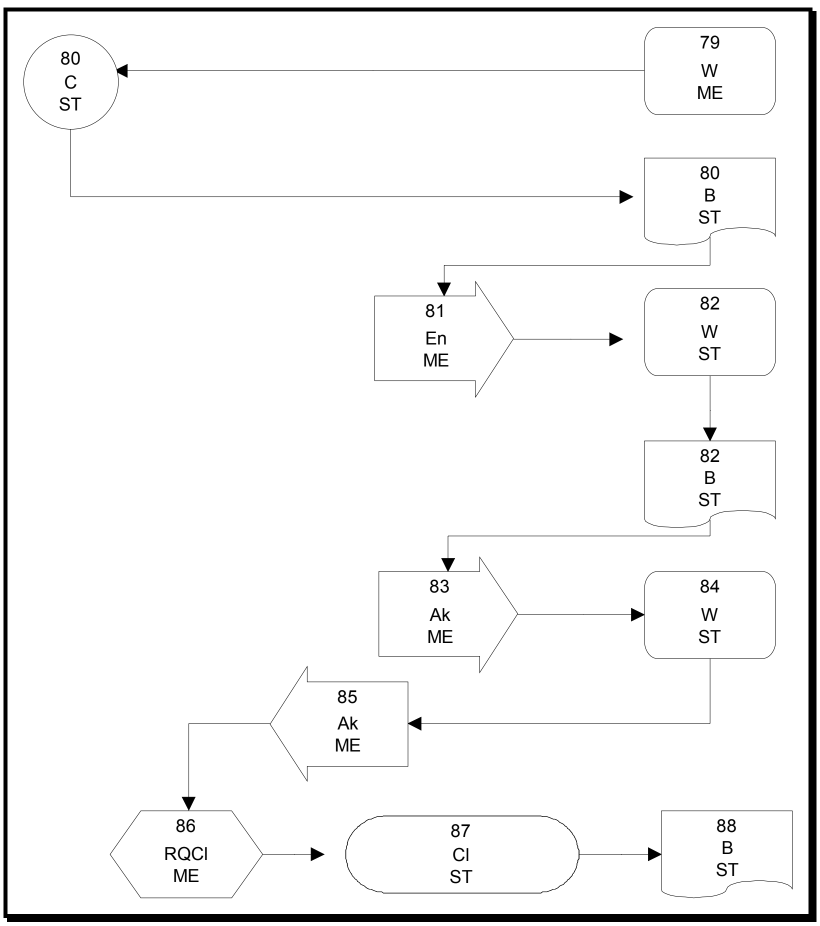


Figure C-6. Group 4D, Episode 11, lines 79-88

112. CB OK, you know how. If you've done any of the problems in the book, you know where they tell you to draw the little dotted line through where the force would go, you know what I mean?	B W	
113. ME Hmm.	Ak	
114. CB And then from, from this point, which would be the origin. You'd draw the...you know what I mean, this line, so it would be a ninety degree angle. Can we do that, anyhow? Know what I'm talking about?	W	
115. ME Well that's...that's what I was thinking. It would be 60 degrees. But we'll just call it alpha. Are you looking at this angle?	G RQCl	
116. CB Yeah.	Ak	
117. ME It's going to be sixty degrees, because 60 and 30 is ninety.	G	
118. ST This is if you count this, this is 30, this one's 30, this one's 60, this is 90.	C	
119. CB So, see, tau equals l times f.	Cl	
120. ST Alpha, this one's alpha here.	Cl	
121. ME It would be the same. This angle should be the same as this one. But we don't have to worry about it, I don't think. Let's just call it alpha and see what we get there. So let's start writing down the sum of forces.	W C	W = the angle is the same. This is a new claim since it neither challenges or modifies 118.

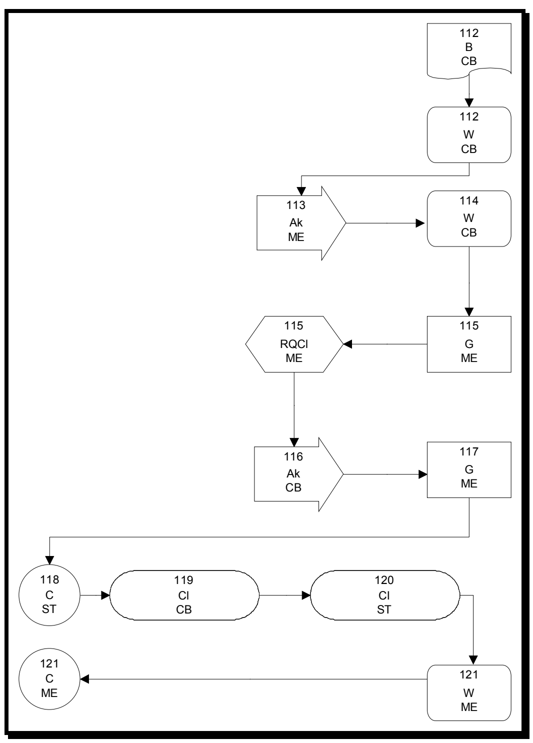


Figure C-7. Group 4D, Episode 15, lines 112-121

APPENDIX D

PROTOTYPE EPISODE FLOWCHARTS

This Appendix contains the 16 prototypical episode flowcharts for the 14 groups. (The flowcharts were draw with Micrografx® ABC FlowCharter® 3.0 and imported into the Microsoft® Word for Windows document.) Following each flowchart is a brief discussion of their typical argument pattern as it is seen in their prototype. For quick reference, Figure 3-4 is reproduced here. Dashed lines show how statements refer back to what was said previously if the reference is non-sequential.

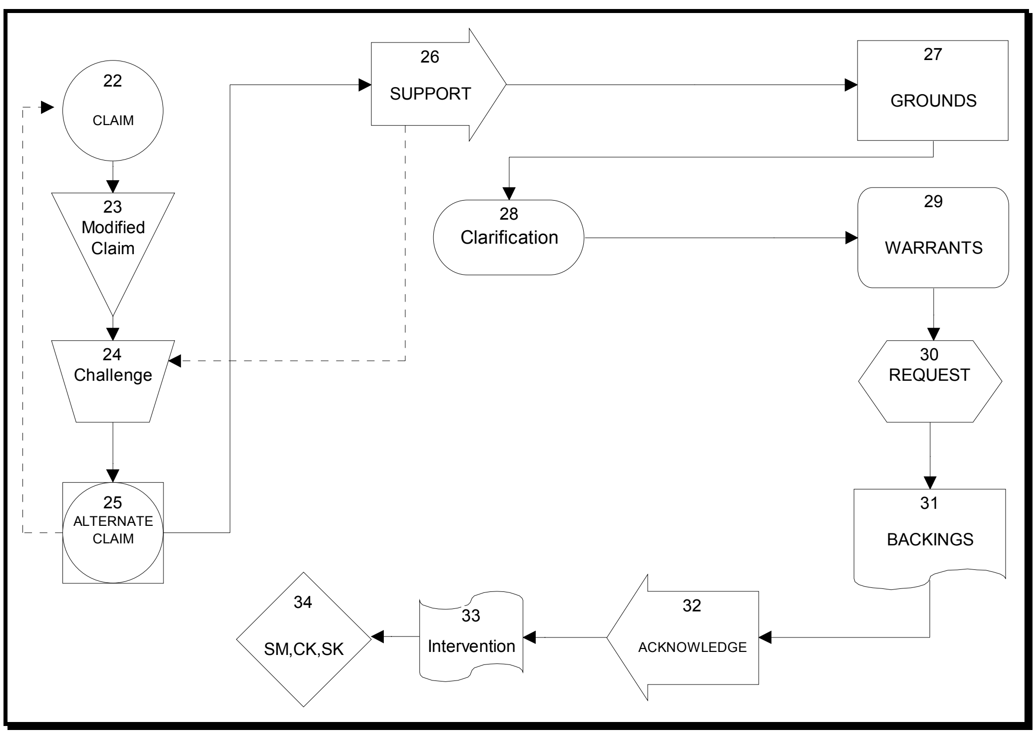


Figure 3-4. Key to Revised Flowchart Symbols.

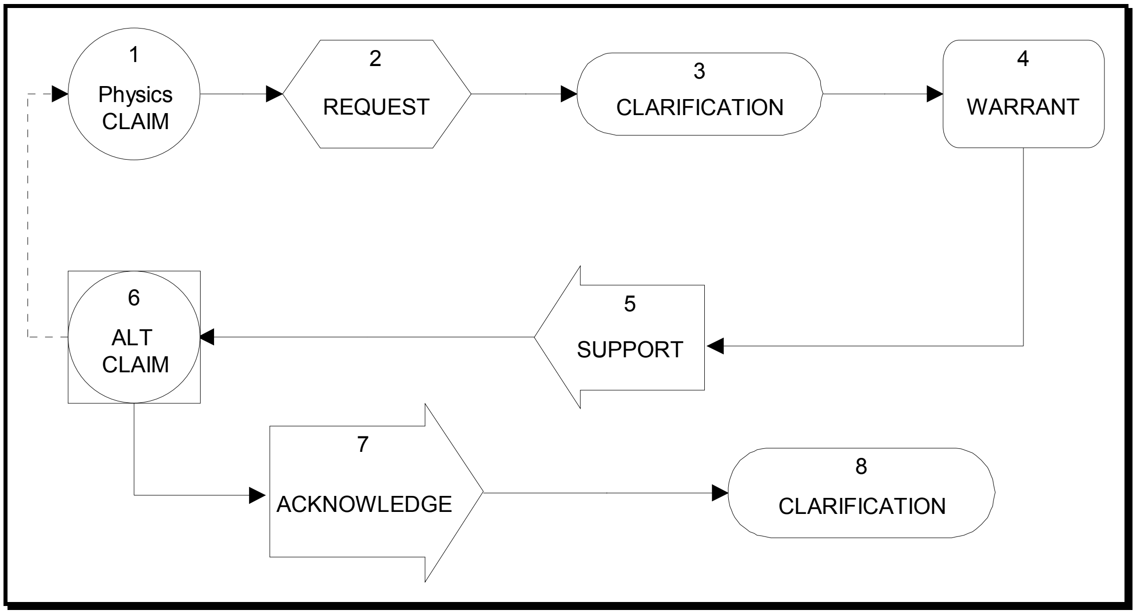


Figure D-1. Group 2A Prototype Episode.

Group 2A sometimes (3 out of 8 episodes) began an episode with a claim based solely on a step of the problem-solving strategy.

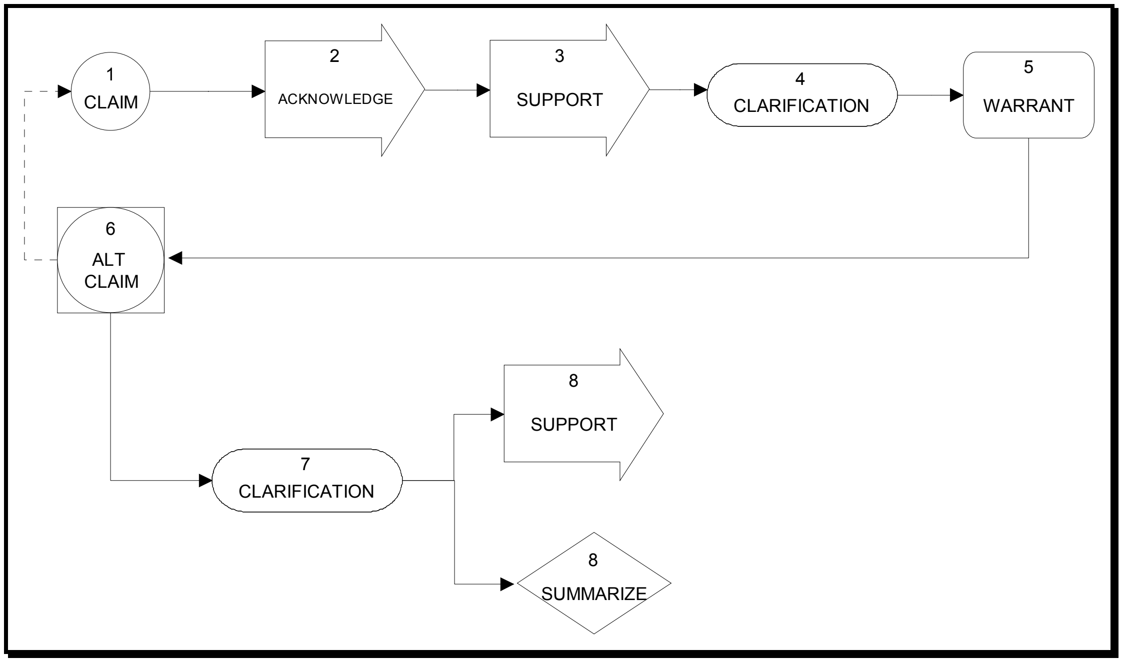


Figure D-2. Group 2B Prototype Episode.

The branch at the end of Group 2B's prototype indicates they occassionally summarize their ideas, but just as frequently merely voice support for the Alternate Claim and its subsequent clarification.

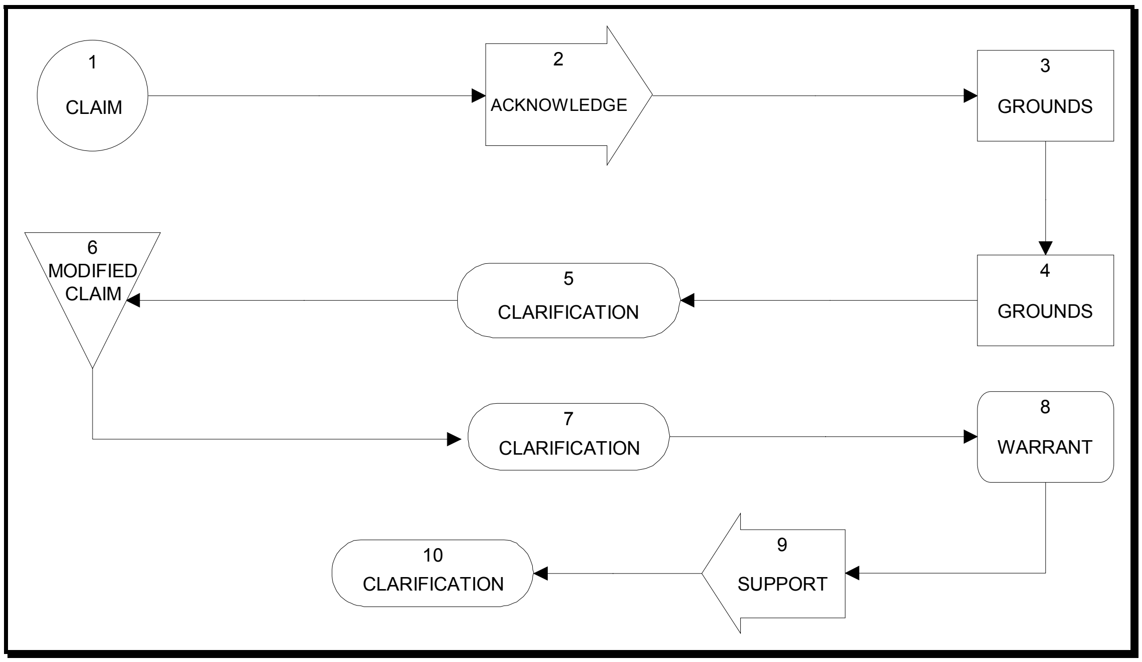


Figure D-3. Group 2D Prototype Episode.

One person in Group 2D, LS, was responsible for most of the Claims and Modified Claims. Many of LS's Modified Claims follow original Claims he also made.

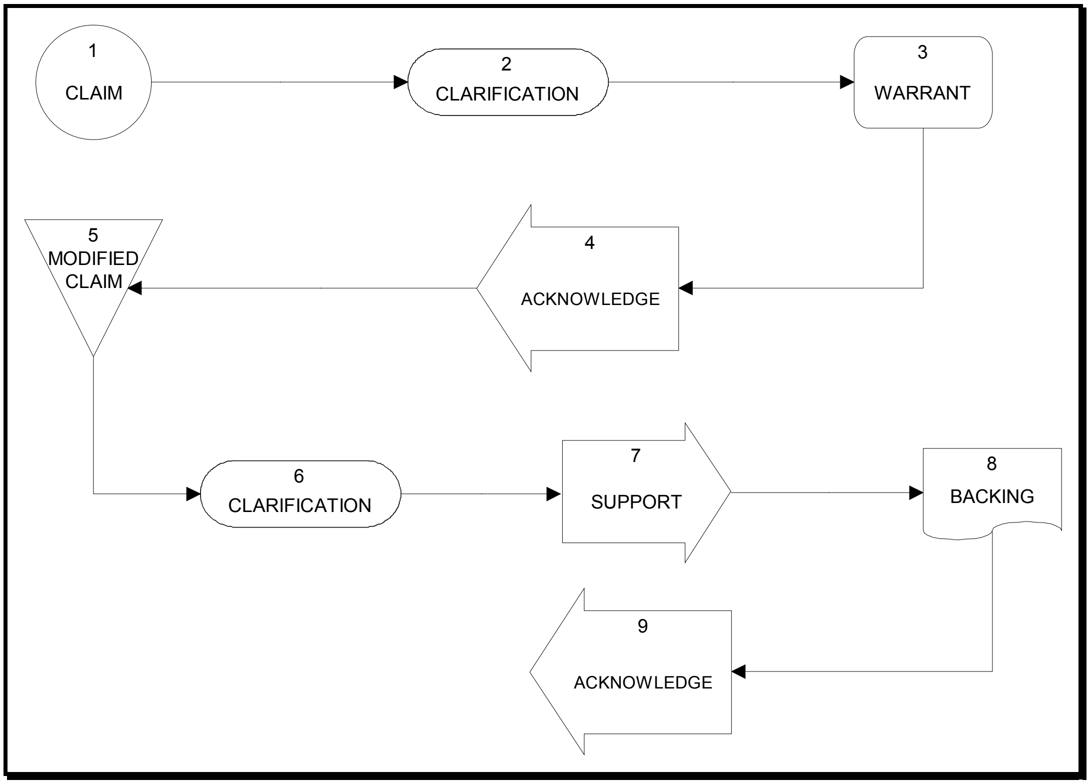


Figure D-4. Group 3A Prototype Episode.

Although Group 3A does use two Alternate Claims in the eight episodes flowcharted, the Alternate Claim did not seem to be a natural argument form for them. Hence the Alternate Claim symbol does not appear on their prototype episode.

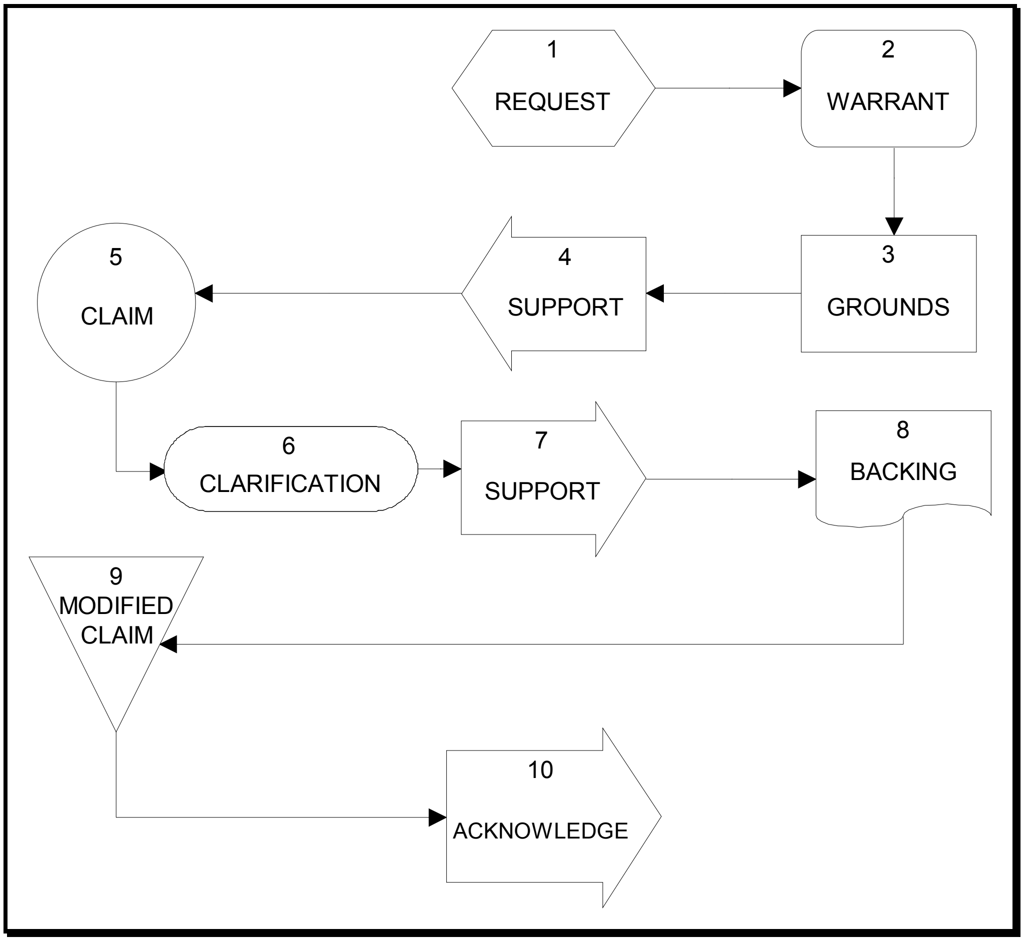


Figure D-5. Group 3B Prototype Episode.

Most (6 of 9) of the original Claims are made by group member CH, yet most of the Modified Claims (5 of 9) are made by member JC. The intervening support statements function to "set up" JC to make the Modified Claim.

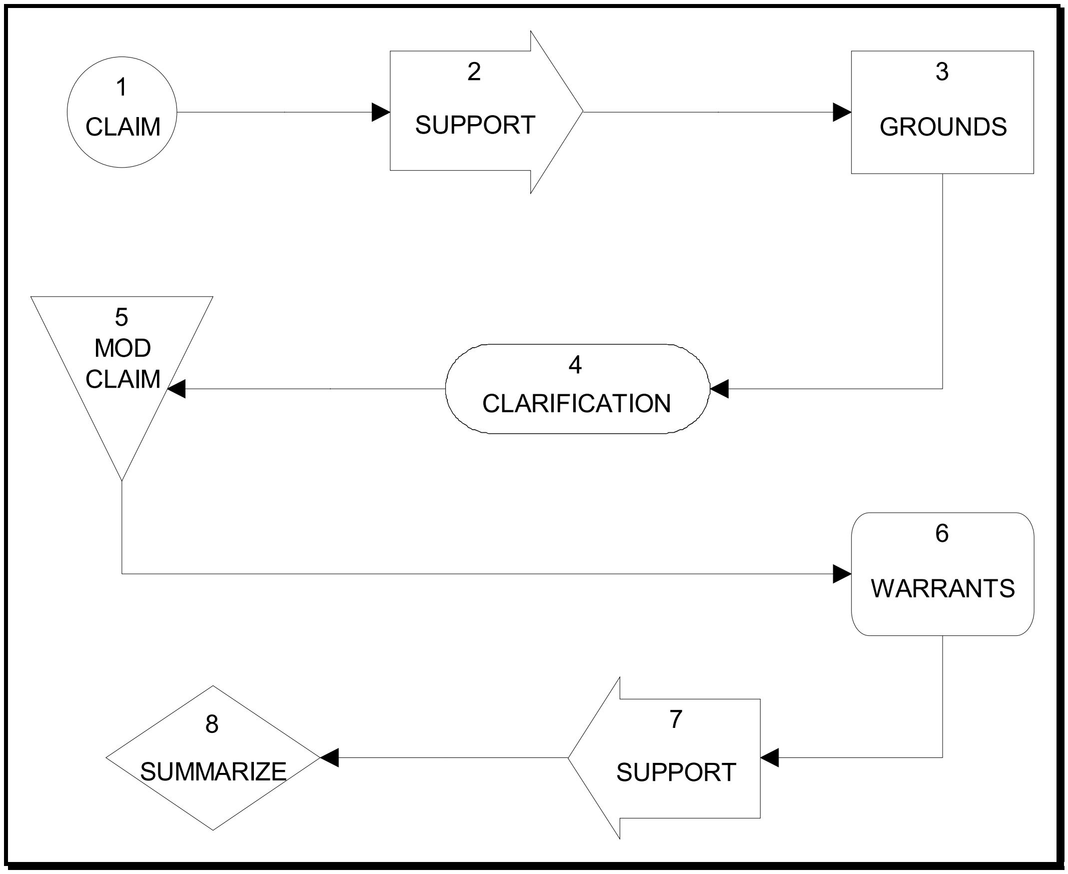


Figure D-6. Group 4A Prototype Episode.

Group 4A uses many Modified Claims. While member MK makes most of the original Claims (6 of 11), member MR makes most of the Modified Claims (5 of 7) as well as their solo Alternate Claim. The most common and noticable characteristic of this group is the summarizing at the end of each episode.

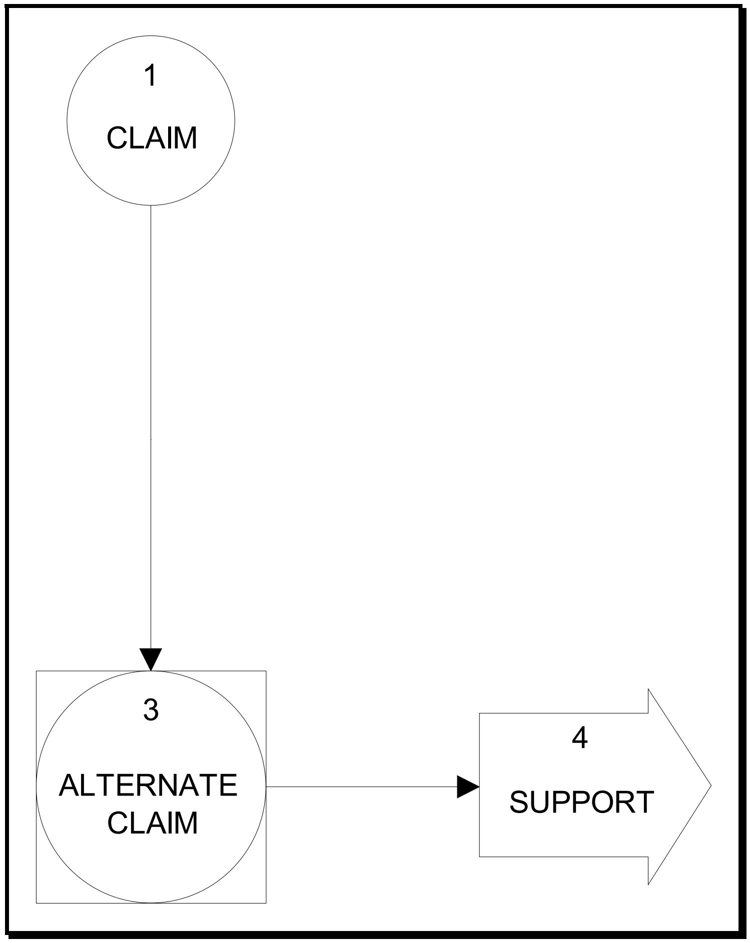


Figure D-7. Group 4B Prototype Episode Type 1.

Group 4B exhibited two patterns in their argument co-construction. In *both* patterns, they used Alternate Claims. In this first pattern, an Alternate Claim follows an original Claim with little or no elaboration.

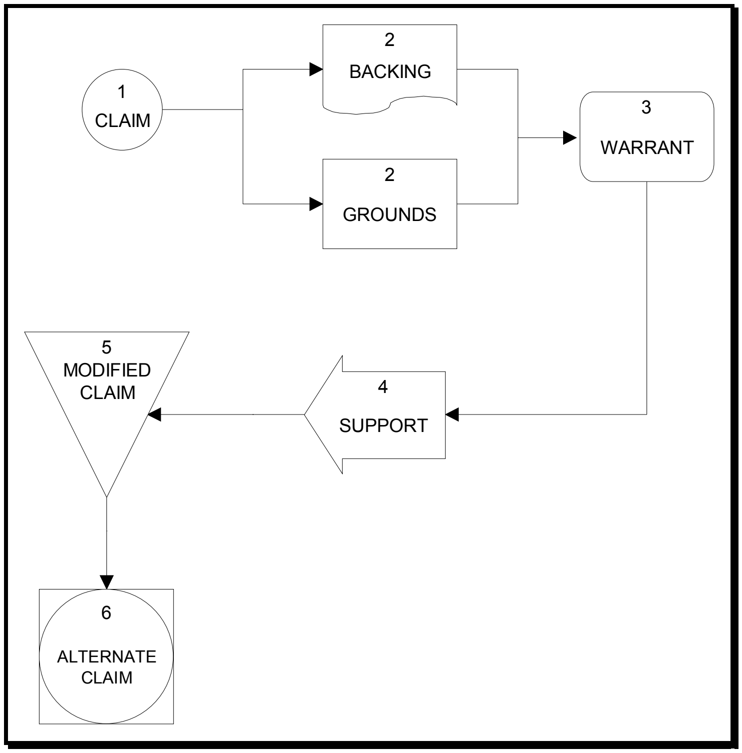


Figure D-8. Group 4B Prototype Episode Type 2.

In this second pattern, an Alternate Claim follows an original Claim with siginficant elaboration in the the form of a Modified Claim and Grounds, Warrants, and Backings. This group tended to follow “fuzzy” Claims with Modified Claims (6 of 10 fuzzy claims), and they followed incorrect claims solely with Alternate Claims (2 of 2).

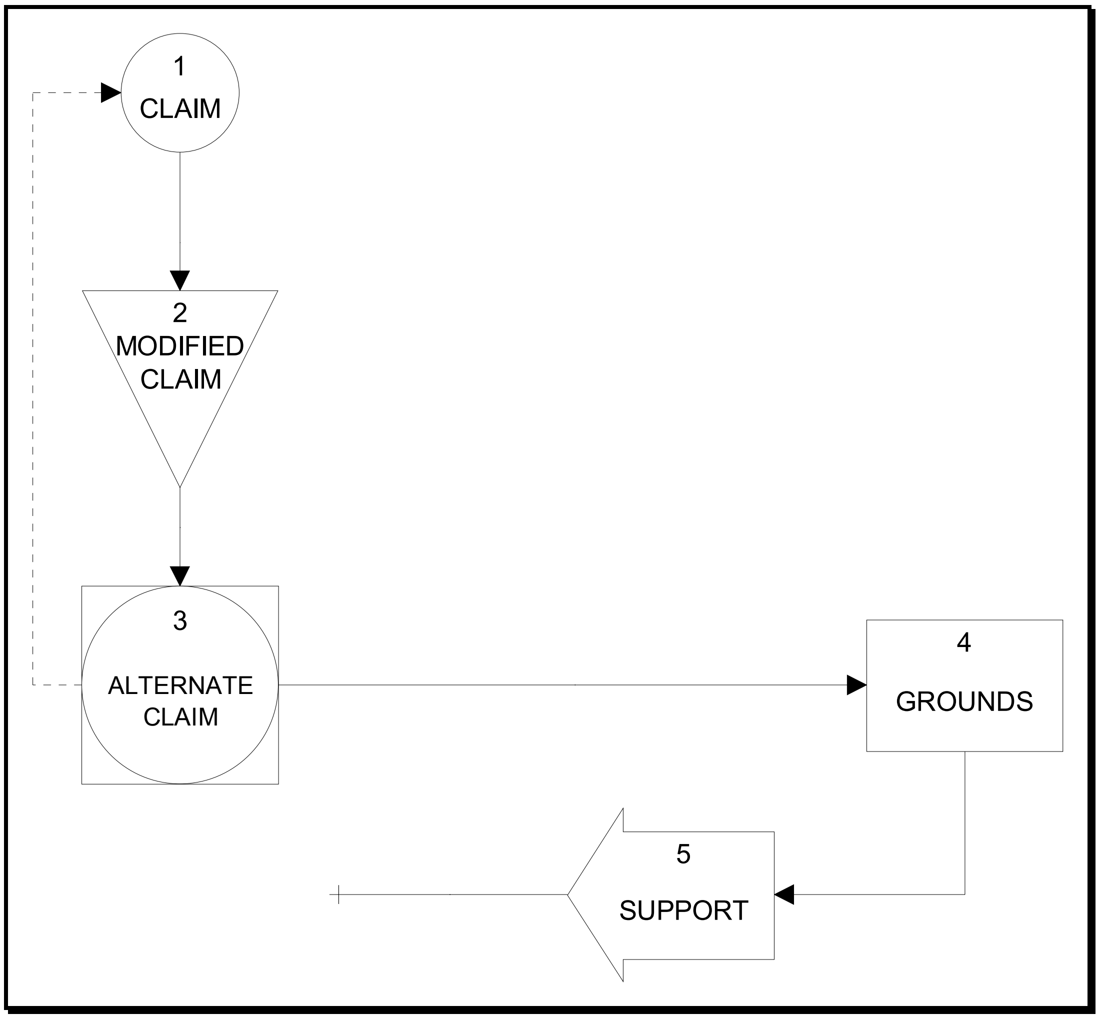


Figure D-9. Group 4C Prototype Episode.

Group 4C's prototype episode contains a symbol not seen in any of the other 13 groups. The final line ($\rightarrow$)doesn't connect to another symbol. This symbolizes the disconnected character of their discourse. Their episodes tend to end without any concrete connection to what follows.

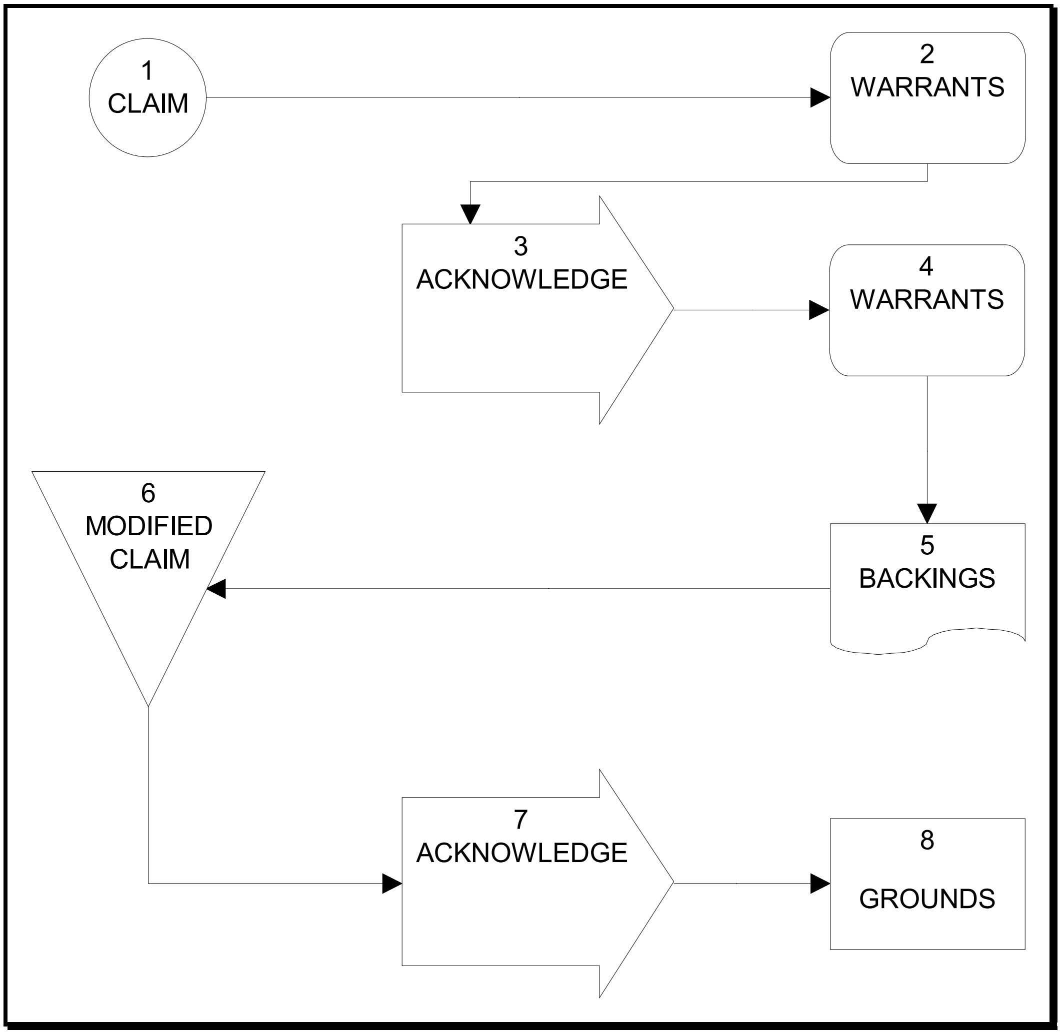


Figure D-10. Group 4D Prototype Episode.

The derivation of Group 4D's prototype has been discussed in detail in Appendix C. This group uses *no* Alternate Claims. Although member ME offers most (5 of 7) of the original claims, member ST offers *all* of the Modified Claims.

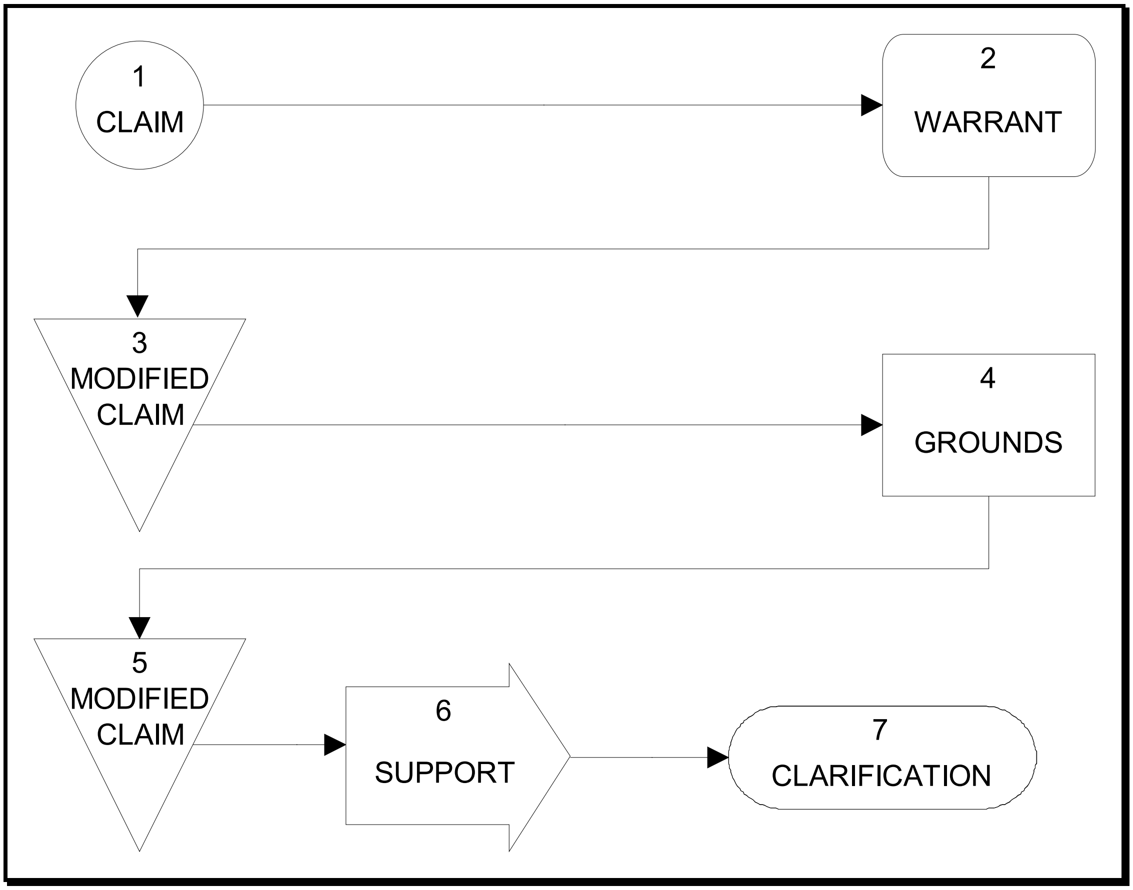


Figure D-11. Group 5A Prototype Episode.

Group 5A has five original Claims and nine Modified Claims. This means there are almost two Modified Claims for each original. Hence, their flowchart contains two Modified Claim symbols.

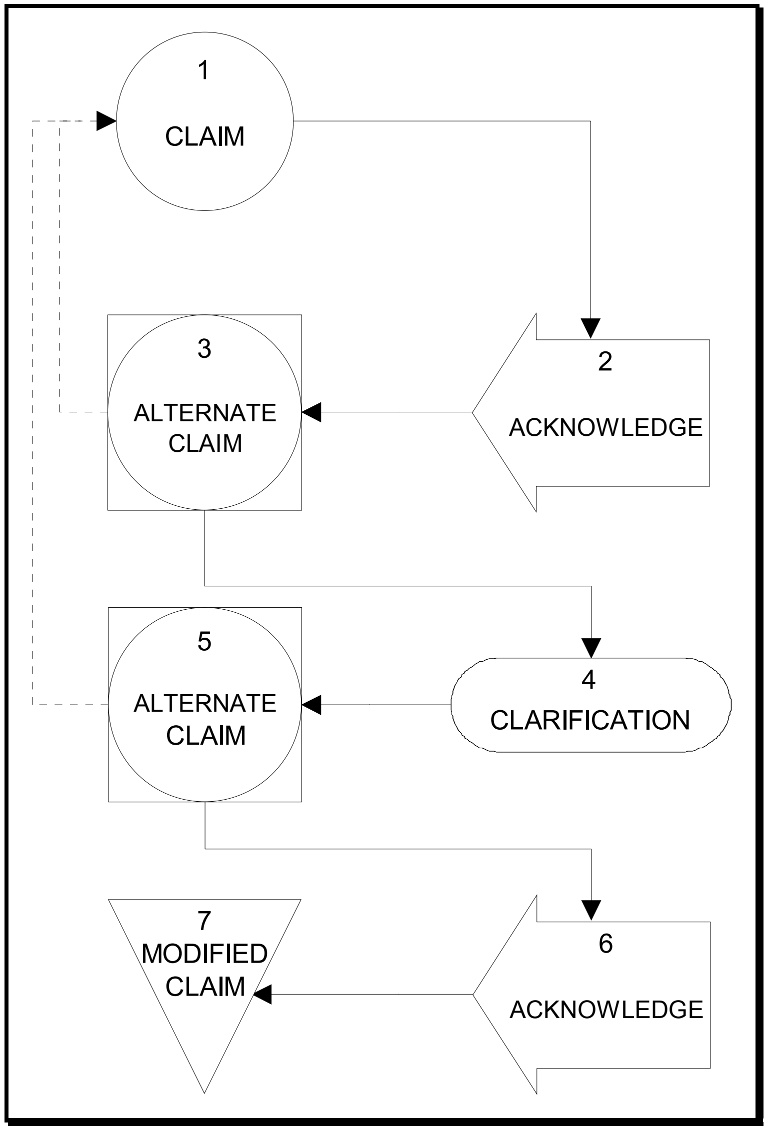


Figure D-12. Group 5B Prototype Episode Type 1.

Group 5B is the other group that exhibits two argument co-construction patterns. They have twice as many Alternate Claims as Modified Claims, and hence, the Alternate Claim symbol appears twice. In this pattern, there is little additional elaboration between the subsequent claims.

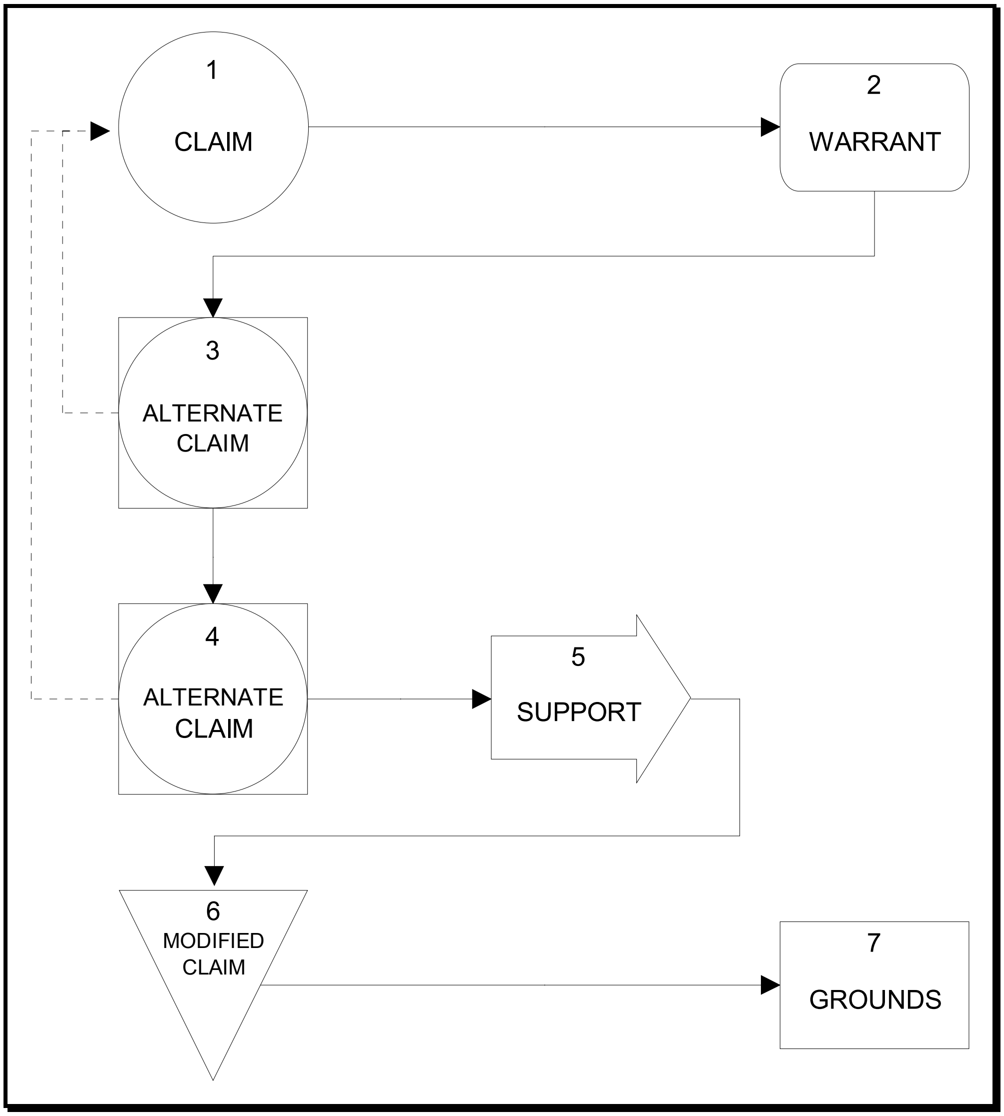


Figure D-13. Group 5B Prototype Episode Type 2.

In Group 5B's second pattern, they do show some support with Grounds, Warrants, and Backings. Their preference is for Grounds and Warrants over Backings.

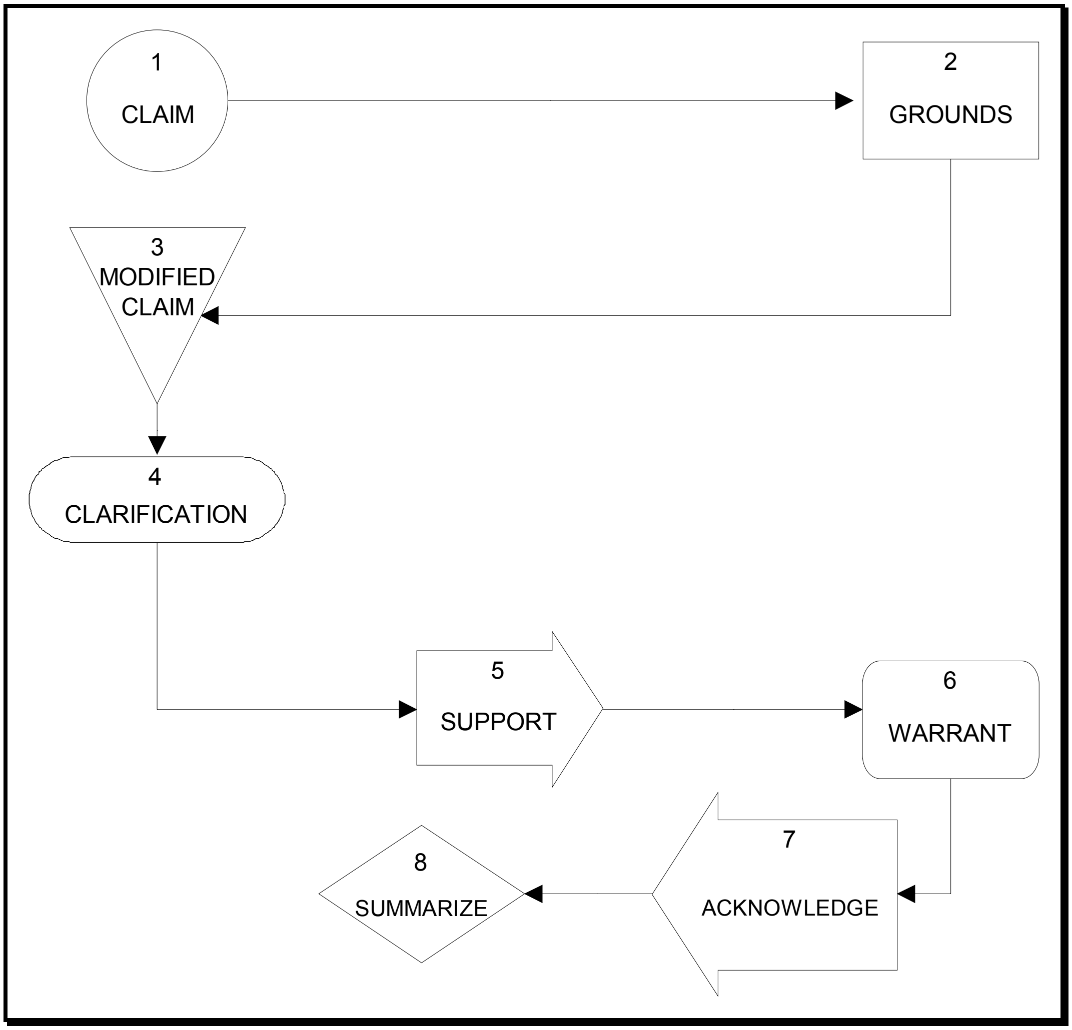


Figure D-14. Group 5C Prototype Episode.

Group 5C also had a tendency to summarize at the end of their episodes. This group uses *no* Alternate Claims, but has a large number (7) of Modified Claims compared to original claims (6). Five of their Modified Claims follow fuzzy Claims.

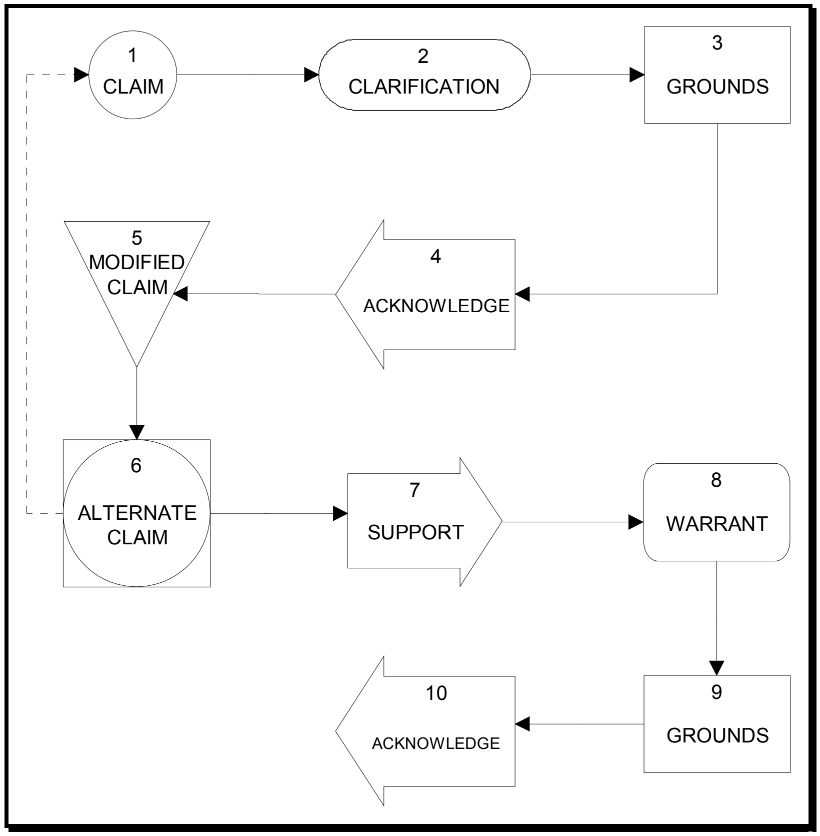


Figure D-15. Group 6B Prototype Episode.

Although Group 6B uses Alternate Claims in only two episodes of the seven flowcharted, the always follow their Alternate Claims with Modified Claims. In another episode which contains a Modified Claim, an Alternate Claim is starting to form, but is cut off by a support statement. It is important to note that one group member, KF, made *no* claims of any type, and this pattern of Modified Claim leading to Alternate Claim is really the claim pattern of members CH and KJ. Hence the sequence of Modified Claim and then Alternate Claim seems most natural for this group.

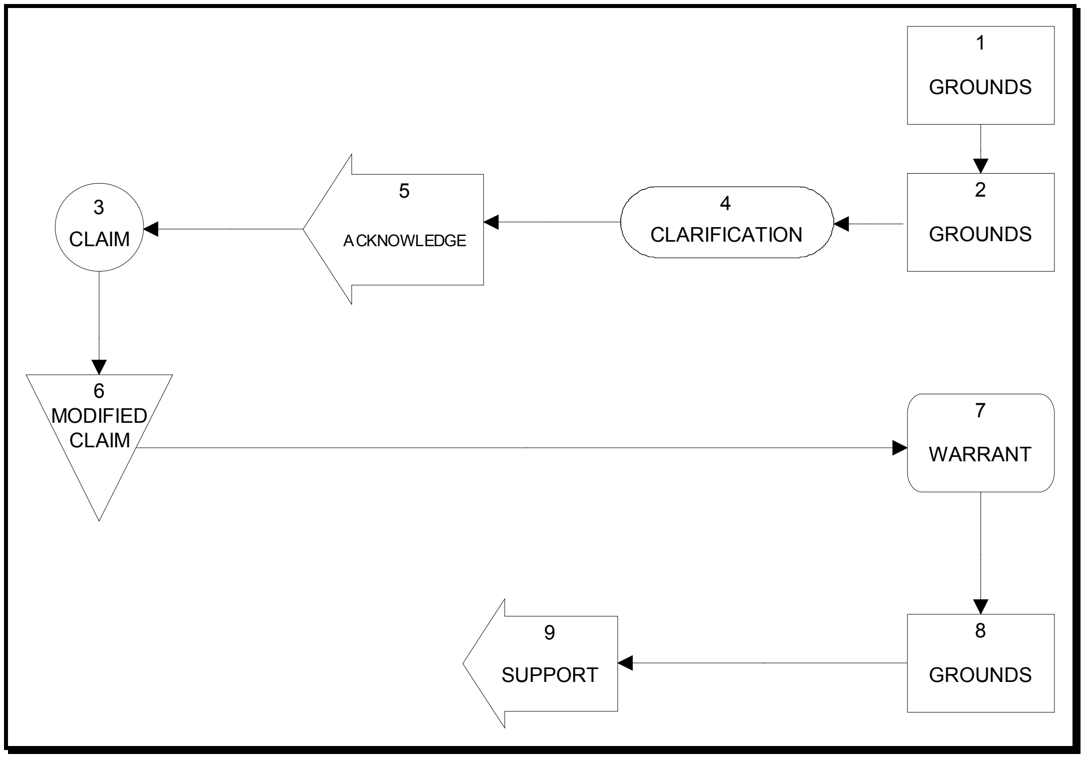


Figure D-16. Group 7A Prototype Episode.

Group 7A did not use *any* Alternate Claims. This group uses Grounds and Warrants to support their argument co-construction but have a definite preference for Grounds.