EXPLORING THE DEVELOPMENT AND TRANSFER OF CASE USE SKILLS IN MIDDLE-SCHOOL PROJECT-BASED INQUIRY CLASSROOMS

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EXPLORING THE DEVELOPMENT AND APPLICATION OF CASE USE SKILLS IN MIDDLE-SCHOOL PROJECT BASED INQUIRY CLASSROOMS

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To my parents, Melvin and Cora Owensby-
"A parent owes a child two things: a light to see by and a club to ward off danger"
(Khalil Gibron)
It is because of God working through you that I have been able to accomplish and achieve thus far. You truly have been, are, and always will be the wind beneath my wings.
I love you.

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LIST OF SYMBOLS AND ABBREVIATIONS

CAS	Case Application Suite
IRSU	Immune and Reproductive Systems Unit
LBD	Learning By Design

EXECUTIVE SUMMARY

The ability to interpret and apply experiences, or cases (Kolodner, 1993; 1997) is a skill (Anderson, et. al, 1981; Anderson, 2000) that is key to successful learning that can be transferred (Bransford, Brown & Cocking, 1999) to new learning situations. For middle-schoolers in a project-based inquiry science classroom, interpreting and applying the experiences of experts to inform their design solutions is not always easy (Owensby & Kolodner, 2002). Interpreting and applying an expert case and then assessing the solution that results from that application are the components of a process we call case use. This work seeks to answer three questions:

1. How do small-group case use capabilities develop over time?
2. How well are students able to apply case use skills in new situations over time?
3. What difficulties do learners have as they learn case use skills and as they apply case use skills in new situations? What do these difficulties suggest about how software might further support cognitive skill development using a cognitive apprenticeship (Collins, Brown & Newman, 1989) framework?

We argue that if learners in project based inquiry classrooms are able to understand, engage in, and carry out the processes involved in interpreting and applying expert cases effectively, then they will be able to do several things. They will learn those process and be able to read an expert case for understanding, glean the lessons they can learn from it, and apply those lessons to their question or challenge. Furthermore, we argue that they may also be able to transfer interpretation, application, and assessment skills to other learning situations where application of cases is appropriate.

Our Approach To Supporting Case Use Skills

To support middle-schoolers as they develop case use skills working in small groups, we designed the Case Application Suite. Its three tools, the Case Interpretation Tool, Case Application Tool, and Solution Assessment Tool, were designed to coach groups and individuals, as cognitive apprenticeship suggests, by using a system of scaffolds. Each scaffold in the system supports groups in a particular way and addresses a particular difficulty that students face when using expert cases. The Case Application Suite can be used help groups interpret and apply expert cases and also assess their design solutions based on that application. In our work, the Case Application Suite was integrated into a 7th grade suburban classroom where the teacher, Mr. J., was enacting Learning By Design (Kolodner, et. al., 2001; Kolodner, et. al., 2003), an approach to project-based inquiry science learning that teaches middle-schoolers science as they solve design challenges and our enactment of a cognitive apprenticeship. We focused on his 5th and 6th period classes.

Method, Data Collection, and Data Analysis

In particular, we integrated the Case Application Suite into Learning By Design's *Tunneling Through Georgia* Unit. In this unit, students working in small groups of three or four and address the challenge of designing a set of tunnels that will run across the state of Georgia. To inform their design solutions, they use the experience of experts in the form of narrative cases as resources. These twelve expert cases describe problems various groups of experts faced as they designed different tunnels around the world and throughout history. The expert cases also describe the solutions the experts used to address the problems they faced as well as the outcomes of those solutions. The expert cases are written in such a way that the lessons that can be learned from them, or the design rules of thumb, are visible. They introduce groups to the problems they might face as they address their challenge, describe strategies the experts used that might be useful to the group's design as well as strategies the experts used that the group should avoid, and they expose groups to the complexities of tunnel design.

Prior to the *Tunneling Through Georgia* Unit, students worked in small groups and engaged in one of Learning By Design's launcher units, *Digging In*. In this unit, groups faced the challenge of designing a basketball court at the bottom of a hill and the surrounding area so that the hill would not erode onto the basketball court. To help them understand erosion, agents that cause erosion, and ways to manage erosion, two case studies were presented: the Dust Bowl and Landslide cases. Individuals used a paper-and-pencil tool, the My Case Summary Design Diary Page, to help them interpret and think about how they might apply to the erosion challenge. Mr. J. helped the class think about the questions they should ask themselves as they used the My Case Summary Design Diary Page to interpret either the Dust Bowl or Landslide cases. During the During the *Tunneling Through Georgia* Unit, Mr. J. repeated this process for the Lotschberg Tunnel case. Then, small groups used the Case Interpretation Tool three times over the course of the unit to interpret three different expert cases, and they used the Case Application Tool once to analyze and apply design rules of thumb gleaned from their interpretation of one of the three expert cases. They did not use the Solution Assessment Tool because due to time constraints.

At the end of the Tunneling Through Georgia Unit, we administered a performance assessment to see the effects of the Case Application Suite on individuals' ability to apply case use skills in a new situation. They did not have the Case Application Suite's scaffolding available to them during this performance assessment. Following the end of the Tunneling Through Georgia Unit, the class engaged in the Immune and Reproductive Systems Unit (IRSU). This unit, designed by Mr. J., students worked in groups of two to learn about sexually transmitted diseases (STDs) by making predictions about the diagnosis of a mock patient and comparing their final prediction to the actual diagnosis of the doctor. Groups did not use the Case Application Suite during this unit. Instead, Mr. J. designed five software tools to support groups during the unit. Following the IRSU, we administered a second performance assessment to further understand the effects of the Case Application Suite on individuals' ability to apply case use skills in another new situation. We also wanted see how well individuals were able to retain case use skills. This second performance assessment occurred five months after the first performance assessment, and groups did not have the Case Application Suite available.

We collected four types of data. First, we collected student work consisting of My Case Summary Design Diary Pages from the Dust Bowl/Landslide and Lotschberg Tunnel cases as well as individual responses from the two performance assessments. We also video taped groups as they used the Case Application Suite, discussed the expert case in the first performance assessment, and used the software tools Mr. J. designed for the IRSU. We conducted two sets of student interviews, one following the Tunneling Through Georgia Unit and the other following the IRSU; and we conducted a teacher interview following the Tunneling Through Georgia Unit.

To begin answering our research questions, we analyzed the different kinds of student work using a coding scheme that was developed using a variation of grounded theory (Glaser & Strauss, 1967; Strauss & Corbin, 1998). We used one coding scheme to analyze different kinds of student work so that we could assess how group and individual performance and capabilities developed over time. We also analyzed video observations to provide context to student work and help us understand the discussions that groups had as they created those artifacts. We presented episodes of Mr. J.'s enactments of case use, our predictions for each episode, coding results, and excerpts of discussions in two case studies that focused on three target groups across Mr. J's 5th and 6th period classes.

Analysis of Research Question One

With respect to our first research question which focuses on how groups develop case use capabilities over time supported by the Case Application Suite and in particular, the Case Interpretation Tool, our analysis revealed that the development of case use skill looks different for every group. There is a lot of variation, and group performance improves or worsens from one episode to the next. Group performance and capability do not improve uniformly; instead, they fluctuate. This fluctuation depends on several facts, but what seems to influence these changes and indicate group interpretation capability the most are a group's discussions and how fully the group is able to reason about the expert case. The completeness of a group's reasoning and a group's interpretation capability are revealed through their discussions, which can be described or characterized as a combination of informed vs. uninformed, chaos-focused vs. classification-focused vs. content-focused, inter-group centered vs. intra-group centered, engaged vs. disengaged, and system-scaffolded vs. single-scaffolded. Factors that seem to influence the character of group discussions include how willing a group is to seek help when help is needed, how fully a group reasons about the expert case, the amount of detail in the expert case, the skills that are focused on early by the teacher and reinforced by the teacher, classroom activities, and software's scaffolding over time, and the personalities of group members. From this analysis, we were able to glean eleven trends about the development of group interpretation capability over time.

Analysis of Research Question Two

Our second research question focuses on the effects of the Case Application Suite by examining how well individuals were able to use interpretation skills before Case Application Suite use and how well they were able to use interpretation, application, and assessment skills in the absence of the Case Application Suite's system of scaffolds. Our analysis revealed that individual performance was also varied, with individuals starting and ending in different places in their capabilities and performance. During the first performance assessment, most individuals experienced difficulties with the same interpretation sub-skills: identifying expert solutions, criteria, constraints, and design rules of thumb. This was the case despite the detailed scaffolding groups used in the Case Interpretation and Case Application Tools that helped them identify and articulate criteria, constraints, and design rules of thumb. Surprisingly, individuals were able to perform and retain case use skills over time, as most individuals performed better for the second performance assessment than they did for the first one almost five months earlier. Their ability to retain case use skills was a surprise because individuals had not engaged in Learning By Design activities or used the Case Application Suite in almost five months.

Given this improvement with no Learning By Design or Case Application Suite use during that five month period, we looked back at the IRSU to understand more about what may have occurred during that unit to explain these surprising results. What we found was that Mr. J. modeled two sub-skills during his enactment of the IRSU. First, he modeled for the whole class how to describe outcomes that occurred as a result of doing or not doing something. For example, he described how doctors were able to reduce the number of infections in hospital operating rooms by washing their hands. Second, he helped the class articulate lessons learned based on those outcomes, but he did not explicitly say that the lessons learned were designed rules of thumb.

When we informally analyzed artifacts generated by groups as they used the software tools for this unit, we saw that dyads also described outcomes that occurred as a result of doing or failing to do something. This seems very similar to the interpretation sub-skill of describing outcomes that occurred as a result of the expert addressing or failing to address constraints. The artifacts also revealed that dyads articulated lessons learned and some had the same form used in the design rule of thumb template. Dyads also made predictions, many of which were described within the lessons learned. These findings were surprising because the software for this unit did not explicitly prompt groups to do those things. As a result, it seems that Mr. J.'s facilitation of class discussions during the IRS Unit seemed to reinforce describing outcomes and articulating lessons learned. This reinforcement also seems to explain why individuals' ability to carry out those skills either improved or remained the same across performance assessments even though they had not interpreted and applied expert cases in almost five months.

Our analysis also examined the relationship between individual and group performance and capability, especially in the context of the performance assessments. When groups engaged in discussion about an expert case during performance assessments, those discussions impacted how fully the group was able to reason about the expert case. Following group discussions, as individuals wrote up their own answers in their performance assessment packets, additional reasoning performed by the individual influenced what an individual took away, or understood, from both group discussion and reasoning as well as their own reasoning. This is individual capability. Individual performance assessment packets tell us what an individual chose to express based on what they understood from the reasoning. As such, individual packets reveal individual performance.

Analysis of Research Question Three

Our third research question examined the difficulties groups and individuals faced when developing and applying case use skills. These difficulties were analyzed not only to make suggestions about how to support and promote case use skill development, but also to accomplish our larger goal of making suggestions about supporting and promoting the development of complex cognitive skills. Looking back at the answers to our first two research questions, we learned that the same facts that most affect group and individual performance and capabilities (i.e., the character of group discussions, the completeness of group and individual reasoning, and what an individual chooses to explicitly express) are also the difficulties that groups and individuals face when developing and applying case use skills. From this, we were able to describe four trends that express the relationship between group performance and capability, group capability and individual capability, and individual capability and individual performance. These trends helped us understand the connections between group and individual performance and capability, which are not synonymous, and they allowed us to make predictions about what impact addressing a particular difficult should have on performance and capability. For example, if we are able to help individuals express more of the reasoning the group as done and more of their own individual reasoning, their written artifacts would be a more accurate reflection of their individual capabilities.

We also analyzed how the Case Application Suite could better support case use skill development and found that we could accomplish this by helping groups have more informed, non-chaotic, engaged discussions and by pushing their reasoning through drawing their attention to more of the full set of software-realized scaffolds. Ways we might accomplish this include adding more explicit hints that encourage groups to engage in practices that are more likely to promote informed, non-chaotic, engaged discussions and including hints that explicitly remind groups about the help available to them.

What Does Our Research Suggest About Designing Software In Support Of Complex Cognitive Skill Development

We also made suggestions for designing and integrating software into a learning environment where software and teacher share scaffolding responsibilities. The software and the teacher have particular strengths when serving as more capable "experts" in a cognitive apprenticeship, with the software providing consistent scaffolding that every group can use simultaneously to organize, structure, and remind them about important aspects of case use, while the teacher can provide in-the-moment scaffolding when groups and individuals have particular difficulties or needs while interpreting and applying a specific expert case. As such, software in support of complex cognitive skill development should encourage groups and individuals to employ the teacher's in-the-moment scaffolding as well as the software's system of scaffolds. Additionally, software designed to coach students to learn complex cognitive skills in an environment that uses cognitive apprenticeship as a framework can be effective as we've shown in this work that software is able to take on a particular role within that environment. Finally, software should be designed to support complex cognitive skills in such a way that it can do so even if the teacher is uncomfortable with modeling or coaching those skills or if the teacher is not as skilled at carrying out those skills. In this way, the help students have available to them is not limited by how well or how completely the teacher models those skills. We also examined possible directions for future work.

CHAPTER 1

INTRODUCTION

Learning from use of cases has been the hallmark of several approaches to education. For example, in law school, students study a series of court cases and write briefs, or summaries of the cases [Williams, 1992]. They study these cases so that they can understand the thinking that lawyers do when they apply cases to their strategy for prosecuting or defending a person. They also study these cases to familiarize themselves with the law. Students prepare briefs so that they can formulate rules and understand how those rules apply to the set of facts presented in the case [Williams, 1992].

In medical problem-based learning [Barrows, 1985] students learn basic science knowledge as well as the processes used to diagnose patients by studying the records of actual patients [Koschmann, Kelson, Feltovich, & Barrows, 1996; Williams, 1992]. Students are initially given a description of a patent's symptoms. As students try to diagnose the case, they ask questions about the patient and read medical literature to build a model of the patient's medical condition [Koschmann, et. al., 1996] and ultimately, they try to diagnose the case themselves. After coming up with their diagnosis, they compare and contrast their own to that of the experts, discovering in the process, new things they need to learn before diagnosing other cases. They might also revisit previously-encountered cases as they diagnose new ones.

The process of conducting research also involves looking at the work of others, interpreting that work, analyzing the ways that it addresses some problem to be solved or explains some phenomena, and then applying the solutions or explanations used previously, either directly or via adaptation, to solve the new problem and advance the field. For example, conducting the work described in this dissertation involved carrying out this process. First, we had to search for and interpret the literatures on skill development, transfer, collaboration, and cognitive apprenticeship. Then, we gleaned the suggestions these works made for supporting complex cognitive skills in a cognitive apprenticeship environment. Next, we applied those suggestions by adapting them to address case use as a particular complex cognitive skill using them to inform our design of the Case Application Suite. Additionally, we used these works and the suggestions they made as a lens through which we could assess our design of the Case Application Suite and its effectiveness as well as interpret the results of this work. Often, debates ensue in a research community regarding whether an interpretation is accurate and whether the application of someone's work was in keeping with the original spirit of that work and its intensions. This debate, about the interpretation and applicability of a research finding, keeps a research community vibrant and moving forward.

From the perspective of learning and education, the ability to interpret and apply cases is a skill that is a key to successful transferable learning. In classrooms in many subjects, the teacher will work examples on the board for the students, and they are expected to understand those examples and apply what they have learned not only to solve problems on a homework assignment, but also to new issues and topics that arise. If the student gets a homework assignment wrong, the teacher helps the student assess where their example application broke down and better understand the example and its applicability. Teachers who use such an approach expect students to interpret the examples they encounter such that they can remember them later and apply the knowledge and skills learned from them in new situations. This, we claim, is what transferable learning is often about--interpreting and applying encountered cases, or experiences [Kolodner 1993, 1997; Schank 1982, 1999], and the knowledge and skills learned from them in new situations. The ability to transfer knowledge or skills from one situation to another and from one domain to another requires a deep understanding of that knowledge or those skills [Bransford, Brown & Cocking, 1999; Donovan, Bransford & Pellegrino, 1999]. Deep understanding is characterized by understanding the connections between the concepts being learned, understanding the conditions under which that knowledge should come to bear, and reflecting on it in such a way that new connections can be made as more knowledge is acquired. And deep understanding is thought to be the cornerstone of being able to use knowledge or skills flexibly. Deep understanding and flexible use are attributes of expertise in a domain, and a major goal of education is to develop more expert-like problem solving strategies and skills in students, so they can understand and engage in more expert practices and processes. In this work, we seek to investigate the viability of the following hypothesis:

If learners in project-based inquiry classrooms are able to understand, engage in, and carry out the processes involved in interpreting and applying cases effectively, then they will learn those processes and be able to read an expert case for understanding, glean the lessons they can learn from it, and apply those lessons to their question or challenge. Furthermore, they may also be able to transfer interpretation, application, and assessment skills to some other learning situations where application of cases is appropriate.

This is a specific statement about the application of case use skills in other project-based inquiry learning situations. We mean it to be a weak version of a much stronger claim--

that such capabilities can result eventually in the development of more broadly-applicable interpretation, argumentation, and application skills. The literature on skill acquisition suggests that in order for problem-solving skills to be acquired and to develop in meaningful ways, several actions must be carried out [Bransford & Stein, 1984, 1993]. Problems must be identified in a learning situation and treated as opportunities for creativity. Goals must be identified for each particular problem and alternative approaches to solving a problem must be explored. Specialized knowledge must be learned that allows a learner to know when, how, and why to apply a strategy. Possible outcomes of applying a strategy must be anticipated, the strategy must be carried out, the effects of the application must be assessed, and the learner must reflect on the experience in order to learn from it. We intend this study to be a first step at developing a more detailed understanding about what skill acquisition and skills learning looks like for case use.

To do this first step, we build on what others have learned about promoting skills learning in project-based inquiry learning environments, e.g., the importance of employing scaffolds to support students as they carry out complex tasks, the importance that iteration has in providing multiple opportunities to carry out a skill in real contexts of use, the importance of authentic problems that allow students to learn and apply skills in situations like those where scientists apply those skills, and the importance of encouraging students to reflect on their learning in such a way that they can use it to support decisions they make along the way [Bell, Davis & Linn, 1995; Bell & Davis, 2000; Kolodner, 1997; Kolodner, et. al, 1998; Reiser, et al., 2000; Reiser, 2004; Songer, 1996]. Project-based inquiry is a sequencing of activities that goes on over a period of time, resulting in a product, presentation, or performance by small groups of students

[Barron, Schwartz, Vye, Moore, Petrosino, Zech, Bransford, & The Cognition and Technology Group at Vanderbilt, 1998]. It typically revolves around a complex, ill-formed question or problem in which students iteratively investigate, create solutions, and refine their solutions and ideas. It normally has a timeline and milestones, and other aspects of formative evaluation as the project proceeds.

While a great deal of research has been devoted to supporting students by scaffolding them as they carry out expert processes (i.e. Learning By Design (LBD), BGuILE, KIE, Kids as Global Scientists projects), little work has been done to understand and chart what that development looks like. In addition, little work has been done to create a systematic approach to scaffolding, defining a topology of scaffolds to support students across multiple complex tasks. This work seeks to understand and describe how middle school students in a project-based inquiry, cognitive apprenticeship learning environment acquire and develop the skills needed to apply expert cases to solve science problems. By seeking to understand and describe how these skills are acquired and developed, we also hope to make suggestions about the ways that software and teachers can better support students as they engage in using expert cases, and we also seek to begin analyzing how effective a system of scaffolds [Owensby & Kolodner, 2002] can be at supporting students across multiple complex tasks (i.e. designing experiments, building and running models, using evidence to support claims). Describing how skills are acquired and developed can be very complex, and little work has been done to begin describing skills acquisition and development for complex expert processes. This work seeks to do this for case use in middle school science using expert cases.

1

1.1 What Is A Case?

A case is an interpreted experience [Kolodner 1993; 1997]. Cases can be divided into three major categories: personal cases, or experiences of the individual learner that he/she experiences first-hand; peer cases, or second-hand experiences of an outside learner who has a similar expertise to that of the individual learner; and expert cases, or second-hand experiences of an expert within that domain. All of these experiences can be used by the individual learner, be they novice or expert, but there is a distinction between first-hand and second-hand cases. First-hand cases are normally more rich, connected, and understood by the individual that experienced them than second-hand cases (Schank, 1999). This is because first-hand cases are like personal narratives and because the individual has experienced them, he/she is able to connect them to other personal experiences and reflect on them using understandings gleaned from the set of experiences he/she has had before. As a result, he/she is able to index them in his/her own memory and call on those experiences in ways that make sense for him/her.

Second-hand experiences are experiences that are being explained to the individual. The individual does not have access to all the other experiences that situate this second-hand experience, but can ask questions to learn more. Such an experience is not as rich as a first-hand experience, nor are the connections as readily evident as they are with personal or first-hand cases.

This distinction between first-hand and second-hand cases does not mean to imply that people do not learn from second-hand cases. Indeed, if a child sees someone place their hand on a hot stove and jerk it away crying out in anguish because they have burned their hand, they might very well learn that touching a hot stove results in being burned.

However, the connection between the experience and the sensation that was felt as the heat burned the person's hand may not be as rich, or as personally meaningful, for the child because the sensation has to be described to the child using words as opposed to using the child's sense of touch.

In addition to the distinction between first-hand and second-hand cases, there is also a distinction between peer cases and expert cases. While both are types of second-hand cases, they have distinct characteristics. Peer cases tend to use language that the individual learner understands because the individual and the peer have a similar level of expertise. Thus, peer cases might not be very well-described. On the other hand, while expert cases are typically more detailed and technical, they may use language that the individual doesn't understand, making it difficult for the individual to interpret the experience, pull out the lessons they can learn, and apply those lessons to their current problem. However, a well-developed expert case that includes all of the descriptiveness needed for students to understand the connections within the case and that is written using language that they can understand can be very useful for learning skills for interpreting expert cases whose sub-skills will be described in the next section. First, they provide technical details we want kids to learn, like the steps used to design a tunnel or how core samples are taken [Kolodner, et al, 1998; Kolodner, et. al, 2001]. Second, they can make good models of how to interpret one's own experiences.

1.2 Case Use[1]: What Is It?

Case use is the process of interpreting, analyzing, and applying experiences in order to address challenges or solve problems. It begins with understanding a case, focusing on making a connection between the challenge and its criteria/constraints and the solution chosen to address the challenge. It then moves to analyzing the outcomes described in the original or source case, identifying the lessons that can be learned from the case. Next, case use involves applying those lessons to the new situation or target case, either directly or via adaptation (depending on how closely the criteria/constraints or the source case align with the criteria/constraints of the target case). Finally, the potential of the application is assessed based on the previous outcomes and predictions made about the target case's solution.

Interpreting an expert case involves correlating problem-solution pairs with the criteria and constraints of the original problem. The resulting outcomes are used to judge the success of the solution in satisfying the criteria and addressing the constraints. For the learner, the end result of interpreting involves identifying the lessons that can be learned from the experts. A lesson learned is in the form of conditions that, if present, suggest a certain response [Kolodner, 1993].

Applying the lessons learned to the target case is a task that involves identifying the criteria and constraints of the target case and analyzing how well they match up to the

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[1] The phrase "case use" will be used to describe the process of interpreting, applying, and assessing expert cases. This phrase will be used instead of the phrase "case application" that has been used in previous publications to alleviate confusion between the process of case application and the application phase of the process [Owensby & Kolodner 2002, Owensby & Kolodner, 2004].

conditions articulated in the lessons learned, or design rules of thumb, from the source case. Once a potential match is discovered, applying involves determining whether the lesson can be incorporated into the solution directly, whether it needs to be adapted in order to meet the particular criteria and constraints of the new situation [Kolodner, 1993, 1997; Simina, 1999], or whether the lesson cannot be applied, perhaps due to constraints that the student did not take into account.

Predicting the success of an application can be carried out in several ways. In situations where the solution can be implemented, the implementation can be tested and its results analyzed to determine which were favorable and which were unfavorable. In situations where the solution cannot be implemented, predictions must be made about both favorable or unfavorable results that might accrue.

Case use can be an iterative process. If a reasoner applies a case and finds that their solution has not addressed all criteria or has unexpected results, he/she may want to apply other cases to make the solution more complete. The process of applying cases would continue until the reasoner has developed an acceptable solution.

1.3 Case Use In A Project-Based Inquiry Environment

In project-based inquiry science classrooms, students learn science by proposing and answering complex science questions and then employing the knowledge and skills they are learning to create a solution to the problem(s) posed. For example, in Learning By Design, a project-based inquiry unit that will be described in more detail later in Chapter 3, student groups must design a set of tunnels that run across the state of Georgia. Among the issues they must address are knowing how deep to go under a city so as not to affect the structures and people living above the tunnel, when it is appropriate to build a bridge over a body of water as opposed to tunneling beneath it, and how to know what the composition of ground is beneath the surface when there is not a great deal of information given. This, in turn, requires that they learn about different kinds of rocks and minerals, their attributes, how they are formed, and how they behave under different conditions. One way to figure out the questions to ask and some of their answers is to read and interpret expert cases. For example, while reading about and interpreting the struggles involved in constructing the Hoosac Tunnel, students learn several lessons that they can apply to their challenge. In the Hoosac Tunnel case, lack of knowledge about the exact composition of the Hoosac Mountain as well as lack of understanding about the kinds of tools required to drill through the mountain resulted in human death, long delays, and money shortages. By reading and interpreting this case, students begin to understand the importance of core sampling (drilling down and pulling up a sample of the underlying make-up of the ground), knowing the properties of different rock, and recognizing the importance that money and time play on projects like this in the real world. As such, the case use becomes integrated into the larger project-based inquiry cycle, further helping students employ the knowledge and skills they are learning to create solutions to the problem(s) posed. More description about how students interpret expert cases in Learning by Design and the scaffolding available to support them will be described in Chapter 3.

Case use is quite natural and useful in solving problems [Kolodner, 1993, 1997; Schank 1982, 1999], but there is a difference between "surface" application of cases and "deep" or expert application. We've found that middle-school science students have several difficulties applying cases [Owensby, & Kolodner, 2001]. First, they don't always understand a case's lessons well after just one reading, making it hard for them to identify how it might apply to a problem. Second, they sometimes don't put the effort into understanding the problem they are trying to solve that would allow for them to recognize that another case might be usefully applied to help them solve the problem. The case-based reasoning literature [Kolodner, 1993, 1997; Schank,1982, 1999] stresses the importance of successfully interpreting both a new situation and a possible applicable case as a prerequisite for productive case use. Third and fourth, even when students understand a situation and case well, they can find it difficult to draw connections needed for application and to predict consequences of application. We know, however, that they can learn all of these things [Owensby & Kolodner, 2001; Owensby & Kolodner, 2002; Owensby & Kolodner, 2003; Owensby & Kolodner, 2004].

1.4 The Use of Expert Cases In This Work

As described earlier, a case is an interpreted experience. This suggests that any experience that one has that is or can be interpreted qualifies as a case. Examples of experiences that can be interpreted and hence qualify as cases range from a child placing his/her hand on a hot stove and recognizing that a hot stove should not be touched to having a short conversation with a peer. This work examines the understanding and use of one kind of case: expert cases.

Expert cases can be represented in a number of different forms. Examples include documentaries, video vignettes, modeling, and narratives or written descriptions of the experiences of experts. Within narrative expert cases, variation can also exist, as different cases can articulate the details surrounding the problem(s) and solution(s) to varying degrees. Narrative expert cases can range from those that simply present the problem and the solution to those that describe the context under which problems arose, solutions analyzed and chosen, and the outcomes that resulted.

This work focuses on the use of expert cases because they are typically very descriptive explanations of an experience [Carroll and Rosson, 2005], pointing out both positive and negative outcomes and the sequence of events that led to those outcomes. Since experts within a domain have a very rich and connected understanding of that domain, their experiences can help students learn about the complex processes carried out in that domain, reinforce strategies that yield positive results within that domain, and keep students from making mistakes the experts have made [Carroll and Rosson, 2005]. Expert cases are typically more detailed and technical, providing details that are important for students to learn (e.g., the steps used to design a tunnel). They can also make good models of how to interpret one's own experiences.

When students are able to have first-hand experiences in a domain, expert cases can describe practices and strategies that have been used in the real world, which students can then apply to their solutions and experience first-hand. These kinds of first-hand experiences based on expert cases can help students develop a richer and more connected understanding of the domain because students have both the expert case and their own first-hand experience with the phenomenon to draw upon. In this work, expert cases are good as descriptive explanations of an experience because a first-hand experience in the domain of geology and tunneling is not possible for students. They cannot experience first-hand designing a tunnel or taking a core sample as it happens in the real world. Therefore, expert cases provide a way for students to understand an experience that they do not have first-hand access to.

As described in more detail in Chapter 3, the fourteen expert cases used in this work are narrative case studies in the domain of Earth Science. They range in length from 1 to 5 pages. Two describe the experiences of experts managing erosion and twelve describe the experiences of experts designing and building tunnels at different times in history around the world. These expert cases are written using language that middle-schoolers can understand, including the descriptiveness needed for students to understand the connections within the expert case, and making the lessons students should be learning from the expert cases visible.

1.5 Our Approach To Helping Learners Develop Case Use Skills

Though students have difficulties engaging in and developing the skills needed for case use to solve science problems in a project-based environment, the literature provides insights into how students can be supported to acquire and develop complex skills. Cognitive apprenticeship describes how students should be supported so they can master complex skills and processes [Collins, Brown, & Newman, 1989]. Skills should initially be modeled by someone expert in their use, with the expert describing how one step connects to another. Once the skills have been modeled, novices should engage in the skills with someone more expert providing hints, reminders, and prompting so the novice can successfully complete the task. As their approximations of the task become more and more expert, the support provided by others is needed less, and eventually, learners who once required a great deal of support are able to provide support for other learners who are less skilled. Skills encompass the thinking that students need to do and the actions that students need to perform in order to successfully complete a complex task, as cognitive apprenticeship suggests. For example, to add a multi-digit number, one must master recognizing the ones place for each multi-digit number, matching up the ones digit for each number, starting with the value of one of the ones digits and counting upward by the value of the other ones digit, recognizing and remembering (if necessary) that the value created by the ones digits is ten or greater and carrying the one over to the tens position, and repeating that process to the left until there are no further digits to line up and count.

A major component of cognitive apprenticeship is scaffolding. Scaffolding [Collins, Brown, & Newman, 1989; Vygotsky, 1978] is help that is provided to a learner so that they can complete a task that they would not be able to complete otherwise. The idea is that scaffolding provides the needed support, and over time, as a learner becomes more proficient at the skill, the scaffolding is faded. Cognitive apprenticeship's focus on modeling, hinting, prompting, reminding, and employing skills and knowledge in the context of their use and in the presence of modeling and coaching form a system of scaffolds that together helps novices acquire and develop more expert-like skills. A system of scaffolds is an integrated set of scaffolds designed to support individuals and groups as they carry out tasks/processes. A set of scaffolds is a system if the scaffolds suggest how a process's tasks are connected and/or how reasoning about a task is connected. The idea is that by designing a well integrated system of scaffolds and supporting students in multiple ways, they may move more quickly across the trajectory toward mastery and that mastery may be more flexible. In addition, a well integrated system of scaffolds may be able to support students across different complex tasks. So the same set of scaffolds used to support students engaging in case use may be employed to support students as they use evidence to justify a claim. More about this will be described in later chapters.

Our approach builds on the cognitive apprenticeship approach. LBD provides our cognitive apprenticeship implementation. LBD provides activities, sequencing, and rituals that provide opportunities for students to acquire and employ expert science skills and practices, while our software, Supportive Multi-user Integrated Learning Environment (SMILE), provides an environment in which students can get the extra support they need using the system of scaffolds as they work in small groups to develop expert science and project skills and learn to use them more flexibly. LBD with SMILE provides an implementation of distributed scaffolding responsibilities across teacher and technology. In addressing learning the skills involved in case use, the teacher provides modeling of the process and the skills needed to engage in the process as well as some coaching during small group discussions and facilitating during whole-class discussions.

However, the teacher can't be with every small group all the time. We know something about the difficulties students face when working in groups to solve problems (i.e. negotiating, listening to everyone's ideas, distributing efforts, etc.) [Scardamalia & Berieter, 1991; Barron, 2003], and we know some of the difficulties that middle school students face as they interpret and apply expert cases to their challenges in LBD. To address the physical limitations that prevent the teacher from coaching every group at all times and to address the difficulties students face as they work together to apply expert cases to their challenge solutions, the software we've developed provides coaching as students are investigating, interpreting, applying and incorporating design rules of thumb from expert cases into their solutions.

1.6 Research Goal And Questions

As stated at the beginning of this section, the goal of this research is

to understand skill development in learning to use expert cases effectively in project-based inquiry science.

Underlying this goal are the following assumptions:

- That expert cases can be engaging learning tools for middle schoolers, and that case use involving expert cases can impact content learning and successful project-based inquiry in a positive way
- That understanding and describing how middle schoolers develop the ability to interpret, apply, and assess the application of expert cases can inform refinement of our system of scaffolds in support of case use
- That understanding and describing how case use skills develop over time can suggest a sequence of development for other complex processes
- That it is not already clear how case use skills develop over time in middle-school science inquiry-based classrooms

To achieve the research goal, this research addresses the following questions:

1. How do small-group case use capabilities develop over time?
2. How well are students able to apply case use skills in new situations over time?
3. What difficulties do learners have as they learn case use skills and as they apply case use skills in new situations? What do these difficulties suggest about how software might further support cognitive skill development using a cognitive apprenticeship framework?

1.7 Contributions

In answering these research questions, this research project will make the following contributions:

- A description of skill development for a reasoning process that may be helpful in informing research not only about how other complex skills and processes are acquired and developed, but also about how we can identify the difficulties students face and scaffold students as they are carrying out those complex skills and processes;
- An example of how one kind of technology can play a specific and active role in helping learners learn skills needed for successful project completion and learning in a project-based inquiry learning environment;
- An example of how the teacher and technology can share scaffolding responsibilities within the framework of a widely accepted approach to skills learning, cognitive apprenticeship;
- A description of case use involving expert cases and how it happens in real classrooms;
- An example of how technology can be used to support students as they engage in applying expert cases and an analysis of that support (through our system of scaffolds);
- A description of a system of scaffolds that can be used to support students in learning complex skills

1.8 Overview

Chapter 2 is a review of the literature on which this work is based. It discusses theoretical findings of the work, namely skills acquisition [Anderson, Greeno, Kline & Neves, 1981; Neves & Anderson, 1981; Anderson, 2000] transferable learning [Bransford, Brown, & Cocking, 1999; Donovan, Bransford, & Pellegrino, 1999], case-based reasoning as a model of process involved in transferable learning [Kolodner, 1993, 1997; Schank, 1982, 1999], and cognitive apprenticeship as an approach to productive learning of complex skills and practices [Collins, Brown, & Newman, 1989]. In addition, three projects that employ software-realized scaffolding [Guzdial, 1994] within an overall inquiry, project-based learning approach are analyzed with respect to the overall environment, the roles of teacher and software, the scaffolding provided, and strengths and weaknesses. Those projects are KIE/WISE [Bell, Davis, & Linn, 1995; Bell & Davis, 2000; Cuthbert, 2000], BGuILE [Reiser, Tabak, Sandoval, Smith, Steinmuller & Leone, 2000; Reiser, 2004], and Symphony [Quintana, Eng, Carra, Wu, & Solloway, 1999].

Chapter 3 describes the learning environment in which students learn to interpret and apply expert cases. In particular, this chapter describes Learning By Design™ [Kolodner, et. al, 1998; Kolodner, et. al, 2003], an approach to project-based inquiry learning that employs the approach of cognitive apprenticeship and engages students in learning science by asking them to achieve design challenges, SMILE , a suite of software tools that support students as they engage in project-based inquiry tasks, and the Case Application Suite, three tools in SMILE's suite of tools that support students as they interpret and apply expert cases. Chapter 4 describes the methods used to answer our research questions. Chapters 5 and 6 describe the "effects with" the Case Application Suite; they describe how students learned and applied case use skills and present the enactments, predictions, coding results, descriptions, and excerpts of group discussions of that learning and use over time.

Chapter 7 describes the "effects of" the Case Application Suite by describing how well individuals were able to apply case use skills in the absence of the Case Application Suite's system of scaffolds. This chapter presents the enactments two performance assessments administered during our study. It presents the enactments, predictions, coding results, descriptions, and when available, excerpts of group discussions during performance assessments. Chapter 7 also describes what may have impacted the improvement in interpretation, application, and assessment skills coding results revealed across performance assessments. Chapter 8 seeks to answer each of our research questions, interpreting the results presented in Chapters 5, 6, and 7. Chapter 9 discusses the limitations of the Case Application Suite, suggestions our study makes for supporting complex cognitive skills development, and potential directions for future work.

CHAPTER 2

BACKGROUND AND RELATED WORK

This chapter presents a review of the literature relevant to this research. The first section reviews several theoretical viewpoints that make suggestions about how to help students develop the skills needed to carry out complex tasks and processes. It focuses on ways that development can be supported in an inquiry-based learning environment and the roles that teacher, student, and software should take on to support skill development in that environment. The second section describes collaboration, focusing on what collaboration is, what it affords, the benefits and potential detriments, aspects of collaboration that have been described, and the ways computers can aid and possibly hinder collaboration. This description will provide context for the description of collaborative group interactions that will be described in the case studies in Chapters 6 and 7, as well as the interpretations that will be made of the data in Chapters 8, 9, and 10. The third section describes several projects in which students are learning complex skills in the hard sciences through inquiry and pays special attention to the scaffolding provided to support the development of those skills. These projects show that supporting students as they develop science skills through inquiry requires understanding and accounting for a complex classroom system, including the roles taken on by the teacher, students, and software. In addition, these projects show approaches used to support science skill development, and demonstrate varying systems of scaffolding that are required to scaffold skill development in a scientific project-based inquiry environment.

As stated in the introduction, our hypothesis is that if learners are able to understand, engage in, and carry out the process involved in interpreting and applying cases effectively, they will not only learn those cases' contents more deeply, but they may also be able to transfer interpretation and application skills to some other learning situations where application of cases is appropriate. But what does it mean to transfer skills to a new situation? What does it mean to use cases for learning? What roles are necessary in a learning environment to promote skill development? The skill acquisition, transfer, case-based reasoning, and cognitive apprenticeship literatures provide insights into the answers to these questions and provide the framework on which our research questions are hung.

2.1 Theories Of Promoting Skill Development

This section presents several theories that serve to paint a complete picture of the classroom system, the role of teacher, software, and students within that system, and the importance of scaffolding to skill acquisition and development. The skill acquisition literature addresses how skills are learned and developed over time. The transfer literature addresses ways to promote use of reasoning skills across situations and domains. Cognitive apprenticeship addresses the roles of teacher and students as they support and are supported, respectively, along a trajectory of skill development, and also addresses scaffolding for skill development. Case-based reasoning makes suggestions for the kind of environment needed for promoting interpretation and application of experiences, activities/practices that the environment should embrace to take advantage of the affordances of cognitive apprenticeship, and suggestions for promoting the application of the skills involved in interpreting and applying experiences to solve problems.

2.1.1 Acquiring Complex Skills – Learning And Developing Skills Over Time

Skill acquisition [Anderson, Kline, Greeno & Neves, 1981; Anderson & Neves, 1981; Anderson, 2000] involves the changing of declarative knowledge, or independent pieces of factual knowledge, to procedural knowledge, or connected knowledge that forms a process for carrying out a skill. An example of declarative knowledge is knowing that two plus two equals four, while an example of procedural knowledge is knowing how to perform long division. According to the literature, skill acquisition involves three distinct stages: cognitive stage, associative stage, and the autonomous stage [Anderson, et. al, 1981; Anderson, 2000]. In the cognitive stage, learners are exposed to the process(es) involved in carrying out a particular skill. As learners attempt to use those skills themselves, they deliberately refer back to the process they were originally exposed to, and they make many mistakes. An example of a learner in the cognitive stage would be a young person learning to drive. They often audibly recite the process of shifting the car from park to drive or the steps to take to correctly change lanes on a multi-lane street. They also tend to make mistakes, like forgetting to signal before changing lanes or incorrectly easing off of the clutch in order to shift gears.

In the associative stage, learners begin to proceduralize their knowledge. This involves both detecting and gradually eliminating errors in the initial understanding and strengthening the connections among the various elements needed for successful performance of the skill. Learners do not need to recall individual steps as frequently as they did in the cognitive phase and they make fewer mistakes. Anderson & Neves [1981] provide an example of a student moving from the cognitive stage to the associative stage when they describe the skill development of a geometry student. In this example, a student is learning to use the Side-Angle-Side (SAS) theorem to prove the congruency of two triangles, and he is given an example of a different proof that uses the same theorem. The student tries to unsuccessfully to reason through the steps of applying the side-angle-side theorem on his own, but makes mistakes in his reasoning and refers to the example a great deal as he solves the proof. After deliberately carrying out many individual steps, the student is able to successfully solve the proof. At a later time, presented with a different problem in which the SAS theorem is applicable, the student makes the connection that the theorem is applicable and identifies how it should be applied to prove the given statement in two fluid steps. He has identified and corrected his mistakes, and he has taken discrete steps and formed a fluid procedure.

In the autonomous phase, the skill acquired is used repeatedly in appropriate contexts, and the learner gains the ability to complete the skill rapidly and accurately with very little effort. Examples of skills used in the autonomous phase include the ability of many people to "just know" that two plus two is four without actively performing the calculation or the ability to press the accelerator with one foot, steer the car, and check the rear view mirror at the same time to drive a car without deliberately thinking about any of those skills separately.

The skills acquisition literature makes the following suggestions with respect to skill development:

- **Mastering a skill involves carrying out the steps of the skill in the proper sequence and knowing when use of the skill is appropriate.**

Moving from the cognitive stage to the associative stage and from the associative stage to the autonomous stage involves understanding the sequence of steps necessary to successfully carry out a skill and then figuring out when to apply a skill in different situations. Knowing the sequence of actions necessary to carry out a skill is referred to as tactical learning [Anderson, 2000] and is necessary for successful proceduralization of a skill (i.e. moving from the cognitive stage to the associative stage). Knowing when to apply a skill involves strategic learning [Anderson, 2000] which is necessary for organizing one's problem solving during the associative stage. Multiple applications of a skill over time and across various domains move a learner from the associative stage to the autonomous stage.

- **For any given process, learners can move between the stages as they carry out the skills that for that process.**

A process may be composed of many different skills that have to be carried out in some sequence. Some skills in the process may be easier for learners to execute due to prior experience, use of skills across many different domains, etc. However, some skills in the process may be more difficult for learners to carry out due to lack of exposure, developmental difficulties, and little use of skills across different domains, etc. In cases such as these, the learner may be in the autonomous stage for certain skills in the process, in the associative stage for others, and in the cognitive stage for still others.

- **Moving from one stage to another (developing a skill) requires multiple opportunities to carry out the skill in contexts where its use is appropriate.**

In order to debug mistakes, create a procedure, and automate that procedure (moving from the cognitive to the associative to the autonomous stage), learners must have opportunities to use the skill in contexts that are appropriate. For example, we know how to tie our shoes with little effort because we have had multiple opportunities to practice the strategy taught to us when we were children. Initially, we had to repeat the strategy over and over. Once we understood the strategy and carried it out on our own, we were able to increase the speed with which we could tie our shoes. Eventually, we were able to tie our shoes without being consciously aware of what we were doing.

- **During these stages, learners need support (scaffolding).**

During the cognitive stage, learners tend to refer back to a process or example. Processes or examples can serve not only as models of a skill in use, but they can also provide reminders of what steps come next, structure for conceptualizing the problem, and an understanding of why one step follows or precedes the next. These are all examples of scaffolding. During the associative stage, learners tend to use the scaffolding to help them figure out why their application may have failed, debugging their procedure for carrying out the skill so that it can be used with favorable outcomes each time.

- **Failure is important to successfully acquiring and developing a skill.**

As learners are in the cognitive phase, they make many mistakes, but these mistakes help them to proceduralize the skill, debugging the steps necessary to carry out the skill. This proceduralization leads to an increase in the speed and accuracy with which the skill is executed, both of which are characteristic of movement into the autonomous stage [Anderson, 2000].

2.1.2 Transfer – Use Of Reasoning Skills Across Situations And Domains

Transfer [Donoavan, Bransford, & Pellegrino, 1999; Bransford, Brown, and Cocking, 1999] is the process by which knowledge learned in one kind of situation is made accessible and applicable to other kinds of situations. Transfer, in the context of science learning, has two parts: (1) learning scientific concepts and their conditions of applicability in order to engage in scientific reasoning and (2) becoming competent practitioners of the practices of the scientific community (e.g., generating questions, designing experiments, managing variables, justifying with evidence, analyzing results, planning investigations, communicating ideas and results). The science education community and the American standards on science literacy [American Association for the Advancement of Science (AAAS), 1993] ask that students become competent in both areas and able to carry out the practices of scientists in skilled ways both inside and outside the classroom.

The transfer literature tells us much about influences on transfer, including the need for students to understand a concept, having abstract representations of knowledge in their minds, which takes both time and “deliberate practice” [Ericsson, Krampe, and Tesch-Romer, 1993] to create and perfect, viewing transfer as an active dynamic process, and taking into account that all new learning involves transfer based on previous learning [Bransford, Brown, & Cocking, 1999]. In particular, skill development in inquiry requires that students have a deep understanding of content, understand that content in the context of skills, processes, and practices (i.e. a conceptual framework), and organize their knowledge in ways that facilitate retrieval and application. Creating that conceptual framework and helping students organize information within that framework allows for greater transfer by allowing the student to apply what was learned in an old situation to a new one and allowing the student to learn related information more quickly.

Skill development in inquiry is a major focus of the transfer literature, and our work seeks to examine one set of skills: case use. One of the goals of this work is to understand ways to support students as they engage in applying cases to solve problems so that they can transfer that set of skills across many different learning situations. This literature suggests [Branford, Brown, & Cocking, 1999]:

- **Students need opportunities to make connections between their experiences and the knowledge or skills they are learning.**

In order for students to use knowledge and skills more flexibly, they need to experience employing knowledge and skills in different contexts. Along with those experiences, students need opportunities to reflect on the similarities and differences across experiences as they use that knowledge and those skills, making connections along the way that help them understand when and how to use knowledge and skills depending on the context of the situation.

- **Students need enough time to learn and develop skills.**

Providing enough time for students to acquire and develop skills is crucial because in order to use the skills they are learning in flexible ways, they need to understand and recognize situations in which they can apply those skills. This means that students need to be supported across multiple, similar situations, and that takes time. Not devoting enough time toward helping students acquire and develop a set of skills will result in them only being able to use those skills in the context in which they were learned. Giving student multiple opportunities to use the set of skills and to reflect on how they were used allows students to learn to use those skills in different kinds of situations, promoting flexibility.

- **Students need to be able to see potential situations in which they can apply the skills they have acquired.**

Part of being able to use skills flexibly involves understanding when skills can and cannot be applied. In order for students to identify when a skill can and cannot be applied, they need to not only reflect on how the skill was used in the present situation, but they also need to reflect on the similarity or difference of this situation to other situations and the impact that has on whether applying a skill will result in the same or different outcomes. Prompting students to consider situations that are slightly different from the current situation can help them begin to understand the conditions of applicability of a skills or set of skills.

- **Students should have opportunities to solve several similar cases to promote flexibility of use of knowledge and skills.**

This suggests that the activities and the tools used to scaffold students through those activities should be organized in ways that give students multiple chances to apply the skills they are learning in different situations. They should then make connections across the cases to understand the conditions of use for a skill or set of skills.

- **Students should be supported as they engage in deliberate practice.**

As students are using the target skills, help should be available that encourages them to reflect on how they are using the skills, why they are using the skills, when they should use the skills, and the kinds of outcomes that should result. This suggests that scaffolding should help students not only as they employ the target skills to make it through the task, but also as they learn from the task and seek to understand more deeply the skills needed to achieve the task and the times when that task needs to be carried out.

- **Students need feedback about how well they are learning and developing skills.**

This suggests that learners should have learning experiences that give them the opportunity to apply what they are learning in such a way that they can experience and interpret the outcomes that result. This feedback should help them not only assess their own progress, but it should also help them gain a deeper understanding of the context of applicability for a skill or set of skills.

- **Students should be supported as they attempt to represent problems at higher levels of abstraction.**

Scaffolding should be provided that helps students pull out abstract concepts or draw out the lessons they can learn as they apply a skill or set of skills in different situations.

- **Students should be encouraged to monitor their learning and should be supported as they learn metacognitive strategies.**

Scaffolding should be provided to help students understand and learn how to assess their own progress and development. Students should also be given opportunities apply those strategies.

2.1.3 Case Based Reasoning (CBR) – Suggestions For Learning Environment And Processes/Practices

Case-based reasoning [Kolodner, 1993; Kolodner, 1997; Kolodner, Gray & Fasse, 2003], which focuses on learning from real-world experiences, suggests a computational model of many of the processes involved in transfer. In CBR, real-world experiences, called cases, are called upon in order to solve current problems, evaluate solutions for favorable and unfavorable outcomes, interpret new situations, re-interpret old situations, and discover connections across experiences. CBR suggests that skills learning is a process of reinterpreting the context of use of skills based on the outcomes that result as skills are used in each situation. That model, in turn, makes many suggestions about how to promote skill development as well as transfer of those skills in the classroom [Owensby & Kolodner, 2002].

- **A case-based reasoner learns by acquiring cases and encoding them actively.**

A case-based reasoner learns best by intentionally interpreting experiences in ways that allow it to extract lessons learned. This allows the reasoner to anticipate the kinds of situations that these lessons may be applicable to, to encode them in such a way that they will be easily accessible when needed. This suggests several rules for the classroom [Kolodner, 1997]: (1) the objectives that students should be learning should be clear and the activities that students engage in should have affordances for achieving those objectives, (2) there should be help available to students to help them interpret their experiences in ways that allow them to extract the lessons learned, and (3) there should be assistance to help students anticipate when what they are learning might be applicable. Schank [1982, 1999] speaks to the richness and connectedness of one's experiences, as well as the difficulties involved in understanding and connecting second-hand experiences.

- **Failure, explanation of failure, and a chance to try again are critical to learning.**

Failure is critical because when one fails to achieve what one expected or when one is surprised, one is motivated to explain why the failure occurred and to apply what one has learned from the failure to do better next time. In other words, failure has the affordance of focusing the learner in on what he/she needs to learn. This suggests that the feedback that students receive should make it clear to them whether their expectations have failed, and it should be meaningful and interpretable enough that it can focus students on what else they need to learn. This also suggests that students should have opportunities to find out what they need to learn and to use it to experience success.

- **A reasoner who is connected to the world will be able to judge how good its predictions are and determine whether he/she has succeeded or failed based on an evaluation of his/her solutions and the results that come from them.**

This suggests that learners should be engaging in the kinds of learning experiences that give them the opportunity to apply what they are learning in ways that allow them to experience the effects of what they have done through real, interpretable, and timely feedback.

- **When an old case fails in a new situation, a need for explanation may result in reinterpreting the old situation and/or discovering new interpretations.**

Sometimes, this cannot be achieved immediately because the learner does not have all the information they need to interpret the situation properly. An iterative cycle can help learners interpret situations because an iterative cycle gives learners the opportunity to revisit old experiences [Kolodner, Hmelo, & Narayanan, 1996]. By attempting to apply the old experiences in a variety of ways, each time the learner refines the experience based on the new explanations the experience can derive. This suggests that students should engage in an iterative cycle of applying what they are learning in new situations, failing in application, explaining why the failure occurred, and repeating the process incrementally. On each iteration, students should be aided in noticing failures, developing explanations, and re-interpreting experiences.

- **If an experience is analyzed very well, it will be interpreted and encoded in memory in better ways. As a result, it will be easier to access—hence, learning will be better.**

This suggests the importance of students to reflect deeply on their experiences and interpret them well.

- **One experience can hold affordances for learning many different things.**

This suggests two things. First, we need to help learners "see" the many things that can be learned from their experiences and help them use those experiences to learn a wide range of abstract concepts, domain-specific skills, and social and cognitive skills that can be gleaned from their experiences. Second, learners may need help identifying the important aspect of an experience so they do not get lost in all of the possibilities.

- **More productive reasoning can be carried out by reasoners that are more expert at reasoning.**

This suggests that we may need to help students strategically recall what they know at the right times, judge the applicability of what they've recalled, and apply what they've recalled. Helping students gain these skills will also help them learn to better carry out this process on their own.

2.1.4 Cognitive Apprenticeship – A Classroom System

Cognitive apprenticeship [Collins, Brown & Newman, 1989] is a framework for designing learning environments that suggests that skills learning can be promoted if learners have the opportunity to see the skills they are trying to learn modeled in contexts of use and then have opportunities to be coached through carrying out those skills themselves, within a context where those skills are needed and used repeatedly. It takes the concept of skills learning employed in traditional apprenticeships and applies it to the idea of learning cognitive skills. The main difference between traditional apprenticeships and cognitive ones is that in traditional apprenticeships, processes and the skills involved in carrying out those processes are observable and external, while cognitive apprenticeships focus on unobservable, internal processes and their associated skills. Both types of apprenticeships involve modeling/observing, coaching, and practice or successive approximation.

Modeling involves a more expert person carrying out the task while focusing the less expert learner's attention on the process and the nuances of that task. The less expert learner observes the more expert person as they engage in the task, thereby developing a conceptual model of the target task or process prior to attempting to carry it out themselves. Creating this conceptual framework serves as an advanced organizer for the learner's initial attempts at carrying out the complex task, provides an interpretive structure for making sense of feedback, and provides an internalized guide for successive approximation.

Coaching involves the more expert person providing guidance or support to the less expert learner as he/she carries out the task. This guidance, called scaffolding, can be in the form of focusing attention, providing reminders, hinting at things to be careful about while carrying out the task, prompting the less expert learner for understanding and helping the less expert learner identify gaps in their knowledge, but in educational settings, scaffolding serves to support students as they are carrying out a task they wouldn't be able to carry out otherwise, and it serves to help students learn from their efforts (i.e. develop the skills needed to carry out the task so that they perform better at the task in the future) [Reiser, Tabak, Sandoval, Smith, Steinmuller, Leone, 2000; Reiser, 2004]. This kind of guidance is aimed at supporting students as they carry out tasks that are within, what Vygotsky [1978] calls, their Zone of Proximal Development**,** which is the difference between what a child can do with help and what he or she can do without guidance.

Successive approximation gives the less expert learner the opportunity to carry out the task repeatedly, using scaffolding as needed, until the less expert learner becomes an expert at the task. The idea that apprentices that are more skilled can scaffold apprentices that are less skilled suggests a trajectory of skill development, with the left end being labeled novice or unskilled apprentice and the right end being labeled expert or master. This trajectory suggests two things: 1) More skilled apprentices are capable of scaffolding less skilled apprentices within this framework (suggesting that learners can scaffold each other), and 2) the trajectory of skill development is important for both the expert and the novice, allowing the expert to assess where a learner's skill development currently lies on the trajectory, and allowing the novice to chart their own skill development. Through the cognitive apprenticeship approach, learners master skills, and as such, shift their Zone of Proximal Development.

These three phases in the cognitive apprenticeship model suggest a classroom system, comprised of an overall approach to learning (i.e. a curriculum that is grounded in a particular approach to learning), activities within the classroom that are grounded in the chosen learning approach and that support and promote skill acquisition and development as well as the roles that the teacher, software, and students should take on as skills are acquired and developed. For example, Learning By Design's classroom system is comprised of activities whose sequencing and enactment are directly informed by case-based reasoning and problem-based learning [Kolodner, 1993, 1997; Koschmann, et. al., 1996]. Students engage in activities that promote and support skill acquisition and development through repeated enactment of scripted activities [Kolodner & Gray, 2002; Kolodner, Camp, Crismond, Fasse, Gray, Holbrook & Ryan, 2003; Kolodner, Gray & Fasse, 2003]. These "rituals" give students multiple opportunities to develop skills and to reflect on the processes of design and inquiry. Within the LBD environment, the teacher plays the role of modeler and coach. As students become more and more familiar with the rituals, they are able to model skills and coach each other, resulting in a shifting of agency [Scardamalia & Bereiter, 1991] and refinement of scientific reasoning and collaborative skills.

Therefore, the classroom environment should be designed to allow teachers to model tasks, in the way cognitive apprenticeship suggests, initially, as well as allow students who are further along the trajectory to model pieces of the task for students who are not as far along the trajectory. The curriculum or overall learning environment in which activities are carried out and skills are acquired and developed should be designed to afford deep learning of content and the skills and practices needed to actively apply that content. Activities within the classroom environment should be designed and implemented in such a way as to not only take advantage of the affordances of the learning environment or curriculum, but also give students opportunities to repeatedly carry out the task and its respective skills in situations and at times when the task is needed in order to learn content or understand a larger process. The classroom environment should be designed in such a way that the roles of modeler and coach, and the ways and times each of these roles should be assumed, are clear to the teacher, so that the trajectory of student skill development can be understood and difficulties can be addressed appropriately.

As a result, cognitive apprenticeship suggests:

- **A trajectory for skill development exists that moves from a novice needing a great deal of scaffolding to an expert that has internalized the skills needed to carry out a task or process.**

With the novice requiring a great deal of scaffolding initially, and with the expert fading the scaffolding as the novice's successive approximations become more and more in line with expert processes, a trajectory can be fleshed out according to the particular task being scaffolded. Included in a trajectory are the skills necessary to engage in that task, the particular kinds of scaffolds needed to support students as they carry out the task, and the activities students engage in that give them the opportunity to employ those skills as they repeatedly carry out the task.

- **Novices need scaffolding during different parts of a task and more skilled learners are able to scaffold less skilled learners.**

Multiple scaffolds are necessary to guide less expert learners through complex tasks. This means that no one scaffold alone can provide all the supports that learners need. These multiple scaffolds make up a system of scaffolds that can be used to meet the varying needs of learners as they carry out complex tasks. Cognitive apprenticeship also suggests that identifying the needs of learners and providing scaffolds to meet those specific needs is important.

- **There are several roles a computer might play in a skills learning classroom.**

Many of them are the same roles it suggests teachers should play: modeling the steps in complex processes for students, helping them make connections between the steps and the knowledge and skills they are learning along the way; coaching students as they attempt to carry out complex tasks, providing scaffolding when needed; and providing opportunities for students to develop their skills through practice as they strive for mastery of the task and associated skills.

- **The computer can act as another scaffolding agent in the classroom, embedded into the system of classroom activities.**

However, in order for the computer to play its role properly or serve as a scaffolding agent in the way that cognitive apprenticeship suggests, the design of the software must be such that it is known and understood within the classroom environment which role(s) are solely taken on by the teacher, which role(s) are primarily taken on by the teacher, which role(s) are solely taken on by the software, which role(s) are primarily taken on by the software, and which role(s) the teacher and software share equally. The software should be integrated within the classroom environment in such a way that its use is seamless and its inclusion in activities is understood and needed by students. Software should be not be included in activities until students have had the opportunity to attempt carrying out the skills themselves, after the skills have been initially modeled by the teacher, and after students have grappled with the difficulties novices experience as they carry out the task [Reiser, et al., 2000]. This helps the students understand what needs of theirs the software should meet, and it helps them not only get an idea of the trajectory of skill development, but also monitor their progression along that trajectory. The software should be designed in such a way that it can be readily used during times where students need scaffolding to carry out skills or when they need to see the task or its processes in order to move forward as they are solving problems.

2.1.5 Summary

Several theoretical viewpoints exist that frame this work. The skills acquisition literature addresses how skills are taken up and developed. The transfer literature addresses ways to promote the application of skills. Case-based reasoning makes suggestions about what is needed in the learning environment to promote productive interpretation and application of experiences so that they can be used to promote learning. Cognitive apprenticeship focuses on the roles that should be played as less expert learners are acquiring and developing skills. This sets the stage for understanding, describing, and analyzing what happens as students develop these skills working together in a classroom.

2.2 Small Group Collaboration During Complex Skill Development

Not only are students developing complex skills in a classroom in our work, but they are also collaboratively solving problems as they develop complex skills. This suggests the need to understand how groups collaborate as they are solving complex problems and what tools may be helpful in aiding them. What is collaboration—what are the benefits and possible detriments? How has small group collaboration been described in the context of complex skills learning—what aspects of collaboration have been described? What affordances exist for small group collaboration around an artifact (like a computer)? This section seeks to address what the literature suggests about these aspects of collaboration.

Some view science as largely social rather than simply individual for a number of reasons [Latour, 1987]. First, much of science involves scientists working on teams to solve problems. Second, the tools that scientists use and the knowledge they employ to solve problems are socially established, validated, and accepted by social means which involves a process created socially during the formation of the discipline. Third, scientists think, act, and reflect on the tools and knowledge of the community, and those activities are directed toward and carried out in the scientific community to which they belong. As a result, scientists are part of local and global networks that are "institutionalized social systems through which any knowledge claim is generated, negotiated, and legitimized" [Latour, 1987]. In addition to knowledge being generated, negotiated, and legitimized, the practices of scientists and the skills useful in carrying out those practices are also socially generated, negotiated, and legitimized. As such, science is collaborative in nature.

2.2.1 Collaboration: Description, Benefits, And Potential Detriments

Three different descriptions of collaboration exist distinguished by the primary benefit resulting from collaborative interactions [Vygotsky, 1978; Piaget, 1932; Roschelle, 1996]. Vygotsky describes collaboration as scaffolding and appropriation in which scaffolding is provided by a more expert peer and knowledge and skills are appropriated by a less expert peer. Piaget describes collaboration as the production of productive individual cognitive conflict. This individual cognitive conflict creates disequilibrium and, as a result of the group and individual attempting to re-establish equilibrium, their collaborative activity drives conceptual change. Roschelle describes collaboration as convergent conceptual change in that collaboration results in a mutual construction of understanding. It is our view that collaboration involves all three of these views. For our purposes, we define collaboration as the appropriation of skills by less expert group members as they are scaffolded by more skilled experts, driven by the need to resolve the disequilibrium created by cognitive conflict that emerges between individual group members in their attempts to negotiate meaning and create a mutual construction of understanding of knowledge and skills. The desired outcome is two-fold [Feltovich, Spiro, Coulson & Feltovich, 1996]: (1) to enable students to understand deeply and to have the ability to apply and transfer knowledge and skills to novel situations where the use of those knowledge and skills is appropriate; and (2) to develop in individual group members the ability to "think like a group" by considering multiple interpretations and using knowledge more flexibly.

How does collaboration seem to achieve these desired outcomes? When does it seem to fall short? The literature has described numerous benefits of collaboration Feltovich, Spiro, Coulson & Feltovich, 1996; Koschmann, Kelson, Feltovich & Barrows, 1996; Roschelle, 1996; Bayer, 1990; Wells & Chang-Wells, 1992; Barron, et. al, 1998, Barron, 2003]:

- Individuals will bring different perspectives to the learning process, which will contribute to a greater understanding by the group.
- In a group setting, it is more likely that the limitations of individuals to adopt single interpretations or representations without entertaining alternative ones will be counteracted by the alternative interpretations of the group.

- Even when group discussion reveals opposing interpretations or perspectives, the discussion can uncover areas of common ground in the midst of opposition and can lead to a newer and richer understanding as well as a negotiation of meaning among the group and individuals within the group.
- The ability of the group to reveal conflicts, negotiate meaning, and uncover common ground can serve to model the thinking necessary to carry out those actions. This helps individuals in the group to think more like a group, which should better prepare them for complexity, both when they are alone and within groups because the likelihood that individuals will develop complexity-supporting cognitive structures should increase.
- The process of group collaboration allows the group to create a shared definition of meaning by allowing each individual the opportunity to see and learn from the struggles of other group members as they try to understand. This access to the struggles of others may facilitate and impact the individual's own ability to adapt their own processes in the face of struggles.
- Collaboration affords conversational interaction that can enable the group to incrementally construct meanings and connections between concepts and skills resulting in increasingly sophisticated approximations to scientific concepts and practices.
- Collaboration provides a mechanism for achieving convergent meanings and connections between concepts and/or skills.

- More knowledgeable/skilled peers in the group can provide expert guidance to less knowledgeable/skilled members of the group, resulting in an apprenticeship process within the group.
- Using collaborative tools with peers challenges learners to construct novel situations, to consider alternatives suggested by others, and to justify and clarify their own point of view in order to communicate with and convince their group members.
- Collaborative discussion for sense-making affords students the opportunity to offer their interpretations and, as the group discusses, allows students to calibrate their interpretations with those of other members of the group (and the teacher as he/she may provide help to the group).

However, one cannot expect for effective and successful collaboration to happen by simply putting students in groups. They must be trained to function as an effective group [Cavali-Sforza, Lesgold & Wiener, 1992]. Repeated interactions with the group as well as the teacher's facilitation of class discussions serve as models of how to interact within a group (i.e. how to entertain multiple perspectives, how to justify claims with evidence, how to question each other, etc.). The development of the "higher mental functions", like those involved in scientific reasoning (i.e. generating hypothesis, using evidence to support a claim, explaining phenomena scientifically, interpreting and applying experiences) start as behavior that is defined by group interactions, and becomes appropriated and transformed into behavior that is developed and used by the individual [Vygotsky, 1978; Wells & Chang-Wells, 1992; Owensby & Kolodner, 2004].

One potential detriment to effective collaboration is the polling problem [Koschmann, Kelson, Feltovich & Barrows, 1996]. The polling problems results when the opinions of individuals vary as a function of the order in which their views are gathered. So, less dominant members' ideas may be suppressed or tainted by more dominant group members, or individuals within a group may be inappropriately influenced by other group members because of personality (more confident, more aggressive, more argumentative, etc.). The polling problem often results in a lack of or a reduction of multiple perspectives, viewpoints, and interpretations for the group to consider. Ineffective collaboration may also result when a few group members do the work while other group members "ride their coattails." These group members do not contribute to the meanings negotiated and the understandings reached by the group, but they are able to share the credit for the meanings and understandings generated by a few group members.

2.2.2 Collaboration: Important Aspects Of Collaboration

The benefits of collaboration have been outlined, but how have those benefits been derived? How has small group collaboration been described in the context of complex skills learning? Several aspects of collaboration have been studied and described, namely collaborative discussion, interactions of members within the group, and intersubjectivity [Roth, 1995; Barron, 2003] within the group. Each of these will be described separately.

2.2.2.1 Collaborative Discussion

"Language is the mechanism through which negotiation of meaning occurs" [Latour, 1987]. This quote captures the essence of collaborative discussion. In particular, students who are collaborating with each other in small groups are likely to use expressive talk which is informal conversational-like talk that allows groups to work out the meanings of concepts under discussion as well as to clarify, expound, and qualify ideas [Latour, 1987]. As meanings are negotiated, group talk becomes less expressive and more formal, including appropriate uses of specialized vocabulary instead of more ambiguous terms like "it" or "that". Discourse related to a task can result in collaboratively constructed, validated, and modified knowledge [Wells & Chang-Wells, 1992]. In fact, what a scientific community knows and believes is constructed in the dialogue, both through speech and text, through which practitioners "maintain, modify, and develop theories and interpretive practices that constitute the different disciplines" [Wells & Chang-Wells, 1992].

2.2.2.2 Interactions Of Members Within The Group

"Actions as they are related to the situation must be considered in order to construct intelligible interpretations of what is taking place" [Roschelle, 1996]. In most cases, collaborative discussion cannot be understood and interpreted without first understanding the context in which that discussion took place. Part of that context involves the interactions among group members. Roth [1995] describes five different kinds of interactional patterns that have been observed in inquiry classrooms:

- Symmetric – interactions in which all group members participate equally and none of the members dominate the group's talk for any significant length of time.
- Asymmetric – interactions in which the students' talk and/or activity is dominated by an individual in the group.

- Shifting asymmetric – interactions in which students contribute to the discourse relatively equally in terms of substantive comments and time, but the contributions are unequally distributed over time.
- Parallel occasional – interactions in which there are long periods of silence, interspersed with occasional interactions of varying length.
- No participation – situations in which students do not contribute at all in the group to which they are members.

2.2.2.3 Intersubjectivity Within The Group

The goal of a collaborative group is to achieve some goal using some process and to know that members of the group understand the goal in a similar way and that members of the group know and refer to the same things. This is called intersubjectivity [Roth, 1995, Barron, 2003]. Intersubjectivity is assumed as the default when groups are collaborating. Whenever a group is attempting to maintain intersubjectivity or it becomes apparent that intersubjectivity has been lost, collaborative groups attempt to maintain or re-establish intersubjectivity through various types of mediation. As they are working to achieve intersubjectivity through mediation, collaborative groups have different resources they can use to assist them. In order for intersubjectivity to be re-established and negotiated, some mechanism must exist that makes it possible for two or more individuals to reach an understanding or a definition of meaning they consider to be shared. Roth [1995] calls this mechanism semiotic mediation. Semiotic mediation to achieve intersubjectivity can occur a number of ways and employ a number of resources. Collaborative discussion and interactions of members within the group are both impacted by a group's level of intersubjectivity. Semiotic mediation can occur in different ways [Roth, 1995; Barron, 2003]:

- Use of verbal signs

This involves using talk to recognize that intersubjectivity does not exist and to establish shared understandings.

- Means of diagrams or other forms of written symbols.

This involves using physical objects and diagrams to mediate a collaborative group's construction of meaning.

- Non-verbal means

This involves using gestures to mediate a collaborative group's construction of meaning.

Different resources are also available to collaborative groups as they engage in semiotic mediation to achieve intersubjectivity [Roth, 1995]:

Teacher – Collaborative groups can ask questions or use information about content or skills presented by the teacher as justification or evidence during collaborative discussion.

Textbook – Students in collaborative groups can use texts as evidence to support their arguments and ideas. This use may be direct (as in reading directly from the text) or indirect (as in recalling from memory a portion of the text).

Student knowledge – Collaborative groups can use individual prior knowledge to establish or validate the credibility of a statement.

Observational evidence – Students in collaborative groups can use or refer to experiments and simulations to support their scientific arguments.

2.2.2.4 Collaboration: Affordances Of Collaboration Around A Tool

The use of “intellectual tools” to aid learners as they encounter particular problems in the context of collaborative goal-directed activity is a key component of the development of cognition and complex skills [Vygotsky, 1978]. Speech is an example of one “intellectual tool” that aids students as they are engaging in collaborative problem-solving. The computer is another, and it serves as a resource that students can use as they engage in semiotic mediation. Computers can aid groups of collaborating learners in several ways [Feltovich, Spiro, Coulson & Feltovich, 1996; Koschmann, Kelson, Feltovich, 1996; Barrows, 2003]:

- Computers afford the acquisition and retention of multiple representations, resulting in exposure of a group to multiple interpretations and multiple connections among different representations and elements of a domain.
- Computers can expose and demonstrate the ill-structured complexity of a domain while providing help for learners to manage that complexity.
- Computers can provide easy access to resources for learning.
- Computers can allow for the selection of cases and provides a mechanism for selection of appropriate cases from the full set of cases as well as a retrievable record of the deliberations of the group with respect to previously studied cases that may be useful by the same group at a later time or by a different group studying the same topic.
- Computers can provide a way for groups and students to index their work so they can retrieve it later.
- Computers can allow for the sharing of information outside of the group.

- Computers can help cumulatively raise the level of quality of discussion, debate, inquiry, and learning within a group and within the class.

However, placing computers and computer-supported collaborative learning tools into a learning environment by itself is not enough to achieve successful collaborative learning. Computers and video displays can be distractions for students, keeping them from focusing on their current task. To decrease the likelihood of this phenomenon, computers and computer supported collaborative tools should [Koschmann, Kelson, Feltovich & Barrows, 1996] strive to accomplish the following things:

Support and augment group discussion, not replace it

Reflect and support current best practices in the learning environment

Meet the instructional requirements of the setting into which they will be integrated

Take advantage of the affordances of the proposed technology

- Allow for adaptation to instructional practice

2.3 Supporting Complex Skill Development In Science With Software

While scaffolding in educational settings supports both carrying out tasks and learning through skill development, no one scaffold alone can provide all of the support students will need. Cognitive apprenticeship suggests that multiple scaffolds across multiple agents are useful in skill development. How have others supported students as they develop complex skills using multiple scaffolds? This section seeks to analyze three approaches that give suggestions about scaffolding students through complex tasks. We claim that a system of scaffolds, an integrated set of scaffolds that serve to support students engaged in complex tasks, is necessary to promote skill development. This is not to suggest that skill development does not occur without scaffolds. However, because every student is not equally capable at every skill, some students will need scaffolding in order to carry out and learn skills and processes. For those students, each scaffold within a system of scaffolds is designed to meet students' specific needs. When integrated into a classroom system, in which teacher, student, and software are effectively taking on their roles and supporting students as they engage in activities designed to take advantage of the affordances of the learning environment, productive skill development should result.

This section reviews several projects that support complex skill development through understanding and addressing the classroom system (to varying degrees) and by employing a system of scaffolds. Each of these projects (and research within the field in general) support employing multiple scaffolds in the design of educational software to support students' skill development. Each of these projects speak to the specific need each scaffold fulfills, place emphasis on the roles that the teacher and software must assume in order for students to acquire the skills each seeks to support and develop, and ground the scaffolds they employ within cognitive apprenticeship. However, none seem to employ the same system of scaffolds to support skill acquisition and development across multiple tools.

The three projects analyzed in this section are the Web-based Integrated Science Environment with the Knowledge Integration Environment as its scaffolding framework (KIE/WISE), the Biology Guided Inquiry Learning Environments (BGuILE), and Symphony. Each of these projects will be described and analyzed with respect to the classroom system and the system of scaffolds, focusing on specific scaffolds employed to support complex skill development. Since there is no unified theory describing principles for software-realized scaffolding [Guzdial, 1994], we seek to identify common types of scaffolds that, while implemented in different ways, are common across a number of projects and educational software. We also seek to describe if and how these projects support students as they learn skills through contextualized experiences, with the goal of helping them abstract more general principles over time. Our framework will build on this.

Since there is no unified theory of scaffolding nor a classification system that can be used to describe various types of scaffolds, we will use the following terms to describe various types of scaffolds that will be discussed in this section and in our work:

- **Prompts** are questions or statements used to focus students' attention as they are carrying out a task or reflecting on a task. They are independent of domain and can be used across a variety of tasks. "What did you learn here?" and "What advice do you have for others?" are examples of prompts.
- **Hints** are task-specific/domain-specific questions or statements used to refine a task. They can be used to explain a step of an activity in detail, to suggest specific strategies to use to carry out a task, or to provide specific suggestions for reflection. "Identify the process in the cell affected by the antibiotic" or "How do you interpret your graphs? What do the graphs "say" to you?" are examples of hints.
- **Examples** are exemplars that can be used to model a process or a specific step to students. Examples can be annotated, describing how each step is connected in a process, or they can be model statements that students can follow to articulate their ideas in appropriate ways. Guzdial & Kehoe [1998] provide annotated examples in

STABLE that can be used by students learning to program so that they can understand how one step logically leads to another step.

- **Charts/Templates** are reminders that help students articulate and organize their ideas in such a way that they can be used by others. BGuILE's Strategic Artifacts is an example of a chart/template—it is designed to help students decompose complex behavior into components that can be characterized and used to help students organize their observations and interpretations [Reiser, 2004].
- **Structure** is used to describe the orientation of information on the screen such that it suggests how a task should be carried out. Structure can also be used to describe the path by which students use educational software such that it suggests a high-level process that students will be engaging in. Examples of structure will be described in detail later.

These descriptions of scaffolds will be used to describe and analyze the software-realized scaffolds employed by the three approaches.

2.3.1 KIE/WISE

2.3.1.1 Overview

KIE/WISE [Bell, Davis, & Linn, 1995; Bell & Davis, 2000; Cuthbert, 2000] is an on-going project that teaches middle-school science topics as well as knowledge integration, which involves linking and connecting ideas, through three types of projects: critique, comparison, and design. Critique projects require students to develop and apply criteria for evaluating scientific evidence. Comparison projects prompt students to engage in debate by comparing and contrasting differing hypotheses about a science problem. Design projects involve supporting students as they critique and refine their own ideas, as well as the ideas of their peers, while creating a solution to a design task. As such, KIE/WISE focuses on developing students' ability to integrate knowledge, create and apply criteria to evaluate scientific evidence, and use the evaluation of scientific evidence to support an argument. When learning and developing these skills, students may experience difficulties identifying the links that connect ideas. They may also struggle to identify the criteria that should be used to evaluate scientific evidence as well as to apply the criteria identified. Students may also experience difficulty using their evaluation of scientific evidence to support an argument or claim.

WISE defines scaffolding as the supports needed by students and teachers to develop learning processes where ideas become linked, connected, and integrated [Cuthbert, 2000]. The researchers call these scaffolds "portable scaffolds" because they help support students' development of knowledge integration skills that can be applied to other situations, but the scaffolds are utilized in specific contexts [Cutberth, 2000]. Scaffolding in WISE is built using the Scaffolded Knowledge Integration Framework.

2.3.1.2 Overall Curriculum/Learning Environment

KIE/WISE embeds the software within the larger curriculum. The software is designed to support students as they engage in the activities that promote using evidence to justify claims. The curriculum is inquiry- and project-based with students solving complex science problems, integrating knowledge through causal explanations, and answering or analyzing complex science questions. KIE/WISE's learning environment (i.e. teacher, peers, software, activities, and culture) is designed and structured to create an environment in which knowledge and skills are integrated to answer science questions. Software is designed with both the classroom system, described earlier, and the development of students' ability to carry out expert skills and processes in mind. For example, in "How Far Does Light Go?", students iteratively refine their understanding of light by engaging in activities that require them to explore two differing theories. Students hypothesize about which theory is correct and then explore a set of evidence to understand how each piece of evidence is related to the two theories, develop an argument based on the set of evidence, and engage in debate with peers based on the evidence and arguments they've developed [Bell & Davis, 2000]. The software's scaffolding helps students carry out these activities.

2.3.1.3 KIE/WISE's System Of Scaffolds

KIE/WISE uses prompts, which they call notes, to help students articulate and reflect on their ideas. Used to support students' use of evidence to support an argument or a claim, these prompts take on the form of sentence starters such as "When we critique evidence, we need to…" and are designed to focus students' thinking on important aspects of the process as they seek to link their ideas to evidence. Prompts are implemented in software as an evidence note-taking feature and are task sensitive, with different styles of prompts being used both for critiquing evidence and making claims as well as different domains [Bell & Davis, 2000], as shown in Figure 2.1. Several studies showed that prompting students to reflect increased their ability to integrate their claims with science and causal evidence during science projects by encouraging them to demonstrate their understanding through integration of their knowledge. These prompts support students as they identify the links that connect ideas.

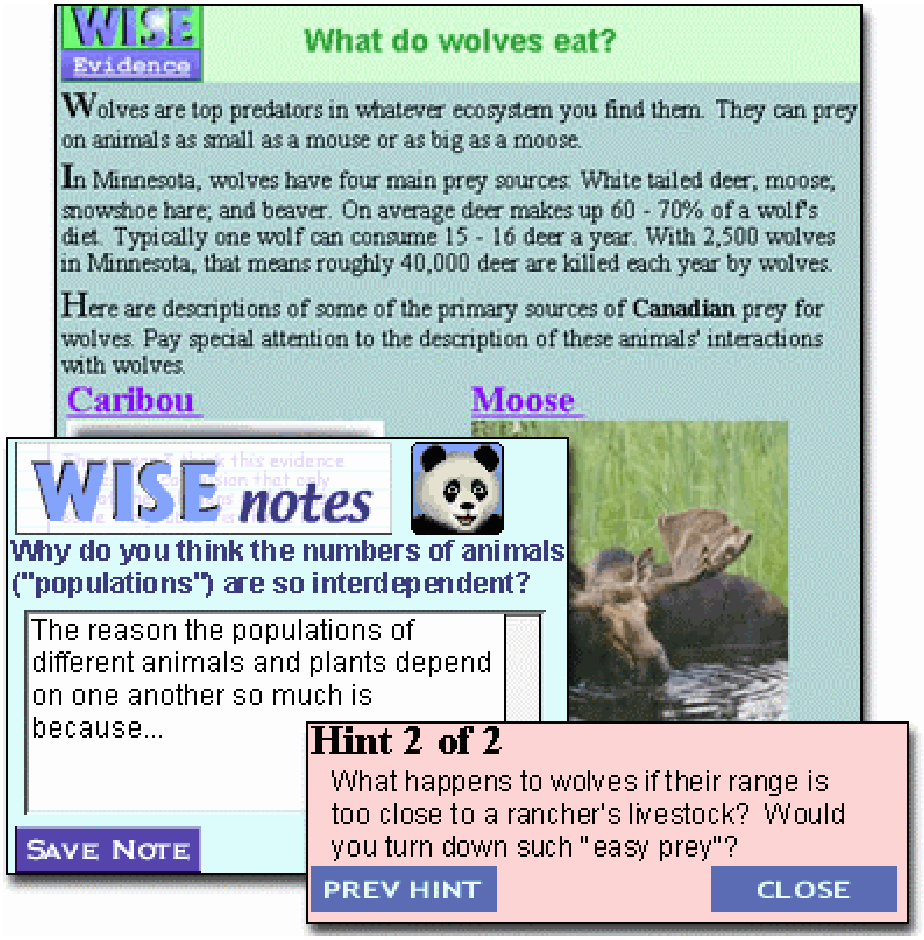


Figure 2.1: KIE/WISE Prompt and Hints

In KIE/WISE, hints serve to help students reflect in particular ways, to connect their own experiences to the science they are learning, and to direct students as they carry out a procedure. The hints support students as they are identifying criteria that can be used to evaluate scientific evidence. Hints are context-sensitive, and students have the option of viewing or not viewing a hint—if they need a hint, they click on a “show hint” button and are then able to view hints, as Figure 2.1 shows.

KIE/WISE uses a project checklist containing an activities list that is specific to each challenge as a structure to make the high-level steps involved in interpreting and applying causal evidence to support or refute a claim more visible to students. Figure 2.2 shows such a checklist for “How Far Does Light Go?” For example, an activities list may include the following: *Get Started, Critique Evidence, Critique Claims,* and *Write Letter*. As students move through the challenge, the appropriate activity in the list is checked off. This very simple structuring can help students keep track of where they are within the larger complex task or process, and it helps them monitor their progress. Structure as a scaffold can help students use their evaluation of scientific evidence to support an argument or claim. Prompts, hints, and the structure of the software could be used to support students as they apply the criteria they've identified to evaluate scientific evidence.

Figure 2.2: KIE Project Checklist

2.3.1.4 Strengths And Weaknesses

KIE/WISE has several strengths:

- Studies have shown that KIE/WISE is effective in helping students understand and construct causal explanation across a number of domains [Bell & Davis, 2000].
- The Scaffolded Knowledge Integration Framework provides a structure upon which various software tools can be designed to help students develop skills across different domains.
- Students get multiple opportunities to employ the skills they are trying to develop.
- Students get multiple opportunities to refine their understanding of the processes and contexts in which the skills are used.

KIE/WISE also has several weaknesses:

- While KIE/WISE employs software-realized scaffolds to support students through complex tasks, the teacher serves as the modeler and coach, and the software as an expert, does not actively take on either of those roles as cognitive apprenticeship suggests.
- The software does not seem employ examples to help students understand how to construct causal explanations or what "good" causal explanations look like.

<u>2.3.1.5 How KIE/WISE Manages The Relationship Between Specific Examples and General Principles</u>

KIE/WISE seems to manage the relationship between specific examples and general principles through the different kinds of projects students engage in. Each critique project provides a specific example of creating and applying criteria to judge evidence. The Design project provides and opportunity for students to critique ideas across different domains. Critiquing their own ideas, the ideas of "expert" evidence, and the ideas of their peers provides opportunities for students to glean more general principles about the processes involved in critiquing evidence that can be applied in many domains.

2.3.2 BGuILE

2.3.2.1 Overview

BGuILE [Reiser, Tabak, Sandoval, Smith, Steinmuller & Leone, 2000; Reiser, 2004] is an on-going project that teaches middle-school and high school biology. Students engage in problem based investigations about natural selection, evolution, and other topics, with a focus on students using primary data to construct empirically-supported arguments and explanations for various biological phenomena. Several software tools serve to support different pieces of the investigative and explanative processes, and they also give students an opportunity to carry out the skills and bring to bear the knowledge they are learning about biology and about including evidentiary support in scientific explanations. BGuILE seeks to scaffold students as they acquire the general skills of interpreting primary evidence to support an argument, but it does so using the strategies of the particular domain (natural selection, evolution, etc.). As such, BGuILE seeks to support students as they develop domain general skills while carrying out specific tasks in specific contexts. When learning and developing these skills, many students have difficulty representing and comparing the evidence in such a way that trends can be identified. They may struggle with interpreting those trends in such a way that the interpretation can be used to construct and support an argument.

2.3.2.2 Overall Curriculum / Learning Environment

BGuILE's software tools are integrated into the larger curriculum. Students use the software tools to help them make predictions, investigate phenomena, analyze data, draw conclusions and explain their results using data and analysis techniques used by experts within a particular domain. BGuILE is an inquiry- and project-based curriculum in which students are solving complex science problems and answering complex science questions to learn how to construct explanations about phenomena using various types of data. BGuILE uses an integrated-environmental approach to software design with the understanding that the classroom system and the integration of software within that system are important and must be addressed by software designers and teachers [Quintana, 2001; Reiser, et al., 2000; Reiser, 2004]. For example, in The Galapagos Finches Unit, students learn about island ecosystems and study an island in crisis in the Galapagos [Reiser, 2004]. The finches are dying out, and the students' task is to understand why. They use software tools designed for the Galapagos Finches Unit to study a dataset from a habitat of the island, exploring characteristics of the island's environment and background information about the plants and animals, particularly the physical and behavioral characteristics of the finch population over time. Students compare data and identify trends and connections that can help them explain what is responsible for the finches' plight.

2.3.2.3 BGuILE's System Of Scaffolds

BGuILE uses prompts to focus students' attention on important aspects of the challenge and to help promote discussion and reflection among group members. Prompts take the form of questions such as "How can tuberculoses bacteria survive antibiotics?". These prompts are domain and context-specific. They help students interpret trends in such a way that the interpretation can be used to construct and support an argument. In addition, BGuILE also employs hints, or Explanation Guides to provide more specific help as students are carrying out particular tasks. These hints support students as they represent evidence to identify trends. Figure 2.3 shows BGuILE's prompts and process hints for using data to create a chart that can be used to compare the effect of antibiotics on bacteria.

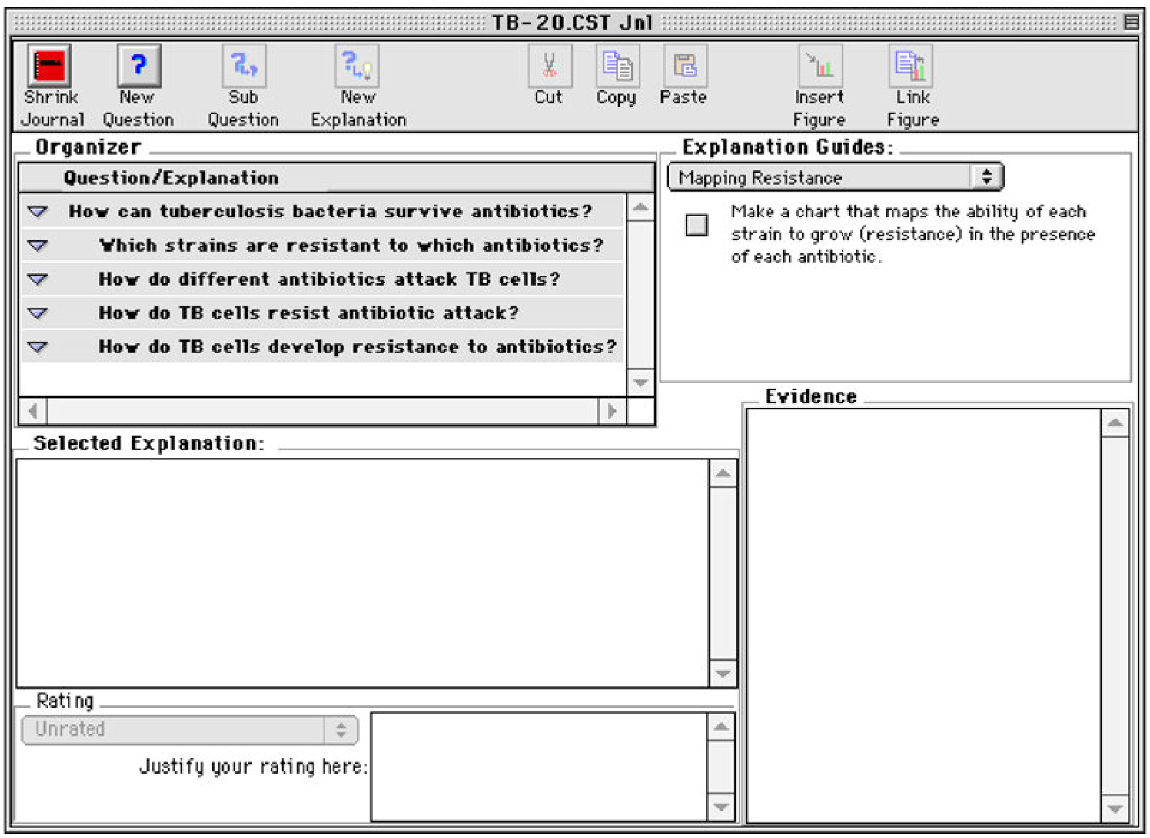


Figure 2.3: BGuILE Prompts and Process Hints

BGuILE includes charts to that serve as reminders. They remind students of things they need to address in their observations and interpretations. Charts are coupled with video footage that the students have identified as being important and prompts that focus the students' attention on important events that occur in the footage. With this scaffold, students are able to make more careful observations and interpret their observations in meaningful ways. Charts also problematize the content, causing students to discuss their ideas and thoughts in order to come to a shared understanding about what their observations and interpretations mean.

BGuILE employs structuring to help organize students' knowledge and learning issues as they investigate to solve the problem. Various aspects of the problem-solving process, including keeping track of questions to be answered, linking questions and explanations, browsing and critiquing specific explanations, and keeping track of evidence, are grouped together, as shown in Figure 2.4. This context-specific scaffolding helps students keep track of various aspects of their investigation simultaneously. It also allows students to compare evidence in such a way that trends can be identified. The explanation guide provides structured process scaffolding by displaying a context-specific list of steps that students should perform in order to create complete explanations. Structure is also employed in BGuILE to help students separate slightly different aspects of the problem, to understand when a skill or set of skills is appropriate to apply to a set of data, and to organize different aspects of their data analysis, as the query screen does.

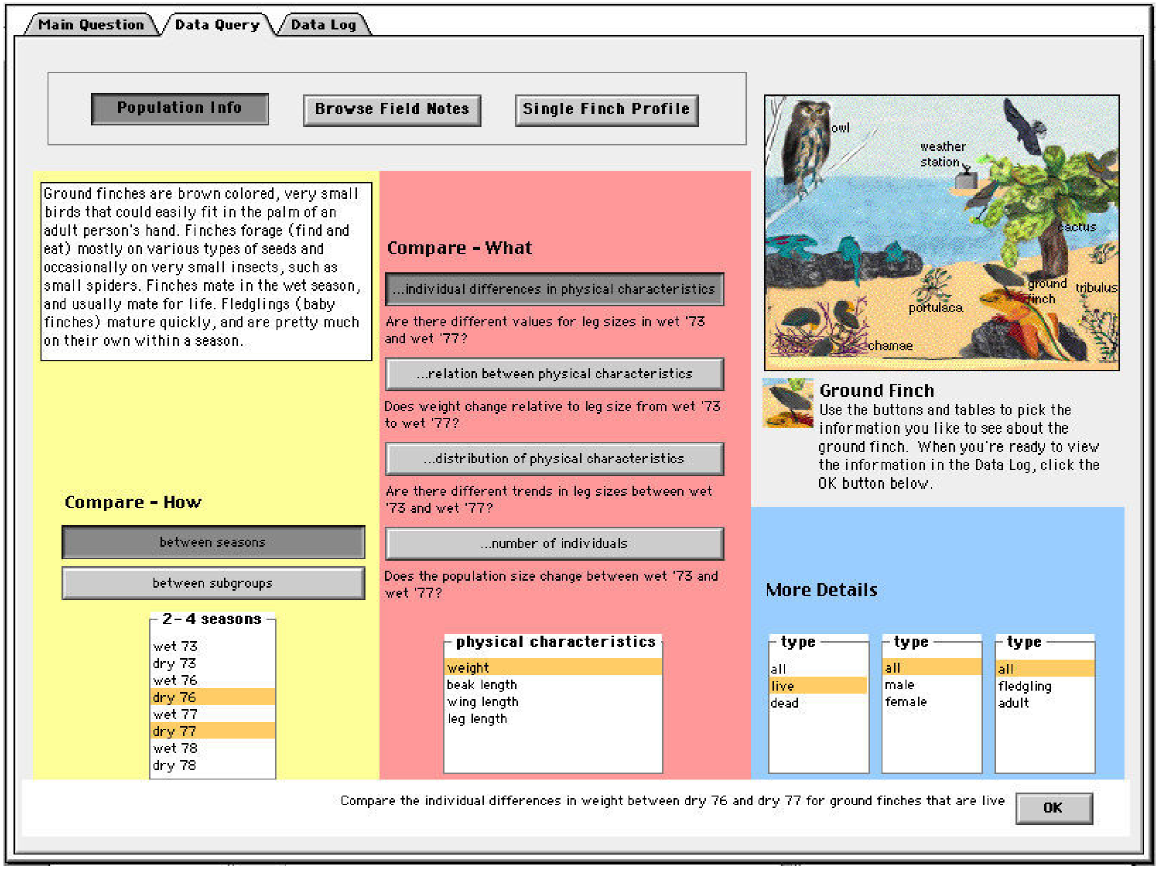


Figure 2.4: BGuILE's Structuring

2.3.2.4 Strengths And Weaknesses

BGuILE has several strengths:

- Students solve problems using real phenomena and authentic data.
- BGuILE gives students the opportunity to actually experience using the target skills in multiple domains, thus promoting flexibility of use.
- Studies show that BGuILE seems to help students pull various forms of data together to explain phenomena [Reiser, 2000; Reiser, 2004].

BGuILE also has several weaknesses:

- It does not seem obvious how students are supposed to move between tools, nor does the software seem to give students a "big picture" of the problem and where they are within it. The connections between different tools do not seem obvious.

- While BGuILE employs scaffolds to help students use evidence to support claims, the software tools do not explicitly model those skills nor do they coach students as they are carrying out those processes in a way that cognitive apprenticeship suggests.
- There does not seem to be a consistent feel to the different tools. Each of the tools supports a different process, but the tools do not appear to have a unified look or feel to them.
- It is not totally clear how and when the teacher assumes roles within this learning environment. Students seem to be mostly left to themselves to grapple with the issues when they are using the software in small groups.

2.3.2.5 How BGuILE Manages The Relationship Between Specific Examples and General Principles

BGuILE seems to manage the relationship between specific examples and general principles through the software's scaffolding and the learning environment that the software is integrated into. Each project presents specific examples and the software tools used in each project seem to support learning from specific examples. For example, the tools used in the context of the Galapagos Finch unit help students understand how to interpret and use primary evidence to construct an argument about the survival of finches with particular traits. Since there is a focus on integrating the tools into the larger learning environment, gleaning more general principles seem to happen outside of the software tools. While it is unclear exactly when more general principles are gleaned, whole-class discussions and presentations seem like likely places where general principles may be gleaned.

2.3.3 Symphony

2.3.3.1 Overview

Symphony [Quintana, 2001; Quintana, Eng, Carra, Wu, & Soloway, 1999] is a scaffolded tool environment (SITE) that is used to scaffold high school students as they engage in science inquiry in the environmental sciences. As students investigate air pollution problems, they use a number of tools to support and integrate various steps in the science inquiry process, namely, researching a problem for possible causes, developing the question to be answered and planning an investigation of that question, collecting data, visualizing data, and interpreting data to glean possible answers to the question and/or revising the plan and investigating further. The final aspects of data collection, visualizing data, and interpreting data are then supported iteratively as students seek to draw conclusions across the set of data and interpretations. Students are scaffolded as they use a particular tool, as they move between tools, as they move through the iterative inquiry process, and as they seek to reflect and draw conclusions across iterations.

As such, Symphony supports students as they understand and solve open-ended problems, understand iteration in inquiry, and judge problem solutions. Students may have difficulty identifying and understanding the problem they are trying to solve. They may also struggle to create a solution to address the problem. Students may have a hard time understanding the processes involved in inquiry, and they may have difficulty knowing when a solution is "good enough" to stop iterating on it.

2.3.3.2 Overall Curriculum / Learning Environment

Symphony is embedded in several project-based inquiry science units. In each unit, students solve complex science problems or answer complex science questions in order to get a better understanding of and to develop the skills needed to engage in inquiry learning. Symphony is integrated into the learning environment and it is designed to take advantage of the affordances of inquiry learning (iteration, depth over breadth, authenticity, etc.), and it is integrated into students inquiry activities [Quintana, et al., 1999]. For example, once students have identified an environmental question that they would like to explore, e.g., "Is pollution near our high school worse than in other parts of Michigan?", they use several tools to support them through that exploration. Artemis is used to help students search the web as a part of their online research of their question; Data Warehouse is used as students collect their data; VizIt is used to help students visualize their data, notice trends, and create visual representations of their data [Quintana, et. al, 1999]. Students use these tools multiple times as they are needed while students are iteratively engaging in inquiry.

2.3.3.3 Symphony's System Of Scaffolds

Symphony uses prompts to help students make predictions and reflect on their experiences through interpretation of data and identification of further learning issues. These prompts take on the form of questions such as "What did you gain or learn here?" or "What do you hope to gain here?" and are designed to focus students' attention on carrying out particular steps in the inquiry process. For example, they can help students identify and understand the problem they are trying to address.

Coupled with prompts, Symphony uses hints to help students reflect in specific ways. These hints are in the form of questions such as "How do you interpret your graphs?" and "What data do you want to visualize and why?", respectively. Hints are coupled with the prompts they hint at and are situated inside the prompt's textbox as Figure 2.5 shows. They can be helpful in supporting students as they create solutions to address inquiry problems. In addition, hints are provided within the Conductor window, described below. Use of prompts and hints coupled with the structural scaffolding in Symphony resulted in students having a better understanding of how to investigate environmental science problems [Quintana, et. al, 1999].

Symphony employs a great deal of structuring to help make the tasks involved in the inquiry process visible to students and to help students recognize when a solution or piece of the inquiry process (e.g., data collection) is "good enough" or complete enough to stop iterating on. Among those are the inquiry map, conductor window, flow diagram, and the sequencing of prompts and flow diagrams within a tool for a particular activity. The inquiry map, shown in Figure 2.5 is a visual representation of the investigation process. Displayed as a sort of circle, 5 buttons are positioned around a conductor and are labeled *Develop Problem, Collect Data, Visualize Data, Model Data,* and *Review Progress*. This map serves to decompose the inquiry process into its high-level components, and it also serves to help students plan their investigations and keep track of where they are within the larger process. In addition, the circular positioning of the buttons suggests that science inquiry is a cyclic or iterative process.

The flow diagrams provide a visual decomposition of the higher level tasks in the inquiry map. For example, the flow diagram for the *Visualize Data* task includes buttons labeled *Select Dataset, Select Graph Type, Select Graph Format,* and *Confirm Choices*. As in normal flow diagrams, Symphony's flow diagrams contain arrows that show linear and circular relationships between the skills involved in a particular task like visualizing data. The flow diagram also gives students a visual notion that the task of visualizing data is comprised of skills that should be carried out iteratively.

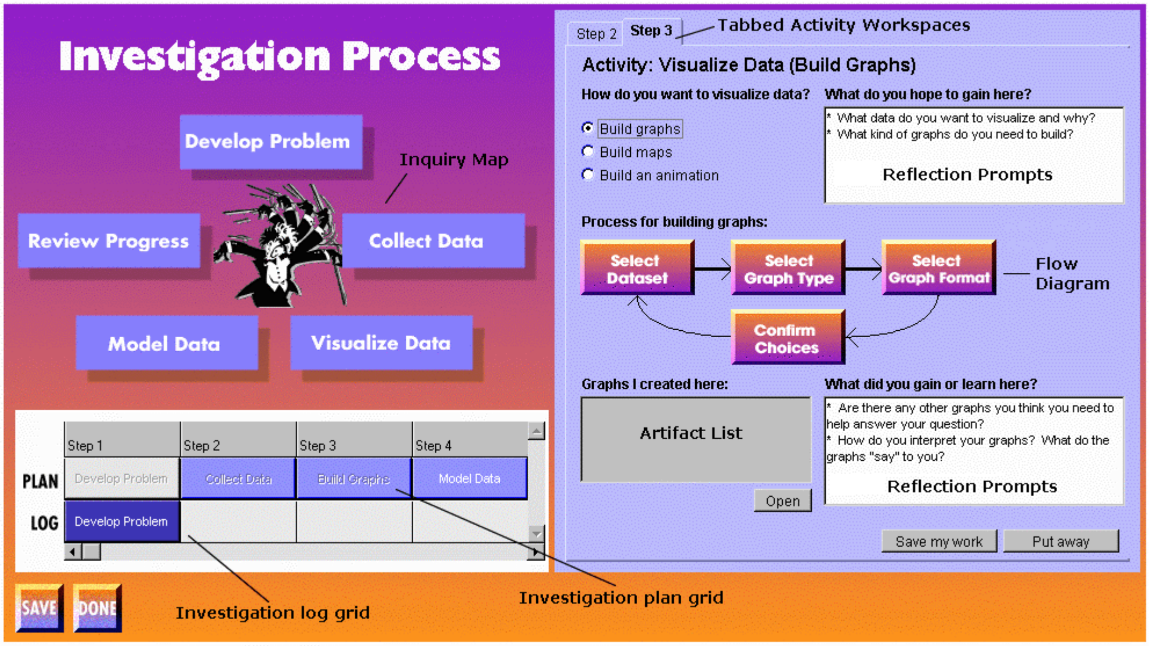


Figure 2.5: Symphony's Prompts, Hints, Inquiry Map, and Flow Diagram

The Conductor, shown in Figure 2.6 serves to help students plan the activities they will carry out as they investigate, and it helps them log how well they adhere to their plan. The four buttons in Conductor serve as visual representations of possible metaprocess activities including *Revise my plan, Do the next activity in my plan, Repeat the last activity,* and *Revisit a logged activity*. This visual representation helps students develop the skills necessary to gauge their progress within an investigation.

Within a tool, prompts and flow diagrams are positioned within a tool in such a way as to visually give students an intuitive understanding of the process used to carry out a high-level inquiry task. This ordering or positioning also gives students an idea of the skills needed to carry out the high level task.

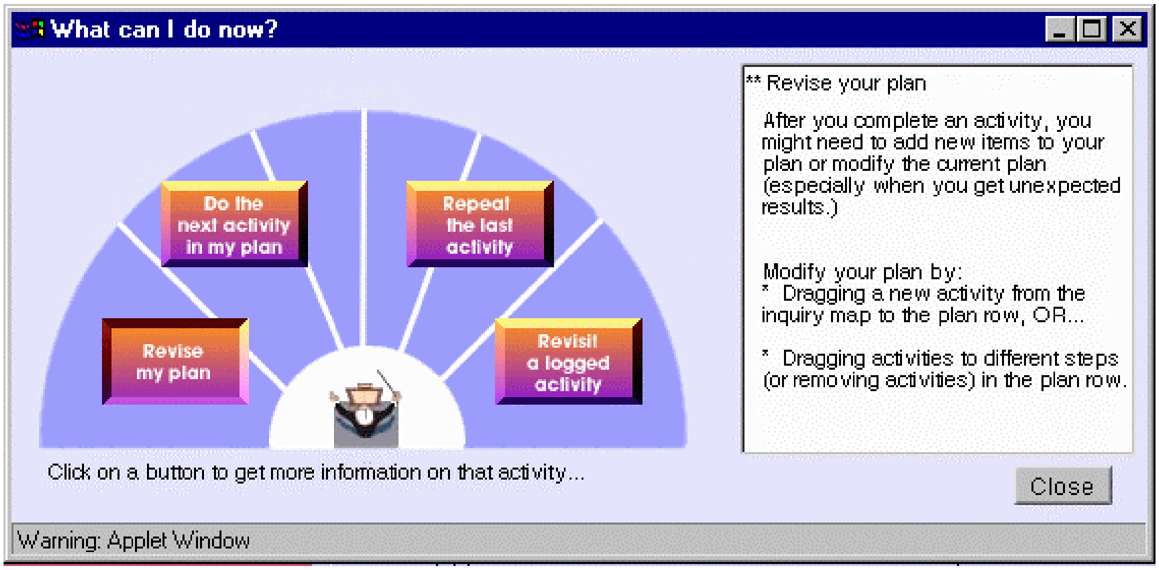


Figure 2.6: The Conductor Window

2.3.3.6 Strengths And Weaknesses

Symphony has several strengths:

- Symphony's focus is on integrating software tools in such a way that students understand how to move between tools and when a particular tool is necessary to help them move forward.
- Symphony employs a framework that makes it possible to incorporate and integrate many different tools to scaffold students through inquiry.
- Symphony relieves students of many of the organizational complexities of inquiry without compromising the complexities of the problem to be solved.

Symphony also has several weaknesses:

- Symphony supports students through different phases of the inquiry process, but it doesn't model the inquiry process for them, nor does it coach them through it in the ways cognitive apprenticeship suggests. Instead, the software serves as additional support to the support the teacher provides as the sole modeler and coach—the software does not take on either of those roles.

- There is practically no data that shows the effectiveness of Symphony's approach in practice. It is not known whether students perform better at inquiry using Symphony or whether students have a better understanding of what inquiry is as a result of Symphony's scaffolding.
- Symphony does not include examples as a part of the design of the software. Explicit use of examples as scaffolds in software would allow the software to take on the role as modeler, modeling skills in the context of using them to solve problems (as is done in STABLE [Guzdial & Kehoe, 1998]). However, none of the projects actively or explicitly takes on the role of modeler or coach. This may be a reason why examples are not included as scaffolds in the software.

2.3.3.4 How Symphony Manages The Relationship Between Specific Examples and General Principles

Symphony seems to manage the relationship between learning from specific examples to abstract more general principles through the software's scaffolding. Symphony's scaffolding is such that the same set of scaffolds can be used to support learning from many instances of its use. As such, the process flow, for example, is a general scaffold that can be used and referenced to help students glean general principles about inquiry from their multiple uses of the tools to solve inquiry problems in specific domains.

2.3.4 GenScope / Biologica

2.3.4.1 Overview

GenScope/Biologica [Hickey, Kindfield, Horwitz & Christie, 2003] is an on-going project that teaches high-school introductory genetics. Students engage in problem-based activities about genotype, phenotype, chromosomes, crossover, DNA, meiosis, mitosis, and evolution with respect to sets of dragons who display various traits. The GenScope software serves to support different pieces of the activity, and they give students the opportunity to visually understand the relationship between these topics and to visually see the results of changes in various traits on the dragons. As such, GenScope/Biologica teaches students domain general reasoning (i.e., cause-to-effect, effect-to-cause, and process reasoning) and domain specific reasoning (i.e., within-generation and between-generation reasoning) with respect to introductory genetics. In introductory genetics, many students have difficulty understanding the relationship between dominant and recessive traits and the offspring that can result based on those traits. Students also struggle to reason from effect-to-cause and across generations, for example, describing the genotype of a group of offspring's parents based on the phenotypes of the offspring. These difficulties tend to arise because students do not have a robust and flexible enough cognitive model of the domain that would allow them to reason in these ways.

2.3.4.2 Overall Curriculum/Learning Environment

GenScope/Biologica's software tools are integrated into a set of activities. These activities are designed to expose and prepare students for the kinds of reasoning they will need to do during the New Worm assessment, administered at the end of their GenScope/Biologica activities [Hickey, et. al, 2003]. The New Worm assessment is a paper-and-pencil tool that asks students a series of more difficult questions based on a set of genetic givens (i.e., description of some traits, chromosomal data, genotype data, etc.). The GenScope/Biologica activities consist of two types of tasks. One task involves understanding the connection between a set of traits, a pair of genotype descriptions, and a pair of phenotype descriptions. The other task involves reasoning about particular outcomes based on those traits, genotypes, and phenotypes.

Students use the software tools during their activities to help them visually make connections between the traits, genotype, and phenotype of organisms and generations of organisms. They also use the software tools to help them reason about the outcomes they are asked to achieve or describe in the second part of the activities. For example, in the Dragon Investigations, students use the GenScope/Biologica software to explore the relationship between traits, genotype, and phenotype by changing the genotype (i.e., the genetic makeup) of one or both of the dragons and seeing the effect that has on the phenotype (the way the dragon looks). They change the genotype by tinkering with the alleles of the X and Y chromosome of a dragon.

During this activity, students engage in challenges. For example, students are shown three dragons: two whose genes can be changed and a comparison dragon whose genes are not shown. Students are given the challenge of choosing one of the two dragons and tinkering with it's genes until it looks like the comparison dragon. At least one of the dragon's genes can be manipulated to look like the comparison dragon, but sometimes, both cannot. For example, if the comparison dragon is a red female, and you are tinkering with the genes of a male dragon, the male dragon's genes cannot be manipulated to create a red color because red skin color is a sex-linked trait. Because the dragons change as their genes are tinkered with, students are able to instantly see whether they are getting closer to achieving their challenge, further from achieving the challenge, or whether they will be unable to achieve the challenge with that particular dragon.

2.3.4.3 GenScope/Biologica's System of Scaffolds

GenScope/Biologica uses prompts to help students reflect on the changes they see as they tinker with genes. These prompts can take on the form of either questions (e.g., "What OTHER differences do you notice?") or statements ("Describe its features in the box below."). Within the body of the prompts are process hints that describe how students should use the content they are shown or how they should begin to answer the prompt. Process hints can also be shown without prompts, describing how students should carry out a task, describing what they might try if they are stuck, or describing what they should do next. For example, when changing the genes on a pair of chromosomes, changing the gene on one chromosome from dominant to recessive may not result in a visible change to the dinosaur. However, the software displays a process hint that explains why changing a gene might not result in a change in visual feedback: "You may have to change the gene on both chromosomes." Figure 2.7 shows prompts and hints together, while Figure 2.8 shows hints without prompts.

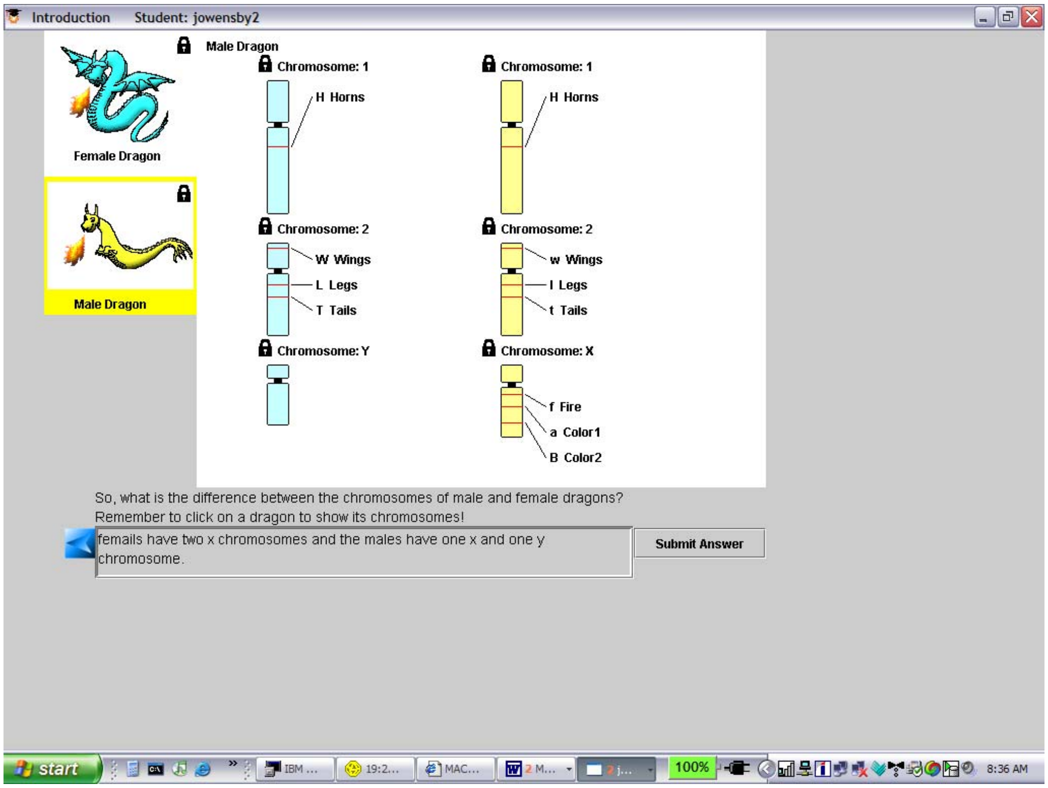


Figure 2.7 Prompt With Embedded Hint

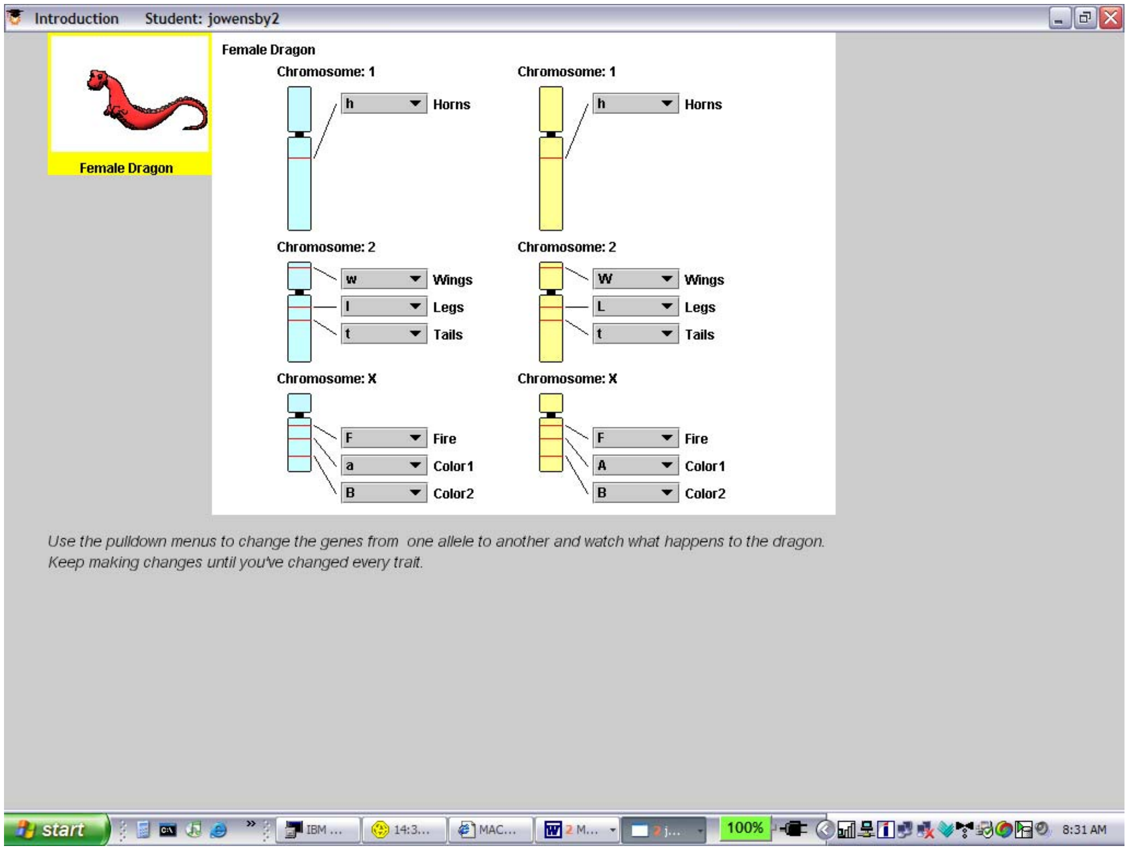


Figure 2.8 – Process Hint (Not Embedded in Prompt)

Process hints are also displayed in pop-up boxes when students click on the question mark in the upper right-hand corner of the page, as shown in Figure 2.9. This question mark help button is present on every screen in GenScope/Biologica, but it is present when students are engaging in challenges.

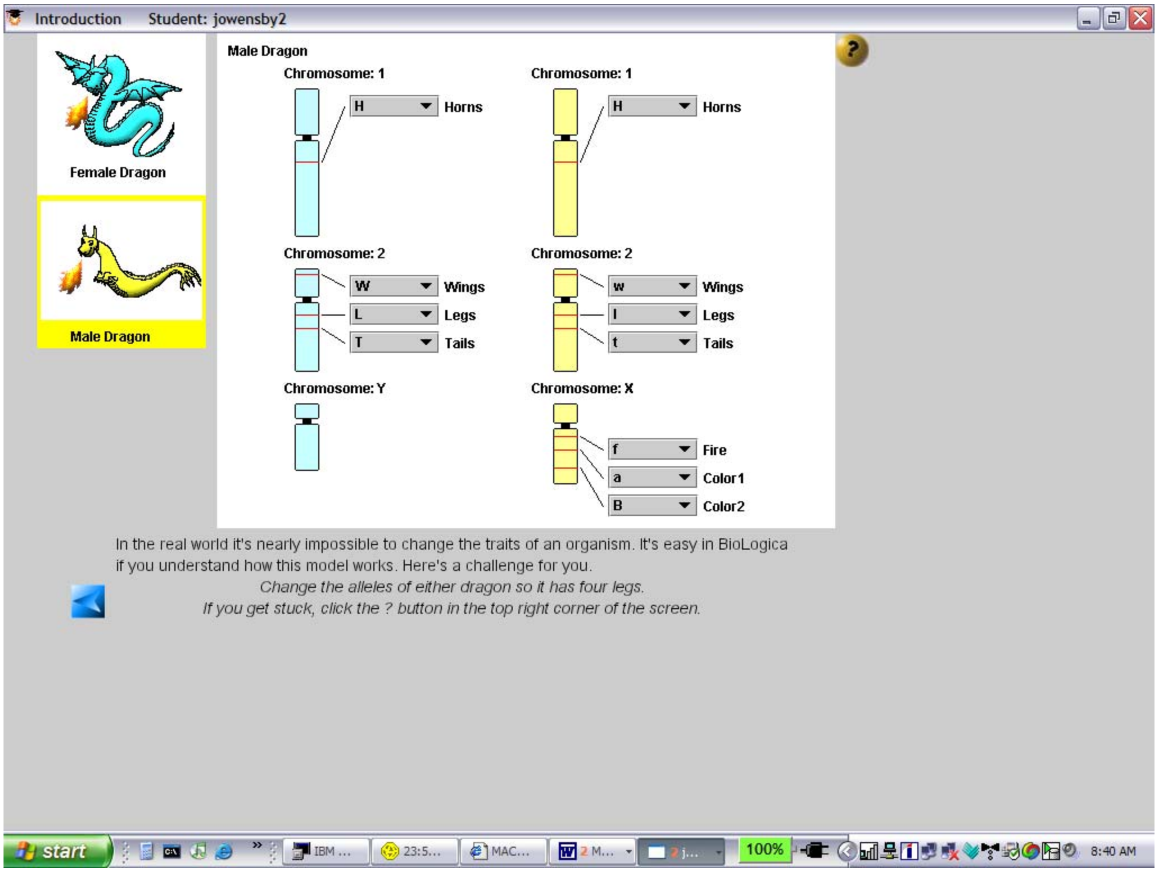


Figure 2.9 – Screen Shot Displaying Help Button In Upper Right-Hand Corner

GenScope/Biologica also employs structure as a scaffold. For example, the software constrains how students move around by only allowing them to move backward or forward one screen at a time. Within a given screen, certain buttons remain inactive until certain actions are taken by the student. For example, the button that allows the student to move to the next screen will remain inactive and grayed out until the student has fully completed the step or has changed a certain number of genes on a chromosome. Once the task has been completed or the threshold of changes has been reached, that button will become active allowing the student to move to the next screen.

The software also employs structure as a scaffold by starting with simple concepts and building on those concepts to introduce more complex concepts. For example, students begin by creating a bunch of different dragons and pointing out the differences in each of the dragons. Then, they learn about how those differences result by learning about chromosomes and genes and by tinkering with the genes of one dragon to see the changes that result. Next, they tinker with the genes of one dragon to get it to look like a comparison dragon, learning about dominant and recessive traits. Then, students tinker with the genes of two different dragons one at a time to get them both to look like a comparison dragon. For one trait, one of the dragon's genes cannot be tinkered with the look like the comparison dragon no matter how many times the genes are tinkered with. Once the student gives up and moves on to the next dragon, the software introduces the concept of sex-linked dominant and recessive traits, or those that only appear in a certain gender. As the student moves through the software, the complexity of the concepts and challenges increases.

2.3.4.4 Strengths and Weaknesses

GenScope/Biologica has several strengths:

- GenScope/Biologica provides instant feedback for students, helping them judge whether their choices are bringing them closer to their goals or moving them further away.
- Students are able to build on previous knowledge as they move through the software, using simpler concepts as a foundation to understand more complex concepts.
- Students were able do more sophisticated domain-general and domain-specific reasoning after engagement with GenScope/Biologica than before [Hickey, et. al, 2003].

GenScope/Biologica also has several weaknesses:

- Students do not solve real-world problems using authentic data. Instead, they solve imaginary problems with data that could potentially confuse students when applied to real-world situations. For example, in the software, a male dragon could have XX chromosomes and a female dragon could have XY chromosomes, but in reality, males always have XY chromosomes and females always have XX chromosomes.

- As students move through the software, the connections between previous screens is not always explicit. For example, the fact that the male dragon's genes could not be changed to match the comparison female dragon's red color while the female dragon's genes could be changed could be missed by students. This could be missed because the only indication that these dragons are not all the same sex is that each dragon is labeled male or female. However, because the focus is on changing the genes (which happens in another part of the screen), students may not pay attention to the labels of the dragons. Even when they give up and are prompted by the software to explain why they gave up, because the prompt covers the screen, if they hadn't noticed the labels before the prompt covered it, they might not be able to respond to the prompt.
- The GenScope software did not seem absolutely critical to improved genetics understanding within the learning the environment. The paper-and-pencil Dragon Investigations were so effective that "in some classes, scores on the NewWorm Assessment increased more when teachers relied exclusively on the Dragon Investigations without using the GenScope software at all." This effect could have been because while GenScope/Biologica does present students with introductory genetic content in small chunks and it does provide opportunities to help students build more complex understandings, the software does not provide any support to explicitly help them make connections between the content they are learning and the more complex

understandings they are building. It is possible that students could complete all of the GenScope software activities and not have a more sophisticated understanding of introductory genetics at the end of the activities than they had before beginning those activities [Hickey, et. al., 2003].

2.3.4.5 How GenScope/Biologica Manages The Relationship Between Specific Examples and General Principles

GenScope/Biologica seems to manage the relationship between specific examples and general principles by sharing that responsibility across the software, activities, and the teacher. The software and activities provide specific examples of introductory genetics concepts as each general concept is covered by its own software lesson (i.e., genotype and phenotype comprise one lesson with different activities and challenges while sex-linked traits covers another lesson with its own activities and challenges). However, the software does not seem to explicitly help students draw out general principles across different concepts. Instead, the software seems to support students as they build more complex understandings of a concept from more simple ideas, and the Dragon Investigations (which can be done either using the software or using pencil and paper) are designed to provide common experiences among the students from which the teacher can help students to connect those experiences and draw out more general principles.

2.3.5 Lessons Learned

We have presented and examined the system of scaffolds for four projects. Although each system is different, each one provides suggestions for designing software in support of complex skill development as well as integrating that software into the larger environment.

2.3.5.1 KIE/WISE

From KIE/WISE, three lessons learned were gleaned. When designing software to support complex skills learning, the structure of the software should be designed in such a way that various tools can help students develop complex cognitive skills across different domains. Being able to develop skills across different domains improves the flexibility with which those skills can be used. Students should also have multiple opportunities to employ the complex skills they are trying to develop using the software-realized scaffolding in different domains. These multiple opportunities across domains help students refine their understanding of the processes and contexts in which complex cognitive skills are used. Finally, if students need to reflect on their ideas and examine their understanding using software, prompting should be included as a scaffold because prompts can help students reflect.

2.3.5.2 BGuILE

Examining BGuILE reveals one lesson that can be learned about integrating software in support of complex cognitive skill development into a learning environment. Students should use software in support of complex skills to address real-world problems using real data. This allows students to actually experience using the complex skills they are developing in different contexts, which improves the flexibility with which those skills can be used.

2.3.5.3 Symphony

Symphony reveals that the same set of scaffolds can be used to support multiple complex cognitive skills. Symphony's scaffolds are designed to support students across different inquiry experiences, and each of those experiences may employ slightly different skills that are particular to the given domain. By employing the same set of scaffolds to support multiple complex skills, students have consistency in the support available to them and they may be able to begin to develop and refine a more general understanding and draw out more general principles about how and when the processes or skills they are learning should be used.

2.3.5.4 GenScope/Biologica

GenScope/Biologica reveals that integrating software into a learning environment in such a way that its effectiveness with respect to other activities in the environment can be determined can be very tricky. Often, activities and software may be used in very different ways than they were intended, making it difficult to ascertain whether learning was the result of the software, the activities, some combination of the two, or something else altogether. GenScope/Biologica also revealed that capturing the transfer of complex cognitive skills and reasoning in new situations is hard. Sometimes, it's difficult because the skills being assessed during the transfer activity are not the same skills that are supported by the software. Other times, it is because the transfer activity looks so different from the context in which the skills were learned, students don't recognize that they should be using those skills in the new situation. Still other times, the transfer activity requires reasoning that is not close enough to the reasoning done earlier—the transfer is too far.

2.3.5.5 Managing The Relationship Between Specific Examples and General Principles

A case-based approach proposes the interpretation of concrete cases--more general principles are gleaned from those concrete cases as they are used and reinterpreted in light of that use. While the four projects described in this chapter do not use a case-based approach, they do manage the relationship between specific examples and more general principles. KIE/WISE does so through different kinds of projects; BGUILE through software use and the environment; Symphony through the software's scaffolding, and GenScope/Biologica through the software, activities, and the teacher. While each of these approaches seem drastically different, they all aim to help students interpret each project experience (software use, activities, class discussions, etc.) in such a way that they learn the content targeted by that experience as well as the skills needed to understand the content. These projects also aim to help students understand how each project experience is connected to the preceding and succeeding project experience, helping them to understand when and how to use knowledge and skills, and helping them to make connections across the overall project experience. If each project experience is viewed as a case, each of these projects aim to help students interpret concrete experiences, or cases, use them in different contexts, and re-interpret across those concrete experiences and different contexts. So, while the approaches of these four projects seem drastically different from a case-based approach, in reality, their aim is not that different. The differences lie in the kinds of experiences each project provides and how they help students make the leap from specific examples to more general principles.

2.4 Implications

This chapter has sought to ground our work using relevant literature. Several theoretical viewpoints regarding skill development have been described, namely, skills acquisition, transfer, case-based reasoning, and cognitive apprenticeship. Three projects were also discussed with special attention given to the use of software within the projects and the system of scaffolds used. What does this analysis of the literature and these three projects tell us about learning to interpret and apply expert cases, collaboratively interpreting and applying expert cases, using the computer or software as a collaborative tool, designing software to support students as they interpret and apply expert cases, strategies teachers can use to promote case use skills learning, and studying the development of case use skills in a project-based inquiry learning environment over time using cognitive apprenticeship as a framework?

2.4.1 Learning To Interpret And Apply Expert Cases

- In order for skills to be successfully acquired, developed, and used flexibly, students should have multiple opportunities to use and refine their understanding of case use skills in authentic contexts where their use is appropriate.
- Since case use is a complex process, no one scaffold can meet all the needs of different students within a classroom. As such, a system of scaffolds should be employed that meets the different needs of students as they interpret and apply cases.
- In order to meet the different needs of students as they engage in case use, it is necessary to identify what those needs are and to develop specific scaffolds that work together to meet those needs.

- Students working collaboratively in small groups in a project-based inquiry environment can scaffold and model case use skills for each other. The learning environment should provide opportunities for this to happen.
- Software should be introduced into the learning environment only after students have seen the processes of interpreting and applying expert cases carried out, e.g., the teacher modeling some or all case use skills for students, and after students have had an opportunity to interpret/apply cases themselves. This approach should help students understand how the software is supposed to help them why they should use the software to help them interpret and apply expert cases.

2.4.2 Collaboratively Interpreting and Applying Expert Cases

- The learning environment and the software that is integrated into that environment should encourage students to voice different perspectives and support discussion so that those different perspectives can yield a newer and richer understanding of case use skills.
- The learning environment should encourage and support discussion that supports negotiation of meaning.
- The software's system of scaffolds should encourage discussion among students when used in groups so that more skilled students can scaffold less skilled students along the way.

2.4.3 Using The Computer As A Collaborative Tool

- Software integrated into an project-based inquiry environment should organize student artifacts in such a way that they are easy to access, easy to retrieve later, and easy to share outside the group.
- Software should support group discussion by helping group members to reflect collectively and individually on tasks, skills, and content.

2.4.4 Designing Software To Support Students As They Interpret And Apply Expert Cases

- Different students will acquire and develop case use skills at different times. Therefore, software-realized scaffolding should be available to those that need it, but should not get in the way for those that do not.
- Software should be designed to support students as they interpret and apply expert cases while providing a means of helping them manage the difficulties of case use and develop an understanding of the high-level processes involved in case use.
- Software designed to help students interpret and apply cases should employ a system of scaffolds that serves as a framework that makes it possible to integrate many different tools to scaffold students through tasks involving complex cognitive skills like case use.
- Software should focus on helping students understand how to carry out the steps involved in case use and when each step should be carried out. In addition, software should be designed to help students understand when case use should be employed in different contexts where using expert cases is appropriate.

- Software designed to scaffold students as they interpret and apply cases should have a primary focus of helping students extract the lessons they can learn from a case. These lessons, or rules of thumb, should be available to students to apply when needed, and these rules of thumb should be re-interpreted in light of the outcomes that result when they are applied or the failure of a rule of thumb from an old case in a new situation.
- Software designed to help students interpret and apply cases should also provide opportunities for them to make predictions and judge how good their predictions are by having them evaluate their solutions and the results that come from them.
- If software designed to scaffold students as they interpret and apply cases contains multiple tools, those tools should have a consistent look and feel so that students can focus on the task instead of focusing on orienting themselves with the new tool.
- Software should be designed to model the kinds of metacognitive strategies (through its scaffolding) that students should employ as they are interpreting and applying cases on their own or in small groups.
- Software should assume active and particular role(s) in the learning environment by providing modeling and/or coaching via scaffolding as students interpret and apply cases. The distribution of these responsibilities and assumption of roles by teacher and software should be considered and understood by both the teacher and the designers, and the software should reflect those considerations.

2.4.5 Suggestions For Teacher Practices For Promoting Case Use Skills Learning

- Teachers need to spend time modeling case use for students, helping them make connections across cases, and providing them with opportunities to interpret and apply cases many times in order for students to acquire and develop case use skills. Though students may not be able to create fully fluid procedures or automate case use skills, teachers should provide enough time for students to learn and develop case use skills.
- Teachers should model the kinds of metacognitive strategies that students should employ as they are interpreting and applying cases on their own or in small groups.
- The teacher should continually encourage students to make connections between their experiences and the skills they are learning. Teachers should ask how a situation is similar to or different from other situations students have learned about, helping them to understand the context of applicability across cases.
- Teachers should help students see potential situations in which they can apply the skills they have acquired.

2.4.6 Studying The Development Of Case Use Skills Over Time

- Studying and describing how case use skills develop over time involves identifying and articulating changes in case use performance and capabilities.
- Expect students to show variation in case use performance and capability before using the Case Application Suite and after using the software's scaffolding different learners experience different difficulties, have different needs, and develop skills at different rates.

- The cognitive, associative, and autonomous stages are characterized by behaviors such as the number of mistakes made, the construction of and fluidness of procedures for a skill, and the reliance on scaffolding needed to successfully carry out the skill. These characterizations may be useful in beginning to segment the developmental trajectory of individual students and/or student groups.

2.5 Summary

This chapter has discussed the skill acquisition, case-based reasoning, transfer, and collaboration literatures (both within the group and around a computer) as well cognitive apprenticeship. This chapter has also analyzed three projects that promote and support complex skills learning, analyzing the scaffolds used to support complex skills learning and the strengths and weaknesses of each. The learning environment that will be described in Chapter 3 was designed with the suggestions and implications described in this chapter in mind.

CHAPTER 3

THE LEARNING ENVIRONMENT, SMILE, AND THE CASE APPLICATION SUITE

The goal of this research involves understanding and describing the trajectory of skill development for using expert cases well in middle-school project-based inquiry classrooms as well as understanding how different developmental trajectories may impact the ability to use expert cases well in activities where use of cases is appropriate. To address this goal, we designed the Case Application Suite to coach students via software-realized scaffolding as they are interpreting and applying expert cases to design a solution to a problem. The literature has made suggestions about acquiring and developing complex skills collaboratively in an inquiry learning environment. However, in order to understand the design of the software, one must understand the learning environment in which the software is used. This chapter introduces Learning By Design (LBD), a project-based inquiry enactment of a cognitive apprenticeship developed at Georgia Tech, SMILE, the suite of computer-supported collaborative tools that were developed to support LBD students as they engage in project-based inquiry learning, and the Case Application Suite, a set of tools in SMILE designed to support students as they interpret and apply expert cases.

3.1 Learning By Design: Our Enactment Of A Cognitive Apprenticeship

Learning By Design [Kolodner, 1997; Kolodner et. al, 1998; Kolodner, et. al, 2003] is an approach to learning in which middle school students learn science skills, practices, and content by engaging in design projects. Based on the suggestions made by cognitive apprenticeship [Collins, Newman & Brown, 1989] and case-based reasoning [Kolodner 1993; Kolodner 1997], LBD's activities are designed so that students experience the concepts and practices they are learning, and its sequencing aims to help students make connections between their experiences (inside and outside of the classroom) and the science they are studying and learning.

Overall, LBD units orchestrate children's classroom experiences to be much like the experiences of case-based reasoning programs in several ways [Kolodner, 1997; Kolodner et. al, 1998; Kolodner, et. al, 2003]:

- By asking students to achieve engaging goals that can be achieved in ways that provide feedback and that require several iterations
- By helping them keep track of their experiences in memory, interpret their experiences so as to extract lessons that could be learned from them and the conditions of applicability for those lessons, and encode those experiences based on those lessons learned and their conditions of applicability;
- By giving them practice retrieving applicable cases from their memories, judging which of several potential cases might be most applicable in a new situation, and merging, adapting, and applying the lessons learned in new situations;
- By making sure they get feedback on their decisions, helping them explain mistakes and/or poor predictions, and helping them revise memory's encodings and interpretations as those explanations suggest;
- By having them notice similarities and general rules and draw out abstractions to use for more sophisticated encoding; and

- By providing a clear, diverse, easily retrievable library of cases to help students make connections, prompting them to recognize when and which cases to apply.

These experiences are in the context of LBD activities that students engage in that help them learn science content and practices. These activities and content are structured around the LBD Cycle.

3.1.1 The LBD Cycle

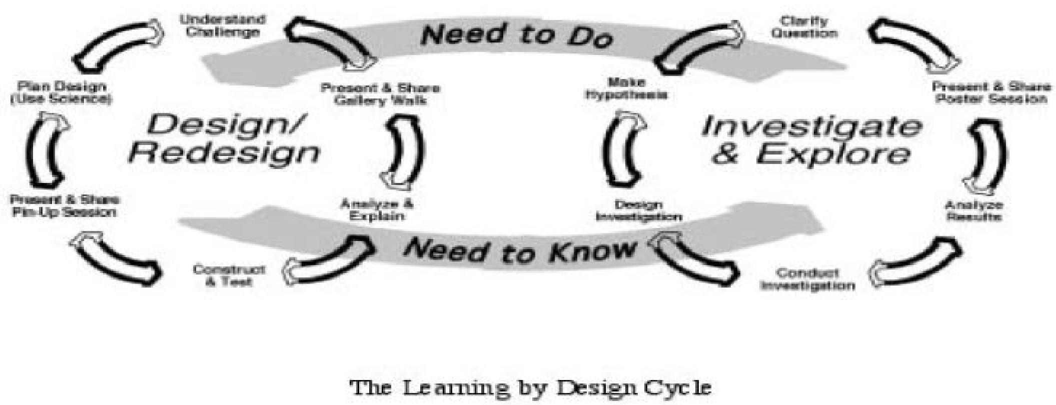


Figure 3.1: The LBD Cycle

Central to LBD is the iterative cycle shown in Figure 3.1. This cycle is hung in LBD classrooms where it is visible to the students and is referred to as students move through the phases of the cycle. It is a cycle composed of cycles. The Design/Redesign cycle focuses on the application of knowledge gained from the Investigate & Explore cycle, while the Investigate & Explore cycle focuses on informing the designs and redesigns that students do as they are addressing the challenge.

There are two Earth Science Units – Digging In and Tunneling Through Georgia. *Tunneling Through Georgia* teaches students about geology and earth science concepts by having them design plans for a set of tunnels that will run across the state of Georgia. They must investigate the geology of their tunnel site and how that geology can impact their design plans. *Digging In* is a unit that introduces students to the skills and practices they will need in order to engage in the *Tunneling Through Georgia* unit. Students investigate agents of erosion and erosion management methods through designing a basketball court at the bottom of a hill and it's surrounding areas in such a way that the hill does not erode onto the basketball court.

As students move through the LBD cycle, they familiarize themselves with the materials, examine examples of the problem, and articulate things they know, things they think they know, and things they would like to know about the challenge. They conduct investigations to confirm facts, support or refute ideas, and address learning issues. This is done through modeling, experimentation, interpreting expert cases, demonstrations, and lectures. They present ideas, results, or iterations to the class, and get feedback from their peers and the teacher through discussing what was learned, critiquing each other's ideas or methods, clarifying questions, and suggesting next steps or things to consider. They apply what they've learned from investigations and presentations to their challenge. Students refine their goals and criteria, apply lessons they have learned from expert cases, apply knowledge gleaned from models or experiments, and/or analyze the data they have collected. Students reflect at each phase in the cycle by using the scaffolding provided by

LBD, which will be described later, and by engaging in small group and whole class discussions.

3.1.2 LBD Scripts/Rituals/Activity Structures

The LBD cycle and the classroom scripts that LBD students engage in are critical to the success of LBD. Scripts [Schank & Abelson, 1977; Kolodner, et al, 2003; Kolodner, in press] are activity sequences that help the students engage not only in the cycle of doing and reflection, but they also encourage the kinds of reasoning that are important to reusing one's experiences. When those scripts are used over and over in the context of LBD activities, they become ritualized activities. The sequencing of scripts helps create a naturally-flowing environment for doing that reasoning. Among the many scripts in LBD are "messing about", "poster session", "gallery walk", and "whiteboarding" scripts [Kolodner, 1997; Kolodner et. al, 1998; Kolodner & Gray, 2002; Kolodner, et. al, 2003]. "Messing about" is a kind of guided play where students explore the way different devices or materials work and grow curious about the causes for their differing behaviors. "Poster sessions" allow students to share ideas and give advice to peers. Preparation for a poster session involves articulating their design ideas and justifying them with evidence gleaned from previously carried-out investigations. "Gallery walks" are presentations in which students present their experiences designing and running an experiment or testing out a design idea. They share ideas with others and have the opportunity to see how others in the class have implemented similar ideas, and they get help with explaining their results and extracting trends and design rules of thumb.

Student groups do many presentations, which are designed to help them interpret their experiences in ways that help them make connections between their experiences and the science they are learning. Presenting ideas to peers can help students in several ways. First, they can gain a perspective or an idea they may not have recognized previously. Second, in the discussion that the teacher facilitates during presentations, she gets the opportunity to model the kinds of questions that students should be asking themselves and each other as she pushes them to articulate and reflect on their ideas. Third, as students ask questions of each other, they get practice developing those skills and may begin to develop the ability to ask those same questions of themselves and their group as they design. Fourth, the presentations give students the opportunity to share with each other, developing students' collaboration skills and helping them learn the importance of collaborating with and learning from each other.

These presentations are also designed to help learners extract out science principles and their conditions of applicability, as well as to help them understand and learn the practices used by the science community. These skills—interpreting, extracting out lessons learned, and applying those lessons are the same kinds of interpretations needed for case interpretation and application. Students need opportunities to carry out these skills in authentic situations where their use makes sense. The Digging In and Tunneling Through Georgia Units provide those opportunities and situations.

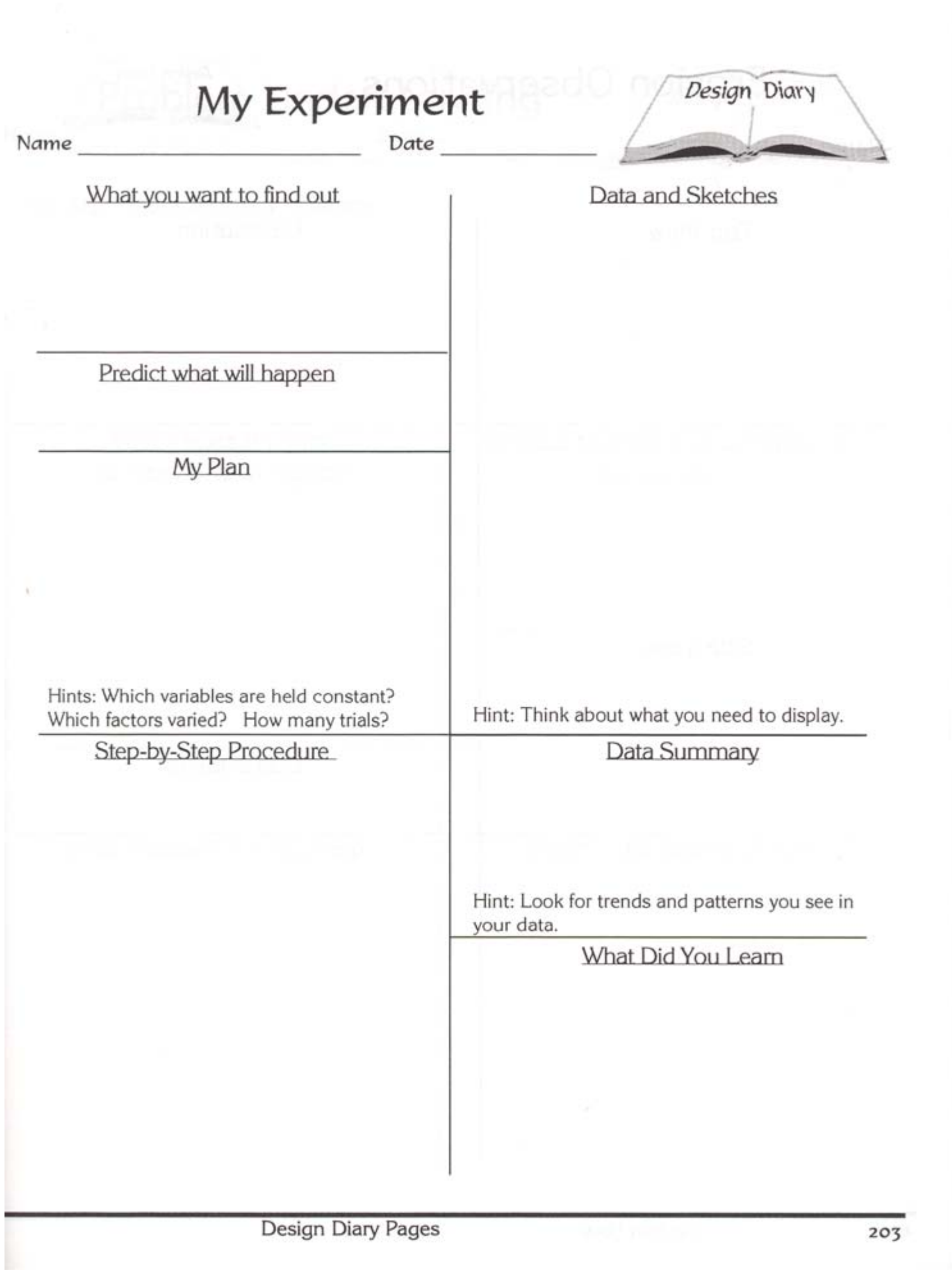
3.1.3 Role Of The Teacher In Learning By Design

Students engage in a number of rituals in LBD as they investigate, explore, design, redesign, mess about, present their design ideas, design and conduct experiments, think about what they know, what they think they know, and what they'd like to know more about, interpret and apply cases, collaborate, and carry out tasks to achieve the challenges in LBD. This can be a tall order for middle school students to successfully engage in all of these things. To support students as they are engaging in these activities, the teacher provides modeling and coaching as cognitive apprenticeship suggests. The teacher models the kinds of questions students should be asking themselves and each other as she facilitates whole class discussions and inquires small groups about their designs. She prompts students to help them focus on important aspects of their design, experiment, expert case, etc., and she provides hints when students get stuck, confused, or lost. She models many of the skills students will learn and use to help them achieve their goals in LBD, like analyzing results from an experiment and whiteboarding. She coaches small groups as they discuss their ideas, design and carry out experiments, build and test models, and plan for presentations.

3.1.4 Design Diary Pages As Scaffolding

In addition to the scaffolding provided by the teacher, Learning By Design also has paper-and-pencil scaffolds that support students as they engage in the scripts, rituals, and activity structures in LBD. Design diary pages [Puntembekar & Kolodner, 1998] provide scaffolding for all of the design activities LBD students engage in, helping them organize their thoughts and prompting them to make their experimental designs, ideas, justifications, and explanations complete and coherent. This scaffolding is mainly in the form of organizers (charts or tables) that help students keep track of where they are in a task and help them to be mindful and careful as they carry out the task, prompts that encourage students to think and reflect in productive ways, and hints that provide more specific help.

Figure 3.2 shows the My Experiment Design Diary Page which is used to support students as they plan an experiment and analyze the results after they have run the experiment. The left column, designed to support students as they plan their experiment, helps them develop an experimental question (What do you want to find out), hypothesis (Predict what will happen), plan (My Plan), and procedure (Step-by-Step Procedure). In addition, there are hints that provide specific help for students as they think about things to include in their experiment plan (i.e. variables to hold constant, variables to vary, trials to run). The right column, designed to support students after they have run their experiment and are analyzing the results, helps them capture and describe the set up of their experiment (Data and Sketches), summarize what the data shows (Data Summary), and articulate what they've learned from the experiment (What Did You Learn). Again, hints help them think about what they need to capture and describe for their description of data and sketches as well as reminding them to look for trends and patterns when summarizing what the data shows.


My Experiment

Design Diary

Name ______________________ Date ____________

What you want to find out

Predict what will happen

My Plan

Hints: Which variables are held constant? Which factors varied? How many trials?

Step-by-Step Procedure

Data and Sketches

Hint: Think about what you need to display.

Data Summary

Hint: Look for trends and patterns you see in your data.

What Did You Learn

Design Diary Pages 203

Figure 3.2: My Experiment Design Diary Page

Design diary pages are used as students are planning for experiments, modeling activities, and presentations. Design diary pages are also used to collect and analyze results from experiments and modeling activities. During presentations and following experiments and modeling activities, the teacher facilitates whole class discussions. During these discussions, the teacher helps students link their ideas, discuss similarities and differences across ideas or results, and analyze why those similarities or differences may have occurred.

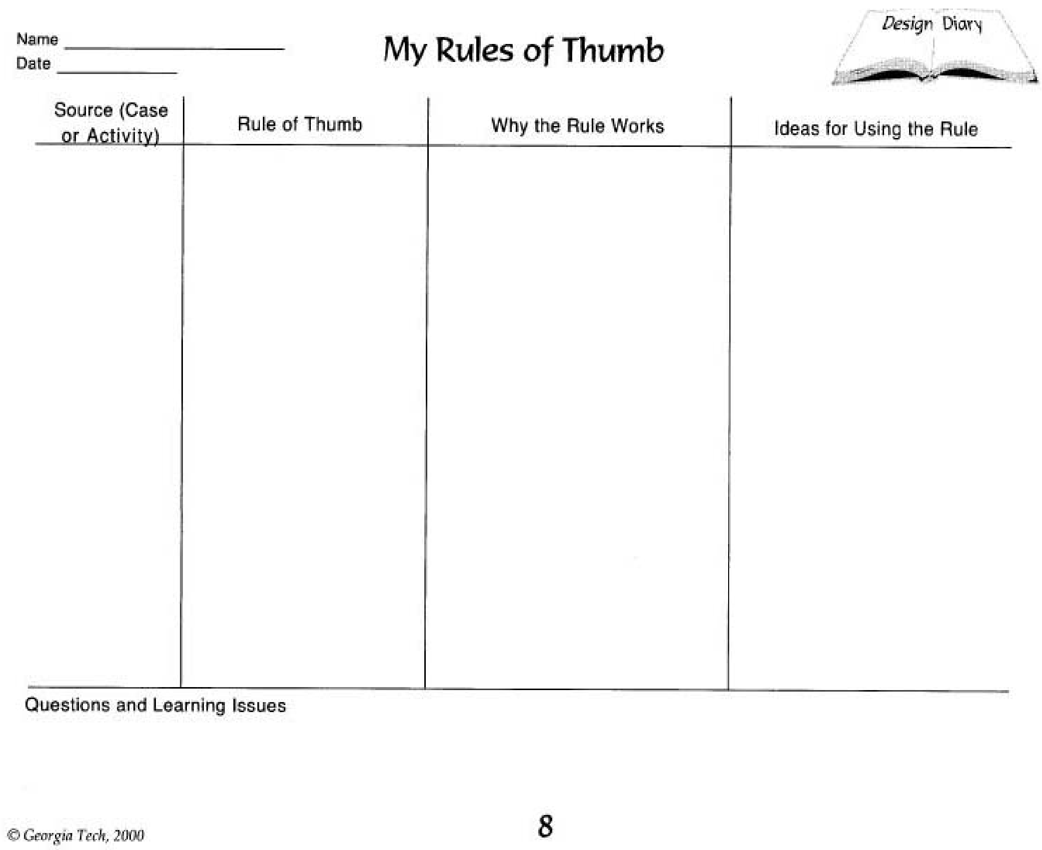
For example, a class of four groups may have conducted the same experiment. As the class is discussing each group's results, it becomes clear that one group's results are markedly different from the other three groups. Looking back to their My Experiment Design Diary pages, the teacher can facilitate a class discussion to help the class determine why one group's results are outliers. The teacher can also help the class articulate design rules of thumb about fair testing and experimental procedure based on this experience. As such, the use of design diary pages when coupled with whole class discussions provide opportunities for students to share their ideas, link their ideas to the ideas of their peers, form arguments as they discuss similarities and differences across ideas, and glean and articulate lessons they have learned from the experiences and the discussion.

3.1.5 From Experience To Science: Design Rules Of Thumb

Whether analyzing results from an experiment, or interpreting an expert case, it is important for students to be able to articulate what they have learned from an experience. In LBD, a lesson that students can learn from an experience is called a "design rule of thumb" [Ryan, Camp & Crismond, 2001; Ryan & Kolodner, submitted]. Students create these design rules of thumb to describe the trends that they see as they conduct experiments, and they help students connect their experiences to evidence, scientific principles, or science concepts they are learning. They then apply them later on when they are designing solutions to the challenge. Evidence can be the experiments of peers, iterations of experiments conducted by the group, an outside source that they have discovered, mention of a class discussion, interpreting an expert case, etc.

In LBD's physical science units, design rules of thumb are used as guidelines about what should be done under a set of circumstances. For example, when investigating the effects of the size of a parachute canopy on the rate of descent of a parachute, a design rule of thumb created from that experiment might be "When designing a parachute that should fall slowly, the canopy should be made as large as possible, but not so large that the canopy collapses, because a larger canopy causes more air resistance that counters the force of gravity on the parachute".

Two forms of scaffolding are available to help students create these design rules of thumb. The first is a design diary page that helps students both create design rules of thumb and begin thinking about how those design rules of thumb might be used in the future. The My Rules of Thumb design diary page, shown in Figure 3.3, provides scaffolding in the form of a chart with five column headings. The first column, Source (Case or Activity) prompts students to identify the expert case or experience the design rule of thumb is being gleaned from. The second column, Rule of Thumb, prompts students to articulate the design rule of thumb. The third column, Why this Rule Works, prompts students to justify their design rule of thumb by connecting it to science content or an outcome that might occur as a result of this design rule of thumb. The fourth column, Ideas for Using the Rule, prompts students to think about situations where using this design rule of thumb makes sense. The final heading, Questions and Learning Issues, prompts students to identify and describe and questions that either arise or remain unanswered about this design rule of thumb and anything else students still need to know to understand this design rule of thumb.



Name ____________________
Date ___________

My Rules of Thumb

Design Diary

Source (Case or Activity)	Rule of Thumb	Why the Rule Works	Ideas for Using the Rule

Questions and Learning Issues

© Georgia Tech, 2000

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Figure 3.3: My Rules of Thumb Design Diary Page

The second form of scaffolding provided is a template of the following form:

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

This template helps students create and articulate design rules of thumb and refine them to make them more complete and connected as they learn more about the experience or the science content involved in the experience. Once a design rule of thumb is extracted, it can be discussed by the class to determine it's usefulness, used to inform a design solution, and refined as student groups begin to understand the conditions for its use.

As groups apply these design rules of thumb to their solutions, seeing the outcomes of that application help them rethink a design rule of thumb and its associated explanation, and through refinement of design rules of thumb, they gradually begin to debug notions of causality [Owensby & Kolodner, 2002]. One study showed that having students derive design rules of thumb in the form described below resulted in students using scientific terminology and increased ability at illustrating and understanding scientific principles [Ryan, Camp & Crismond, 2001, Ryan (Master's Thesis), 2002, Ryan & Kolodner, 2004, Ryan & Kolodner, submitted].

3.1.6 Cases As Resources In LBD

Cases are another resource that students use in LBD. Remember that cases are interpreted experiences and can be personal cases, peer cases, or expert cases. Personal cases are first-hand experiences, e.g., experiments that the students have conducted, models they have designed and tested, or outside experiences that students have lived through, like putting their hand on a hot stove or riding a roller coaster. Peer cases can be those same kinds of experiences, but those that are experienced by someone else with similar expertise. For example, a group describing their experiment and what they learned from it to the class as the class discusses experiments and results becomes a peer case to the other students in the class. Expert cases, for example reading about how car manufacturers design and build cars, are second-hand experiences of an expert in a domain that serve to describe how experts solve problems in real-world situations.

In LBD, expert cases are in the form of narrative stories, describing the experiences of experts as they try to achieve goals and address problems that come up along the way. They are written to include all of the descriptiveness needed for students to understand the connections within the expert case, making the lessons students should be learning from the expert cases clear. Students can glean design rules of thumb from expert cases just as they can from experiments, refining design rules of thumb with their conditions of applicability and connecting the experiences of the experts to science content, just as they do with the design rules of thumb gleaned from experiments. The intention is that as they work to achieve the challenge, students in LBD should build a library of cases in their minds using the materials in LBD and the scaffolding to help them focus and analyze in productive ways during activities such as designing an experiment, interpreting a case, designing a model, etc. The Case Application Suite provides a system of scaffolds to help students take advantage of the descriptiveness of the expert cases in LBD, understand the connections within the expert case, and glean and refine design rules of thumb. As a result, expert cases become useful resources that student groups can use as they investigate and explore, uncovering things they need to learn more about and informing their designs and redesigns.

3.2 LBD In Practice

3.2.1 Digging In: Getting Started With Earth Science

Students come to the LBD classroom with different backgrounds. Some have had little or no experience with inquiry learning. Some have had experiences working on projects, but not in the integrated way that they do in LBD. Some have had experience learning in inquiry, project-based environments. To introduce students to project-based inquiry learning and to create opportunities for them to carry out the skills they will need to successfully solve challenges in the LBD units, each year of LBD's Earth Science is begun with a unit called Digging In. This "launcher" unit seeks to give students and the teacher common experiences to which they can refer in small group and whole class discussions, and it provides a common ground from which they can build and connect their understanding [Holbrook, Fasse, & Gray, 2001; Holbrook & Kolodner, 2000]. Students use design diary pages individually and in small groups to support them as they are designing and running experiments, designing and testing models, articulating design rules of thumb, and interpreting expert cases. The teacher models skills for the whole class, facilitates class discussions, and provides coaching via prompting, hinting, and reminding as students are working in small groups to achieve *Digging In's* challenges.

Students begin Digging In by engaging in small design challenges to help them understand what design involves and to introduce them to the goals of the unit. The first challenge students engage in is The Key Relay Challenge. In this challenge, students work in groups to design, test, and choose the best aluminum foil boat that will be used to transport keys from one team to another for a fictitious relay race. Student teams then have the opportunity to redesign their aluminum foil boat using four times the amount of foil. At each phase in the challenge, students answer questions that encourage them to reflect on the challenge like 'Why did your group select the features you used?', 'Which criteria did your design fulfill?', and 'What part was incorrect?'

Then, student groups engage in the Oreo Cookie Challenge, which helps them understand how to control variables, introduces them to fair testing, and introduces the concepts of data reliability and outliers in data. In this challenge, student teams make recommendations to a fictitious Oreo factory of NABISCO regarding the number of drops of filling that should be placed on each cookie without leaking during the manufacturing process. A penny is used to represent one half of the Oreo cookie and drops of water represent the filling. Students identify criteria and constraints as a class, create a procedure as a small group, and collect and discuss results as a class. The Oreo cookie challenge is carried out over two iterations. The class answers reflection questions at each iteration like 'What procedures did your group follow?', 'Did all groups get results similar to yours? Why do you think there are differences?', 'What is important about data collection?', and 'Once data has been collected, what do scientists and engineers need to do with the data and what do they look for in the data?'

Following this challenge, the class watches a video about a company called IDEO, showing how employees work on real-world design challenges together. Following the viewing of the IDEO video, students answer reflection questions. Students also learn about criteria and constraints focusing on what they are and how they impacted the IDEO team, Key Relay Challenge, and the Oreo Cookie Challenge. They do an informed decision making activity where they have thirty-five dollars and a number of things they can buy for a friend's birthday and for themselves. They don't have enough money to buy everything, so they have to decide what is most important, decide multiple ways they can spend the thirty-five dollars, discuss the pros and cons of each alternative, select an alternative, and discuss the tradeoffs that were made while making the decision. Again, there are reflection questions that address issues of teamwork, collaboration, making informed decisions, iterating, working with constraints, and using cases to reason.

In the Product Comparisons Challenge, they do the same reasoning to choose a backpack, locker organizer, or sports shoes. For this challenge, planning and writing about the tests they could conduct is a requirement for the task, but performing the tests is optional.

Students' knowledge of experiment design, fair testing, making informed decisions, criteria, constraints, and product comparisons is brought to bear in the Keep It Hot Challenge. In this challenge, student groups work to figure out how to insulate paper coffee cups well given different supplies to create the insulation like aluminum foil, plastic wrap, mylar, bubble wrap, construction paper, and corrugated paper, as well as materials to test how well each of the supplies listed above insulates. Examples of materials used to test how well the supplies insulate are thermometers, scissors, rulers, tape, rubber bands, and the cups themselves. Each group designs and conducts an experiment to explore how well the different materials are able to keep liquid in a paper cup warm. Each group presents their experiment results to the class in a poster session, making a poster that hangs on the wall for others to see. Following the poster session, the class comes up with criteria and constraints for the challenge, considering whether there are enough of certain materials to create the number of insulators needed and the durability of the insulator. The class also does a whiteboarding activity, and having identified things they want to know more about, each group investigates one of those questions. Following each group's investigation, a gallery walk is held, and after the gallery walk, the class discusses the pros and cons of each insulation method studied and makes a recommendation about what materials should be used to insulate coffee cups and how the materials should be used. Again, reflection questions are at the end of the challenge encouraging students to reflect on the challenges they have experienced and the things they've learned, for example, 'Was your prediction accurate?', 'Is there a "rule of thumb your group can recommend to the class?', and 'What did you learn about designing and/or running an experiment?'

3.2.2 Managing Erosion: Final Launcher Activity

All of the scripts, rituals, and activity structures learned in the smaller challenges of Digging In previously described come together during the final challenge of Digging In, Managing Erosion. This is not only the first earth science activity, but it is also the first activity where students use expert cases as resources. In Managing Erosion, students work in small groups to find a way to manage or prevent erosion on a hillside. In particular, a basketball court sits at the bottom of a hill, and student groups must design and model a combination of management methods to keep the hill from eroding onto the basketball court. As they engage in the challenge, they discover what erosion is, what causes erosion, and how erosion can be managed. They design and build models, interpret and apply expert cases, and engage in all of the LBD scripts, rituals, and activity structures described earlier.

Students begin Managing Erosion by walking around the schoolyard together and identifying instances of erosion and places where they would have expected erosion but there was none. They continue by drawing and describing examples of erosion they've seen and then sharing their observations with the class. As they walk around and then discuss what they've seen, students also remember their own individual experiences with erosion as they've played in their own yards or city parks or anywhere in nature. They continue by attempting to model erosion in stream tables.

They also read about erosion disasters, the Dust Bowl and Landslide cases, and how they could have been prevented, and they build models of erosion management techniques in their stream tables. In the Landslide case, students learn about the landslides that occurred in the Cascade Mountains of Washington State. Among the causes of these landslides were water, clear cutting by humans, and gravelly soil. The landslides were managed using retaining walls, dewatering systems, warning systems, and governmental development controls. However, before many of these management methods were employed and even in spite of some of these management methods being employed, many people died or were injured as a result of the landslides.

In the Dust Bowl case, students learn about the Dust Bowl that occurred in the Midwest in the early 1930's. This area had been a desert in during the 1860's, but looked fertile due to exceptionally heavy rains. Settlers, ignoring that this area had been a desert, began plowing the lands in ways that stripped nutrients from the topsoil and overusing the land for cattle grazing. Drought caused the tall grass to die resulting in the topsoil being blown away. To manage the Dust Bowl after decades of death and destruction, cattle grazing was reduced, trees were planted as windbreakers, dams were built, and contour plowing, or plowing along the contour of the land instead of in straight lines, was introduced as a farming method. Many of these management methods were introduced by the government. From these expert cases, students can learn about what may contribute to erosion, and how it can be managed, and they can apply what they've learned to their models in stream tables. For example, from interpreting the Landslide case, students learn that when roots from plants and trees are not present to hold the soil in place in areas where there are heavy rains, during long heavy rains, water will carry the soil away causing landslides. Likewise, students learn that when roots from plants and trees are not present to hold the soil in place in areas where there is dry soil, during heavy winds, the wind will carry the soil away causing dust storms from interpreting the Dust Bowl case.

All the while, interleaved with the hands-on activities described above, are whiteboarding sessions where the class identifies what they need to learn more about in order to achieve their design challenge, presentations to the class where they explain and share their experiences with each other, and planning sessions where they consider what they've been learning, articulate design rules of thumb to describe what they've been learning and connect it to the content they've been learning, and consider how to apply it to the challenge [Owensby & Koloder, 2002]. After Managing Erosion, students are ready to begin the second Earth Science unit, Tunneling Through Georgia.

3.2.3 Tunneling Through Georgia Unit

In the Tunneling Through Georgia Unit, students learn about rock and minerals, the structure of the land, and modeling and aquifers, and students also continue to develop their collaboration, communication, science, decision making and design and technology skills as they work in small groups to design a piece of a tunnel that will run across the state of Georgia. They use design diary pages to scaffold many of their activities, and the teacher models these activities for students and coaches them in small groups as they engage in unit activities including modeling, whiteboarding, and interpreting expert cases. Expert cases inform the design and redesign of each group's piece of the tunnel by being resources that students groups can use to understand strategies the expert used, things the experts have overlooked, tools and technology available for tunnel building, and the complexities of tunnel design. For example, the Chunnel case describes strategies for tunneling underwater, while the Hoosac Tunnel case describes the problems that arose as a result of the expert failing to take core samples to understand the composition of the rock they were tunneling through.

Students begin Tunneling Through Georgia by reading about how erosion builds rocks. Then, they build and examine models of sedimentary rock using different glue and substrate materials to begin understanding how sedimentary rocks form and the impact that the composition of rocks can have on their levels of hardness and permeability.

Next, they read about the Lotschberg Tunnel, and learn about tunnel design and the complexities involved in building a tunnel, like crossing rivers, hitting different kinds of rock, considering working conditions, and flooding. In the Lotschberg Tunnel case, the experts were attempting to build a tunnel that ran through the Lotschberg Mountains. Because they were working in the Alps, they had to construct a city to house the workers. Since the experts neither took core samples nor listened to the townspeople regarding the site they chose to build housing for the workers on, the experts experienced a number of devastating problems, which resulted in a high number of deaths among the workers. The Lotschberg Tunnel case is read by the whole class as the teacher models how students should interpret an expert case: reading a case, identifying the problems and solutions, pulling out the lessons learned, and identifying further learning issues. Students use the My Case Summary Design Diary Page, described and shown earlier, as they are interpreting the Lotschberg Tunnel case with the teacher.

Student groups are then assigned other tunnel cases that they must interpret and present to the class. Students then conduct a rock and mineral lab to learn about the properties of certain rocks that may be found in the section of the tunnel that they must design. Student groups learn about metamorphic rocks and the rock cycle by learning about different kinds of rock like breccia and limestone, picking out rocks from the class collection, and writing a short story about each rock's life history. They learn how various kinds of maps can help them understand the composition of rock as well as the characteristics of a section of land (such as whether it contains mountains, rivers, faults, etc.) by studying topographic and relief maps and by creating their own topographic maps using Play-Doh, food coloring, and water. Student groups build and test models of land formations to understand and make predictions about problems that may arise in the section of the tunnel they must design based on that section's land formations. They learn about cross sections and make their own cross sections by taking core samples of the ground in their schoolyard or taking core samples of Play-Doh models of a section of soil in their schoolyard, and they use those core samples to draw a cross section of the soil in their schoolyard.

Next, student groups learn about aquifers and their impact on building a tunnel. Then, they design a plan for their section of the tunnel, applying all that they have learned throughout the unit to help them design the most thorough plan possible. They present their plans in a poster session and give and receive feedback. Throughout these activities, students answer reflective questions and interpret a variety of expert cases whose problems and solutions correspond to the different concepts that the students are learning about.

3.3 Use of Cases

As in expert design and problem solving, in LBD, students and student groups use the experiences of others to aid them in design and problem solving. In LBD, expert cases play an important role in student design processes as they design decisions, focus students' attention on problems that they may encounter, and help them connect their experiences to the challenge they are trying to achieve. Expert cases help students as they design strategies and solutions that should result in favorable outcomes, and they help students think about solutions the experts used that resulted in unfavorable outcomes. Expert cases help students focus on things they need to be mindful about, consider, and address as they design their final plans. For example, in the Lotschberg Tunnel case, students learn that they need to be mindful of the composition of the rock they must tunnel through by taking core samples. Taking core samples can help students understand what technology and tools are needed given the composition of the rock, resulting in a more informed and complete design. LBD provides affordances for students to see the importance of using the experiences of others as they solve the challenge. Iterating through the LBD cycle gives students many opportunities to generate questions, critique ideas, interpret and apply expert cases, and reflect on their experiences in ways that the case-based reasoning and the transfer literatures suggest promote more flexible use of experiences and knowledge.

3.3.1 Tunneling Cases

During Tunneling Through Georgia, students use up to twelve expert cases as resources, interpreting and applying them to address potential problems that may arise in their section of the tunnel. The expert cases are taken from tunnels that were built in various parts of the world at different times in history, helping students understand the complexity of tunnel design, the different kinds of problems that can arise during tunnel design and building, the different solutions that have been employed to design and build tunnels, and the different kinds of technologies available that have been used to build tunnels. Table 3.1 gives a brief description of all of the cases available for use as resources in the Tunneling Through Georgia Unit.

Table 3.1: Description of the Expert Cases Available In Tunneling Through Georgia Unit

Expert Case Name	Description
Hoosac	Tunnel built in the 1800's in which the composition of the Hoosac Mountain was not well understood and modern tools were not supported. This case describes huge time delays and a project in which the team ran out of money. This case chronicles one of the first large-scale uses of nitroglycerine.
Frejus/Mont Cenis	Tunnel built in the 1850's in which technology was an initial limitation and in which sustaining the well being of the workers was a focus. Ventilating the tunnel so workers could breathe was a huge problem. This is one of the first uses of air compressed drills.
Saint Gotthard	Tunnel built in the late 1800's in which technology was a limitation. Serious problems encountered were flooding, well-being of the workers, keeping the tunnel walls from caving in, and running out of money.
Queens Midtown	Tunnel built in the early 1900's in which building a tunnel beneath a city and beneath the East River were problems. Experts took core samples and discovered rock that could be problematic. Flooding was also a problem.
Washington D.C. Subway	A geological survey of the area where this tunnel was built is described including fall lines, soil type and hardness, and water levels. There is a great deal of variation among soil types, hardness, and water levels on along the tunnel route.
Mono Craters Tunnel	Tunnel built near Leevining, California as part of the Los Angeles aqueduct from the Sierra Nevada. Experts ran into every kind of problem including water, squeezing ground, and soft earth conditions occurring in parts of a hard rock tunnel.
Mont Blanc Tunnel	Tunnel built in the 1950's and 60's by the Swiss to bring tourist dollars into Geneva by connecting Italy and France. Ventilation systems were designed and concrete lining was proposed to keep water out. Drilling test holes was not possible—expert hit water springs, crumbling rock, falling roofs, faults, and avalanches.

Table 3.1: Description of the Expert Cases Available In Tunneling Through Georgia Unit (Continued)

Tecolote Tunnel	Tunnel built in the 1940's and 50's to connect Lake Cachuma and the South Coast Conduit through the Santa Ynez Mountains. Experts faced problems such as water, soft rock, potential landslides, seismic activity, and fractured rock. Experts drilled holes ahead of the tunnel and filled them with concrete grout to keep water out. They also dug smaller tunnels ahead and to the sides of the main tunnel to drain the water out of the way before it reached the tunnel.
Simplon Tunnel	Tunnel built during the late 1890's and early 1900's. The Lotschberg Tunnel led up to the Simplon Tunnel. Using an inaccurate geologic report, experts hit hot springs and ventilation problems, as well as fissures, heavy air pressure, soft rock, and faults. Among the solutions used to address the problems were spraying a find mist of cold water, building a cross tunnel to divert the flow of water, build an underground bridge and supporting the bridge with masonry and steel arches, and enlarging the drainage tunnel, respectively.
Seikan Tunnel	Tunnel built from 1960's to 1980's. An underwater tunnel that crosses under the ocean between the Japanese islands of Hokkaido and Honshu. The experts ran into many faults and fissures, swelling rocks, water pressure. One of the first uses of the boring machine, but the machine was too hard to steer in the soft sandstone and siltstone, so it was abandoned for old fashioned drill and blast methods. Experts forced grout into fissures, encircled the tunnel with a cutoff ring of rock grouted as tightly as possible, pumped water out, lined the tunnel with concrete, and included a service tunnel and a drainage tunnel to address the problems they faced.
Hudson River Tunnel	Tunnel built in the late 1800's and early 1900's. It was built to connect New York and New Jersey. Composition of the tunnel was fine silt. The airlock was used in early construction, but it was not enough to keep air pressure low and to keep mud from flooding the tunnel. After the death of the first designer, DeWitt Haskins, James Greathead took over, and invented the Greathead Shield, which was used to complete the tunneling and address the problems of air pressure and mud. Steel rings and brick and sheet lining were also used to line the tunnel.
Chunnel	Tunnel built in 1960's and 1970's beneath the English Channel to connect France and England. Experts faced chalk marl, water problems, fissured chalk, and ventilation problems. Experts stayed within the chalk, lined with concrete and iron, design special cars for escape and a service shaft, used the boring machine, dug small holes in all directions and forced in sodium silicate grout to seal cracks in the chalk to address problems.

These cases are written and presented in such a way that lessons that can be learned from them are visible. For example, the Queens Midtown Tunnel case reads, “Core samples were taken to produce topographic maps and cross sections for a geologic report. With this information, the builders were able to plan to have the right equipment on hand and to keep workers safe.” This excerpt suggests that taking core samples can result in more informed decision decisions including using the right equipment and tools, understanding the composition of the tunnel site, and keeping workers safe while building the tunnel. Even though the expert cases in the Tunneling Through Georgia Unit are written to make the lessons student can learn from them visible, students still need help interpreting the expert cases and applying the lessons to their designs.

3.3.2 Role Of The Teacher

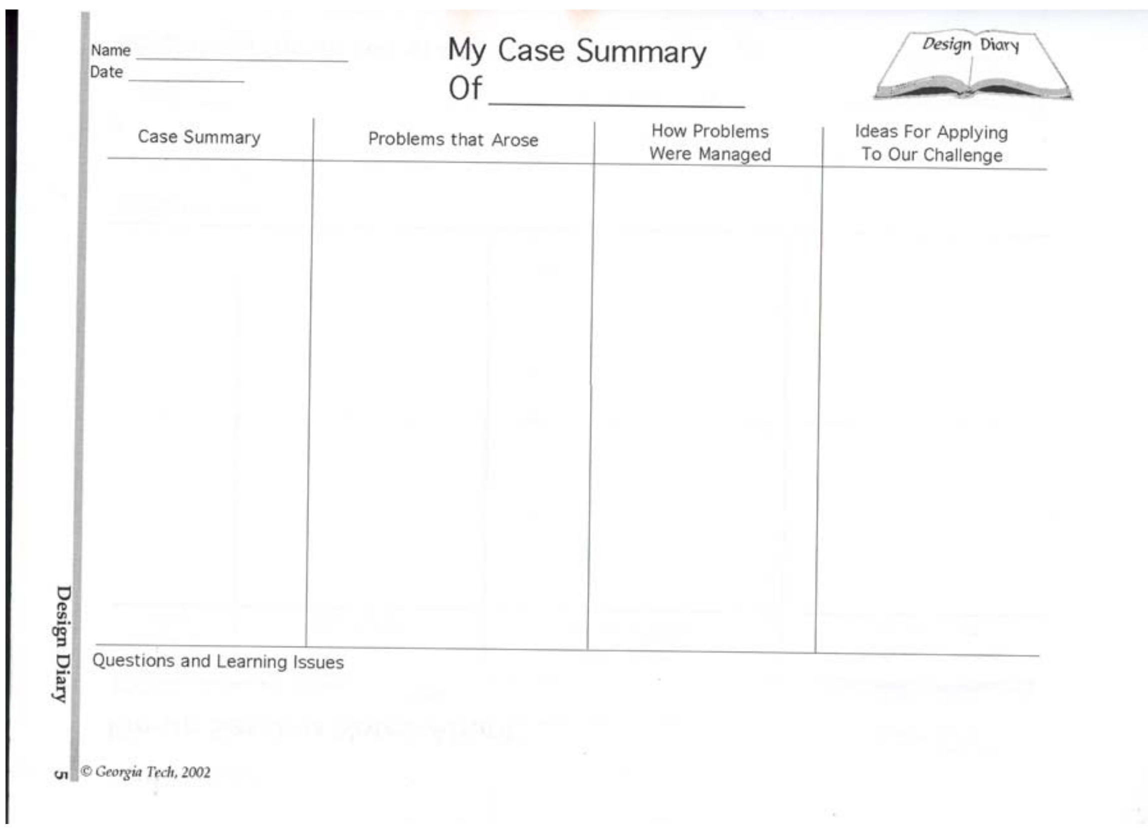
Teachers play a critical role in the success of students’ skill development serving first as the primary modeler in LBD and then as coach and scaffolder, especially as students are learning to understand and apply cases. Initially, with the Lotschberg case, the teacher reads the case with the class, not only modeling for them the kinds of questions that they should be asking themselves and each other as they read cases for understanding, but also helping them understand that the experiences of others, experts in particular, can be useful resources for solving problems.

In addition, the teacher facilitates discussions about the cases during presentations that help students make connections between concepts they are learning and the experiences of the experts, understand the ways those concepts play out in the real world, and reflect on their understanding of the concepts. The teacher encourages groups to explain and make connections within their case, helps the class as a whole make connections across cases, and models the kinds of questions students should ask themselves and their peers as they interpret and apply expert cases either alone or in small groups. As students work in small groups interpreting and applying other cases to the tunnel challenge, the teacher walks from group to group asking them questions about their designs, helping them apply design rules of thumb, helping them identify learning issues, illustrating for them how to use the tools and resources provided to help them achieve the challenge, and serving as a sounding board for groups as they apply what they've learned from the expert cases to their designs. In this capacity, the teacher serves as a coach, scaffolding small groups as they interpret and apply expert cases.

For every unit they enact, teachers are given written materials that provide descriptions for each of the activities (i.e., goals and objectives, amount of time for the activity, supplies needed, ideas for facilitating class discussions and helping students connect their experiences across activities, and suggestions for modeling skills for students). Despite having teacher materials available, some teachers are better at doing these things than other teachers for several reasons. Some teachers are more comfortable with the content than others, giving them more insight into the materials that they can use to help students understand the content. Some teachers are better facilitators, helping to push students' thinking and prompting them to reason more deeply. Other teachers are more familiar with project-based inquiry learning and are more comfortable with the flow, format, and activities in LBD.

3.3.3 My Case Summary Design Diary Page

Although the teacher walks from group to group coaching small groups as they are interpreting and applying expert cases, she cannot be with every group all of the time. Because of this limitation, the My Case Summary Design Diary Page is used as students interpret and apply expert cases. It provides some scaffolding that can be used by all students and groups at the same time.   Figure 3.4 shows the My Case Summary Design Diary Page. It is a chart with four columns labeled *Case Summary, Problems that Arose, How Problems were Managed, and Ideas to Apply to Our Challenge*. This design diary page provides minimal scaffolding for students as they identify the important problems and solutions in the case and as they begin thinking about how the case might be applicable in the future, as suggested by the transfer literature and case-based reasoning. The My Case Summary design diary page serves to focus students' attention on important aspects of the case and organize their findings in such a way that they can be applied to the challenge and/or used by other groups as they solve the same or a similar challenge.



Name ____________
Date ____________

My Case Summary
Of ____________

Design Diary

Case Summary	Problems that Arose	How Problems Were Managed	Ideas For Applying To Our Challenge

Questions and Learning Issues

Design Diary

5 © Georgia Tech, 2002

Figure 3.4: My Case Summary Design Diary Page

3.3.4 Extracting Lessons Learned From The Expert Cases: Design Rules Of Thumb

As stated earlier, design rules of thumb are lessons that are learned from experiences. They are extracted so that students and student groups can make connections between their experiences and the science content they are learning, and they are refined as students learn more about the conditions of applicability of a design rule of thumb. We have found that the design rule of thumb template described earlier and used to help students extract and articulate design rules of thumb from their experiences designing experiments can also help students extract and articulate design rules of thumb from the expert cases in LBD. The design rule of thumb template helps students articulate the connection between problems faced by the experts, the solutions used to address those problems, and the conditions under which particular solutions are more successful or particular problems are more likely to arise. As we'll show in our study, being able to identify problems and solutions in the expert case and then being able to connect problem and solution pairs seems to help make the design rules of thumb more visible to students. Design rules of thumb also seem to be helpful in helping students make connections between the expert cases they read and the design challenge they must achieve. The application process revolves around identifying rules of thumb, analyzing their applicability and applying them to a challenge, and then predicting the effects of the solution and assessing how well it meets the challenge. An example of an excellent rule of thumb in Earth Science might be:

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

Teachers are encouraged to help the class understand the lessons they can learn from all of the expert cases as student groups are presenting interpretations of expert cases to the class, as student groups are presenting design ideas during a poster session, and as teachers are facilitating whiteboarding activities to pool together the lessons that student groups have learned as they have interpreted different expert cases.

3.4 Roles For The Computer

When piloting Learning by Design in middle school physical science classrooms, the LBD team found that students who participated in LBD learned science content as well or better than those learning in more traditional settings. In addition, students who participated in LBD engaged in collaboration, communication, informed decision making, and design of investigations in a far more expert manner than their matched comparisons [Kolodner, Gray & Fasse, 2003]. This finding is due in part to the modeling, coaching via scaffolding, and facilitating that the teacher does during whole class discussions. However, when students worked in small groups, the teacher was not able to be with every group all the time, and students were sometimes less focused and not as rigorous and productive, often unable to focus their attention appropriately on the reasoning they needed to do [Owensby & Kolodner, 2004]. Design Diary Pages helped to alleviate some of the limitations of the teacher as students worked in small groups, but they have very little scaffolding because of the limitations of the size of the page.

To address these limitations, computers can be used to provide more scaffolding than paper can. The affordances of computers alleviate many of the limitations of the teacher and the design diary pages by providing more scaffolding without cluttering the screen. They also can provide easy access to artifacts, providing a library of artifacts that are available to everyone, and providing scaffolds that help students achieve and reflect on tasks and skills. In particular, software designed to support students as they interpret and apply expert cases can also alleviate many of the limitations of the teacher as well as the limitation of the Design Diary Page by providing easy access to cases, allowing students to select particular cases they want to interpret and/or apply, making the interpretations and applications of students and student groups available to everyone for future use, supporting small group discussion, and helping students and student groups reflect on content, skills, and practices.

The computer can play the role of modeler, providing examples for students to follow and stepping through examples in a way that can help students make connections. The computer can also play the role of coach, providing scaffolding to support students as they engage in complex tasks. As such, software has been developed to support LBD activities, and that software takes advantage of the affordances of computers for learning.

3.5 Supportive Multi-User Integrated Learning Environment (SMILE)

Supportive Multi-user Integrated Learning Environment (SMILE) [Kolodner & Nagel, 1999; Lamberty, Mitchell, Owensby, & Sternberg, 2000; Kolodner, Owensby & Guzdial, 2004] is a suite of tools designed to scaffold students as they engage in various aspects of project-based inquiry learning in LBD. SMILE was designed to promote the kinds of reflection that case-based reasoning suggests are needed to learn from an experience [Kolodner & Nagel, 1999]. SMILE was also designed to be used by individuals or groups, and it contains tools that help students design experiments, analyze results, design and test models, brainstorm, plan presentations, look at the lessons they and their peers have learned, and interpret and apply expert cases. It began as a suite of tools that supported planning investigations and presenting investigative results, design plans, and design experiences, guided the interpretation of expert cases, and helped students summarize over their extended project experience and extract the lessons they learned from it. The current version of SMILE continues to do all of those things, supporting students as they engage in project-based inquiry learning tasks through a system of scaffolds.

3.5.1 SMILE's System Of Scaffolds

SMILE's system of scaffolding has 5 parts [Owensby & Kolodner, 2004; as mentioned in Chapter 2]:

- Tool sequences make process sequence visible – this scaffold addresses the *structuring* of tools to suggest a high-level process that students are engaging in.
- Within each tool, structured questioning makes the task sequence clea*r* – this scaffold addresses prompts, which are questions or statements used to focus students' attention as they are carrying out or reflecting on a task.
- For each prompt in the sequence, hints are provided – Hints are task-specific/domain-specific questions or statements used to refine a task.
- For each prompt in the sequence, sample nice answers (examples) are provided. Examples are exemplars that can be used to model a process or a specific step.
- For some tasks in the sequencing, a template or chart to help with lining up ones reasoning is provided.

An example of SMILE's system of scaffolds can be seen in the tools used to scaffold students as they design, carry out, and analyze results from an experiment. To design an experiment plan, students use the Experiment Plan Tool shown in Figure 3.5. Once they have planned their experiment, carried it out, and collected data from the experiment, they use the Experiment Result Tool shown in Figure 3.6, accessing this tool through a link in the Experiment Plan Tool. This sequencing or structuring of tools suggests that carrying out an experiment involves the high-level processes of planning the experiment, conducting the experiment, and analyzing the results from the experiment, in that order.

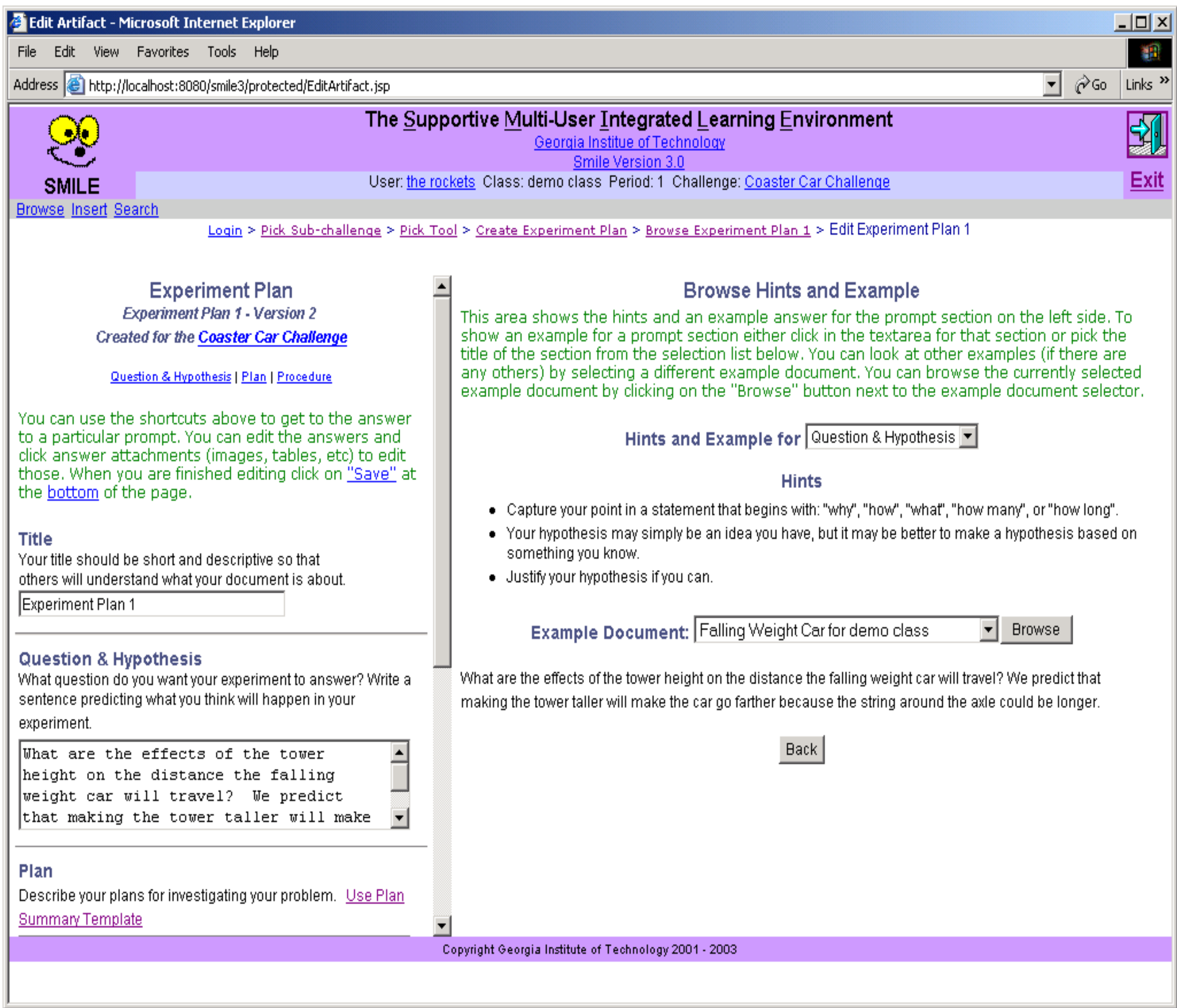


Figure 3.5: Experiment Plan Tool

Notice the prompts in the left frame, and hints and examples in the right frame. The Experiment Plan Tool has three prompts, Question and Hypothesis, Plan, and Procedure. For each prompt, there is an accompanying hint and example that are displayed in the right frame. For example, the one of the hints for the Question and Hypothesis prompt reads ‘Capture your point in a statement that begins with “Why”, “How”, “What”, “How many”, or “How long”, while the example for this prompt reads ‘What are the effects of the tower height on the distance the falling weight car will travel? We predict that making the tower taller will make the car go farther because the string around the axle could be longer.’

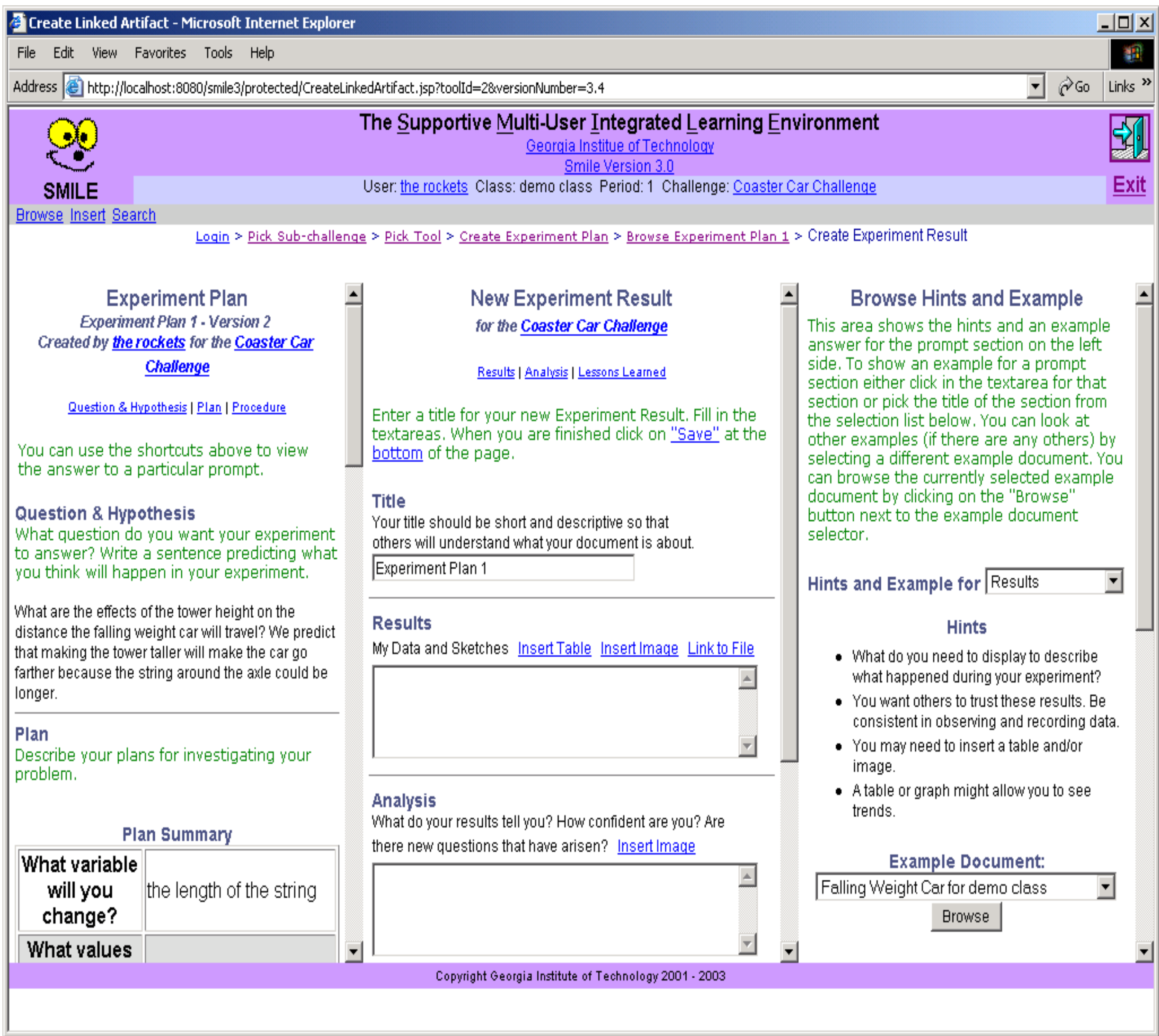


Figure 3.6: Experiment Result Tool Linked To Experiment Plan

The Experiment Result Tool has a similar structure, but it prompts for describing results (Results), analyzing trends (Analysis), and describing design rules of thumb that can be gleaned from the experiment (Lessons Learned). Notice, too, that the Experiment Plan created for this experiment is also available in the left frame.

Templates are used as scaffolding in both the Experiment Plan and Experiment Result Tools, as the Procedure Template shows in Figure 3.7. This template is linked to the Procedure prompt in the Experiment Plan Tool. The Procedure Template helps students create and describe the procedure they will use when they run their experiment. This template reminds students and student groups to include a description of a step in the procedure in the order in which the steps should be carried out (Procedure step description), to think about what they should be careful about when carrying out that step in the procedure (Thing(s) to be careful about), and what they will do to insure that the step will be carried out carefully (How we will be careful).

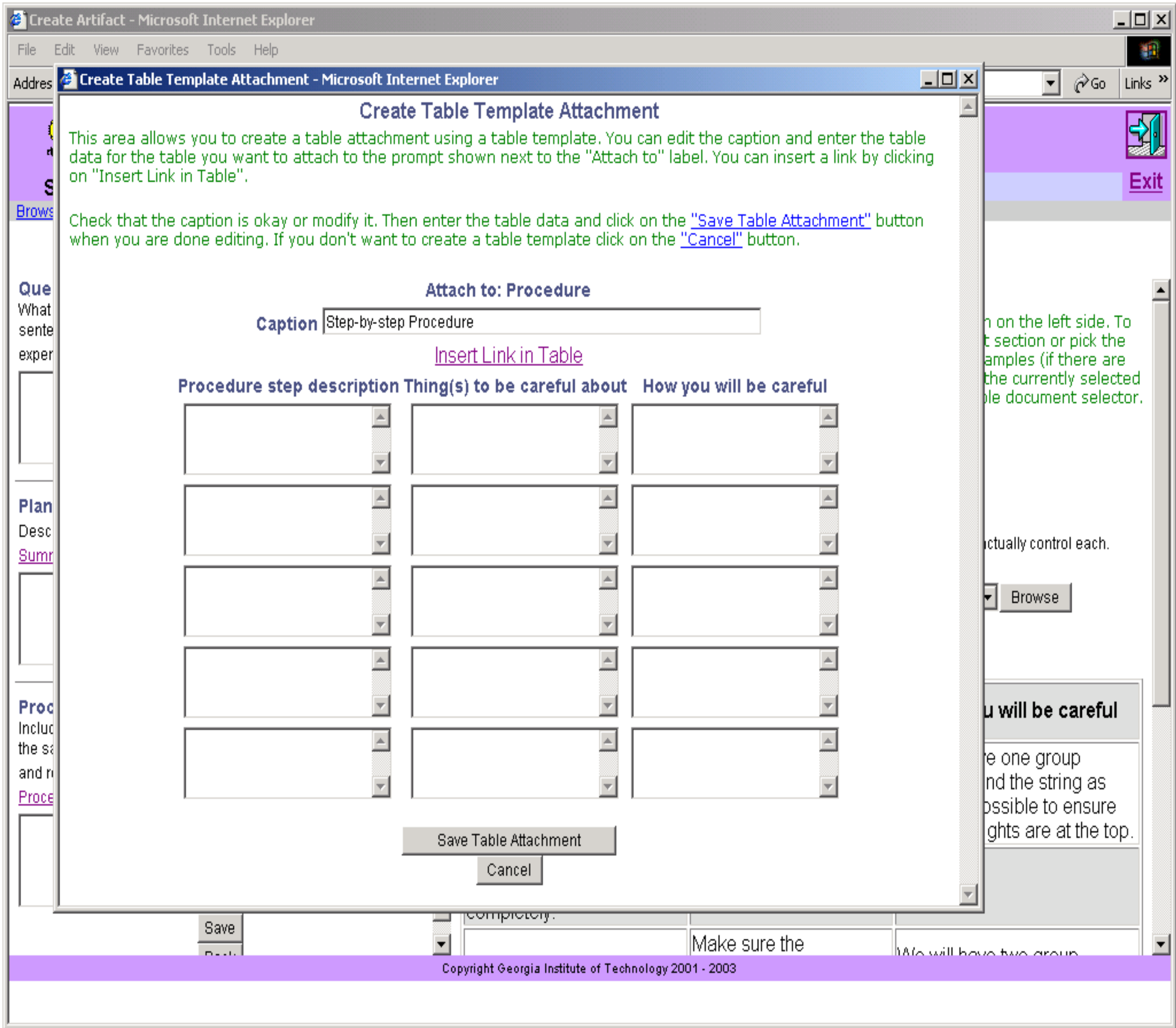


Figure 3.7: Experiment Plan Tool With Procedure Template

When using the software, groups or individuals access templates by clicking on a link within the prompt associated with a template. Once they have completed and saved the template, it shows up as a link within the prompt. If a group or individual wants to revise a template based on comments or small group/whole-class discussion, they can return to the artifact where they created the template and click the "Edit table" link next to the link for the template. The template will open in edit mode and revisions can be made and saved. Teacher tools also exist that allow teachers to create custom templates and link them to prompts in existing SMILE tools or in tools they create in SMILE [Owensby & Kolodner, 2004].

3.5.2 The Look Of SMILE: 2- and 3- Frame Design

In addition to the system of scaffolds that is used in all of SMILE's tools, a particular interface design is also used. This interface design relates to how information is displayed and divided on the screen. Most tools in SMILE contain two frames as in Figure 3.5 that shows the Experiment Plan Tool. The left frame displays prompts for the tool, and the right frame displays hints and examples, comments, and templates depending on what is selected. The default view in the right frame displays hints and examples.

When using tools that are linked, like the Experiment Plan and Experiment Result Tools, three frames are used as shown in Figure 3.6. When creating an Experiment Result that corresponds to an Experiment Plan previously created, the left frame displays the previously created Experiment Plan in browse mode; the middle frame displays the Experiment Result in edit mode; and the right frame is the same as with the two-frame design. This three-frame design allows students to refer back to linked resources that may contain relevant information as they are working in the middle frame.

3.6 Case Application Suite

As described earlier, reading expert cases, pulling out the lessons they can learn from the experts, and applying those lessons by addressing the lessons' implications within the group's design plans is an important part of LBD's Earth Science Units. Students must interpret and apply expert cases to help them solve their challenges. The Case Application Suite, integrated into SMILE, provides scaffolding for interpreting, applying and assessing expert cases. Because all of case use's functions require references to an expert case or previously created artifact, the Case Application Suite's tools all use a 3-frame design. The left frame displays the case or previous linked artifacts; the middle frame displays prompts; and the right frame displays hints and examples and comments, depending on what is selected. The default view in the right frame displays hints and examples. Templates are displayed in separate windows, and they are attached to the prompt in the artifact they are linked to by a blue hyperlink. The Case Application Suite also uses the same system of scaffolds as the other tools in SMILE described earlier.

3.6.1 Tool Sequence Makes The Case Use Process Sequence Visible

Because of the suggestions made by the skills acquisition literature and cognitive apprenticeship concerning the importance of students seeing and understanding the process(es) they are trying to carry out as they develop complex cognitive skills, we designed three linked tools in SMILE to scaffold students, using our system of scaffolds described earlier, as they engage in case use. These three tools are linked in sequence to make the process sequence of interpreting and applying expert cases visible to students and student groups. First, they should interpret a case, using the Case Interpretation Tool shown in Figure 3.8 to identify the goal(s) of the experts, the criteria and constraints that are present in the expert case and how they inform the problems that arise and the solutions that are employed to address those problems, the tools and technology needed to implement the solutions, and any design rules of thumb the expert case suggests.

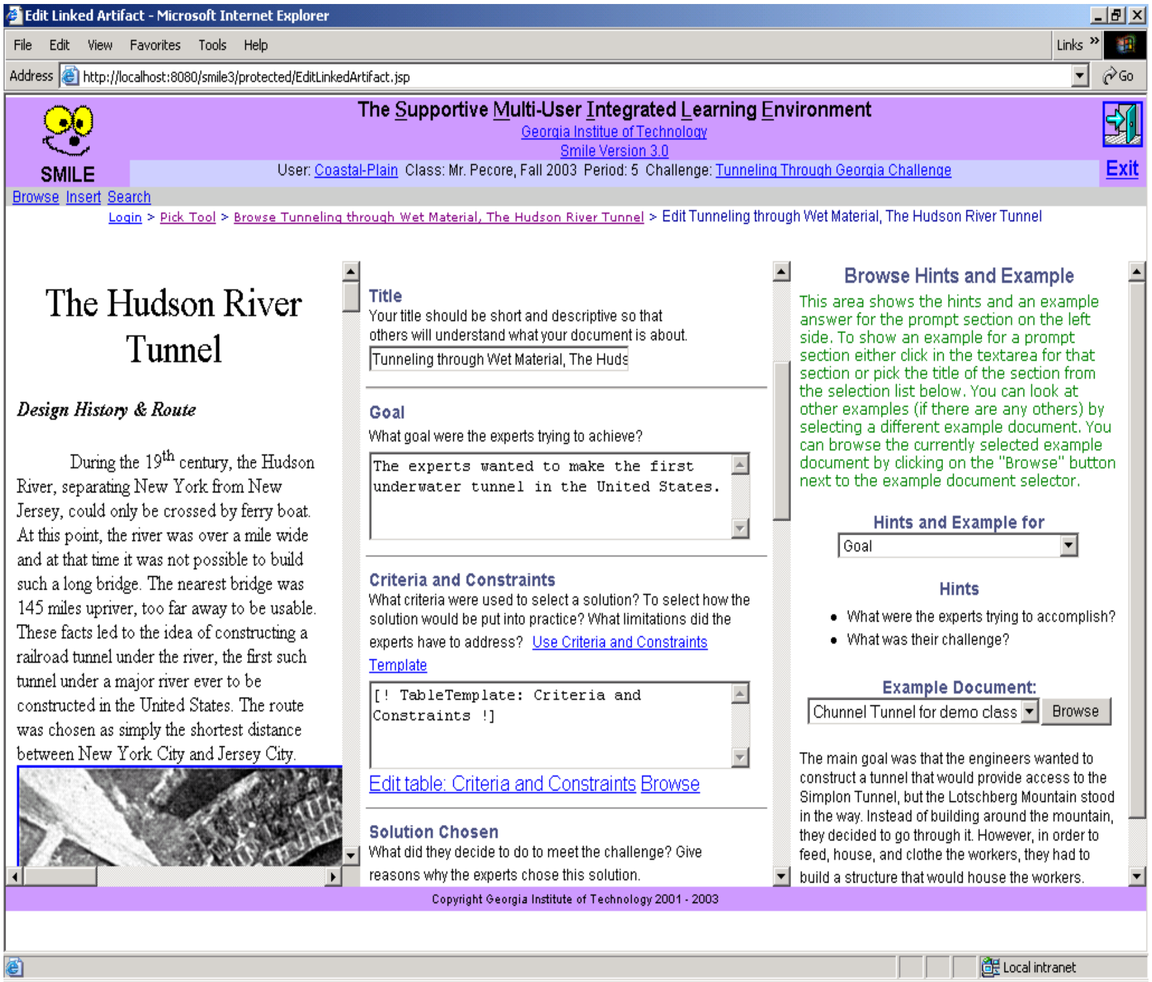


Figure 3.8: Case Interpretation Tool

Next, they need to apply the design rules of thumb gleaned from their interpretation using the Case Application Tool as shown in Figure 3.9 to examine their challenge's goal(s) and criteria and constraints, and to analyze the design rules of thumb based on the criteria they match and the suggestions they make for a possible solution. Then, as the last piece in applying the design rules of thumb, students and student groups should determine whether the design rule of thumb makes sense for their challenge; if it does not, the design rule of thumb should be abandoned, but if it does make sense, it should be determined whether the design rule of thumb can be applied directly or whether the design rule of thumb should be modified in any way to address the particular criteria and constraints of the challenge.

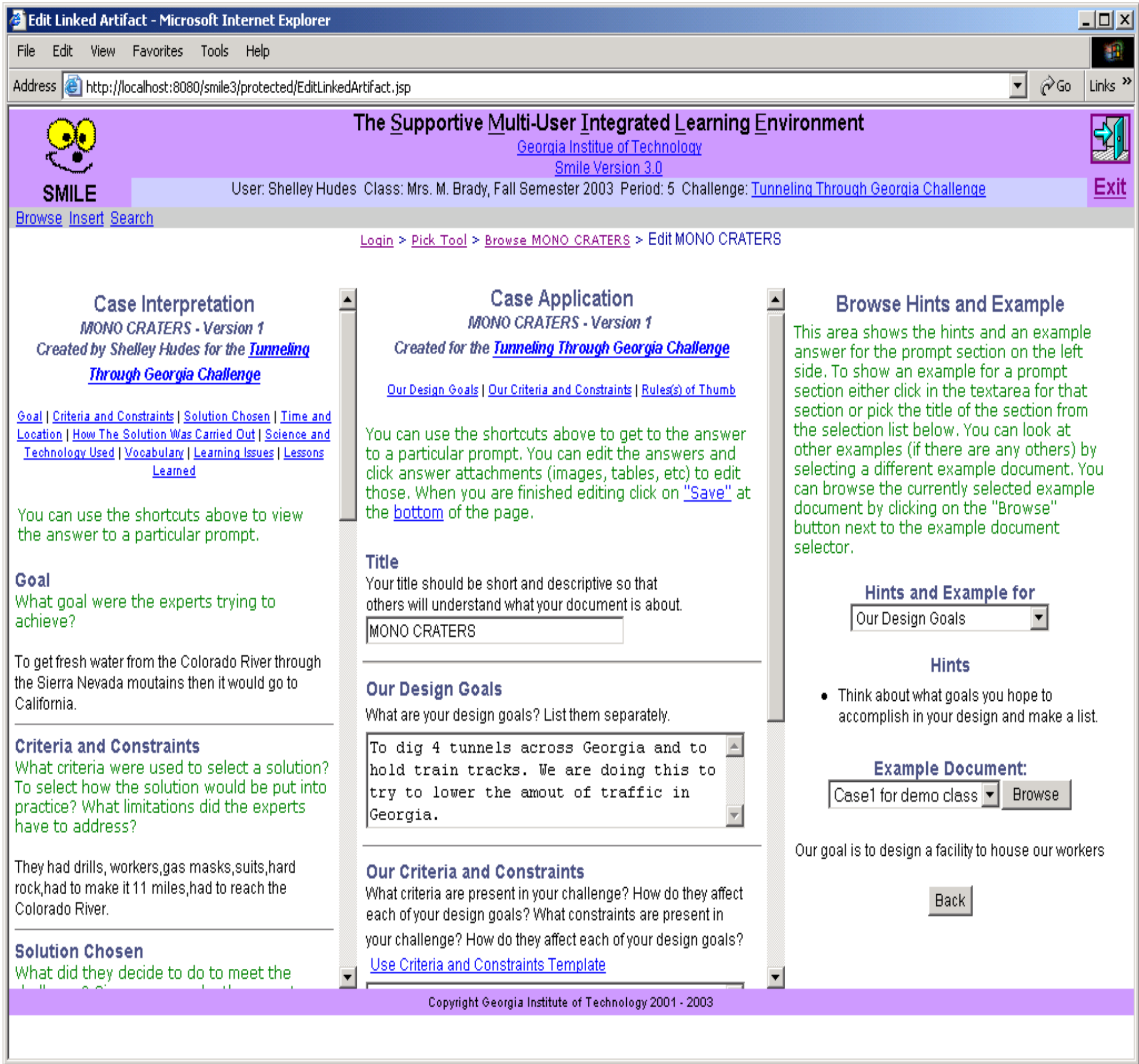


Figure 3.9: Case Application Tool

Finally, the application of the design rules of thumb to the students' or student group's challenge can be assessed using the Solution Assessment Tool shown in Figure 3.10. In particular, students and groups engage in an assessment of their solutions by making predictions about which criteria and constraints they think are addressed by applying the design rule of thumb to the challenge solution, making predictions about which criteria and constraints are not addressed by applying the design rule of thumb to the challenge solution, and deciding if the challenge solution is complete as is, requires the application of other design rules of thumb to become more complete, or requires further investigation to become more complete. Because of the sequencing of the process of interpreting and applying expert cases, the Case Application Suite's three tools, the Case Interpretation, Case Application, and Solution Assessment Tools, are linked together to make this process sequence visible to students and student groups.

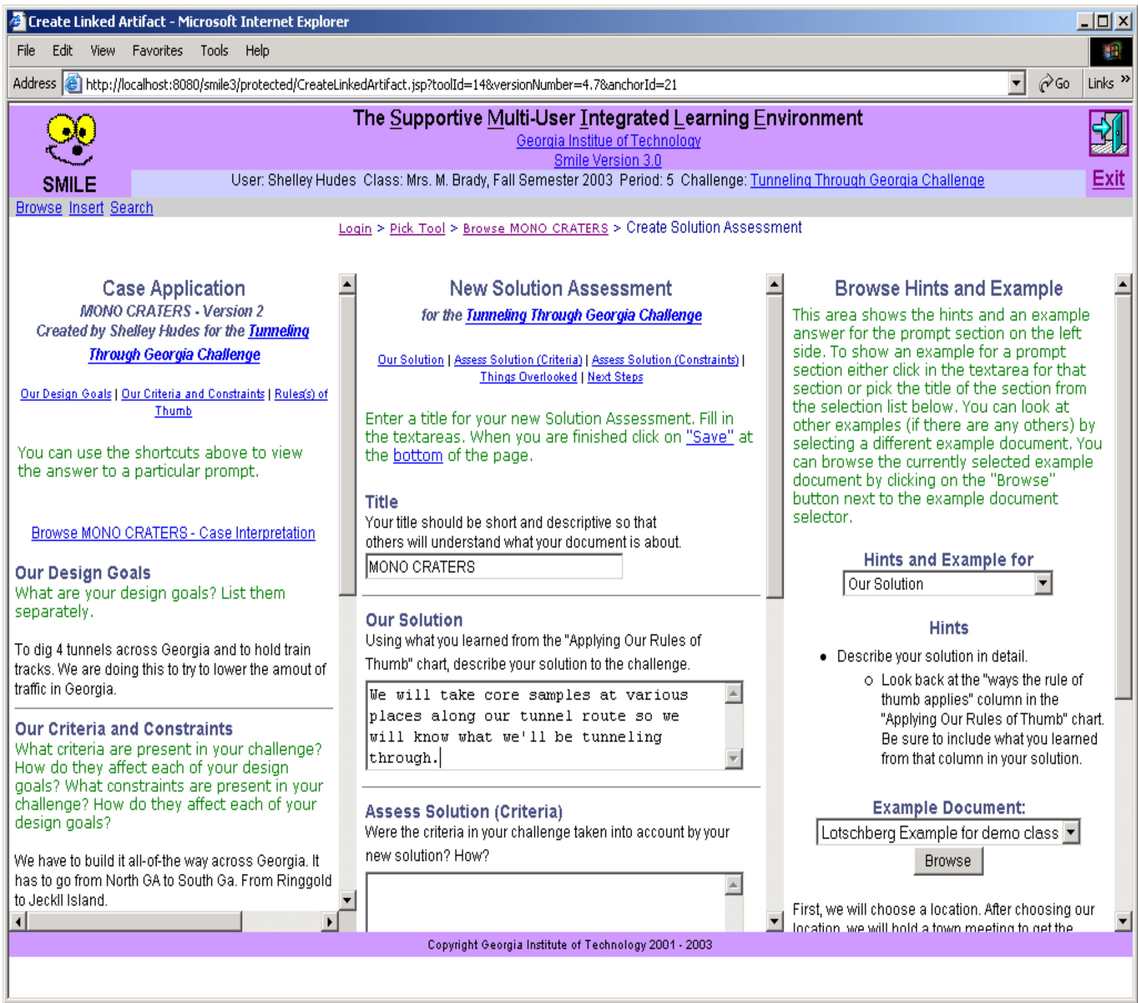


Figure 3.10: Solution Assessment Tool

3.6.2 Structured Questioning Makes The Task Sequence Clear

Because of the roles suggested by cognitive apprenticeship, the Case Application Suite was designed primarily to play the role of coach as individuals or small groups of students are working to interpret an expert case and apply it to their challenge. This coaching is carried out by asking the kinds of questions and making the kinds of suggestions that can push students' understanding, and by questioning the decisions they make to help students make connections and develop the ability to justify their decisions and the connections they make with evidence. The Case Application Suite's questions generally require a deep level of analysis and prompt students to reason as case-based reasoning suggests, (e.g., to identify the different design rules of thumb that they can glean from the case, analyze their applicability to the new situation, justify their decisions, and consider alternatives). Examples of prompts in the Case Interpretation Tool shown in Figure 3.8 are 'What goals were the experts trying to achieve?' and 'What criteria were used to select a solution? To put that solution into practice? What limitations did the experts have to address?'. Examples of prompts in the Case Application Tool shown in Figure 3.9 are 'What are your design goals? List them separately.', 'What criteria and constraints are present in your challenge? How do they affect each of your design goals? What constraints are present in your design goals?'. Examples of prompts in the Solution Assessment Tool shown in Figure 3.10 are 'Using what you learned from the 'Applying Our Rules of Thumb' chart, describe your solution to the challenge' and 'Were the criteria in your challenge taken into account by your new solution? How?'.

Table 3.2 shows all of the prompts for each tool in the Case Application Suite. As this table shows, the Case Interpretation Tool's prompts help students understand the expert's goal(s) (Goal), criteria and constraints that were present in the expert case (Criteria and Constraints), the solution the experts used to address the problems in the challenge (Solution Chosen), the time and location where the challenge took place (Time and Location), how the solution was implemented (How The Solution Was Carried Out), the tools and technology used to implement the solution (Tools and Technology), any vocabulary in the case that students or student groups did not understand (Vocabulary), any other questions that interpreting the expert case either uncovered or did not answer (Learning Issues), and any design rules of thumb gleaned from the expert case (Lessons Learned). The Case Application Tool's prompts help students understand their challenge's goals (Our Goals), criteria and constraints (Our Criteria and Constraints) and also helps them analyze the design rules of thumb that were gleaned during their interpretation of the expert case to determine which design rules of thumb are applicable to their challenge (Rule(s) of Thumb). The Solution Assessment Tool's prompts help students make predictions about the completeness of their solution by describing the solution (Our Solution), making predictions about which criteria were addressed (Assess Solution (Criteria)), making predictions about which constraints were addressed (Assess Solution (Constraints)), making predictions about which criteria and constraints were overlooked (Things Overlooked), and explaining what next steps should be taken to make the solution more complete (Next Steps).

Table 3.2: Prompts From Case Interpretation, Case Application, and Solution Assessment Tools

Case Interpretation Tool	Case Application Tool	Solution Assessment Tool
Goal What goal were the experts trying to achieve? Criteria and Constraints What criteria were used to select a solution? To select how the solution would be put into practice? What limitations did the experts have to address? **Solution Chosen** What did they decide to do to meet the challenge? Give reasons why the experts chose this solution. Time and Location Where and when did this challenge take place? Be as specific as possible in telling the sequence of events. **How The Solution Was Carried Out** What process did the experts use to design and build their solution? What steps did they take to carry the solution out? Science and Technology Used What science and technology were used in choosing the solution? In designing and building the solution? Vocabulary Provide the definitions for terms needed to understand this case. Learning Issues What else do you need to know about this case to move on? What other questions do you still need to answer to know whether this case can help you solve your challenge? Lessons Learned What lessons have you learned that might be helpful to others? You may want to use the Rule of Thumb template to help you describe those lessons.	Our Design Goals What are your design goals? List them separately. Our Criteria and Constraints What criteria are present in your challenge? How do they affect each of your design goals? What constraints are present in your challenge? How do they affect each of your design goals? Rules(s) of Thumb Use the "Applying Rules of Thumb" chart to figure out which rules of thumb apply to your challenge.	Our Solution Using what you learned from the "Applying Our Rules of Thumb" chart, describe your solution to the challenge. Assess Solution (Criteria) Were the criteria in your challenge taken into account by your new solution? How? Assess Solution (Constraints) Which constraints were addressed by your solution? Things Overlooked Were any criteria and constraints overlooked? How? Next Steps If design goals, issues/sub-issues, or criteria/constraints were not met, decide if your current solution covers enough to stand alone, whether it should be meshed with another solution to make a more complete solution, or if it should be abandoned.

3.6.3 Hints And Examples Provide More Focused Help And Exemplars

Each prompt in each of the three tools in the Case Application Suite contain hints and examples. An example of a hint/example pair for the prompt in the Case Interpretation Tool shown in Figure 3.8 reads 'What were the experts trying to accomplish? What was their challenge?' (hint)/ 'The main goal was that the engineers wanted to construct a tunnel that would provide access to the Simplon Tunnel, but the Lotschberg Mountain stood in the way. Instead of building around the mountain, they decided to go through it. However, in order to feed, house, and clothe the workers, they had to build a structure that would house the workers' (example). An example of a hint/example pair for the prompt in the Case Application Tool shown in Figure 3.9 reads 'Think about what goals you hope to accomplish in your design and make a list' (hint) / 'Our goal is to design a facility to house our workers' (example). An example of a hint/example pair for the prompt in the Solution Assessment Tool shown in Figure 3.10 reads 'If any criteria or constraints were not met, think about why they weren't met. Also think about how you might take them into account' (hint) / 'We have not thought about the actual design of the facility yet (i.e. living quarters on the one side of the facility and bathrooms on the other, recreation room, kitchen, etc.)' (example).

3.6.4 Templates And Charts Designed To Help Learners Line Up Their Reasoning

Several templates and charts are included in the Case Application Suite to serve as reminders to help students articulate and organize their ideas in such a way that they are useful to them later and to others who may solve the same challenge or a similar one. In LBD, there is a great deal of attention given to the importance of criteria and constraints in informing design decisions. The same is true when interpreting the design decisions made by the experts. As such, in the Case Interpretation Tool, there is a chart that helps students identify and describe the criteria and constraints in the expert problem. It is a link that is included with the 'Criteria and Constraints' prompt, and, as Figure 3.11 shows, it is a two column chart that separates criteria from constraints.

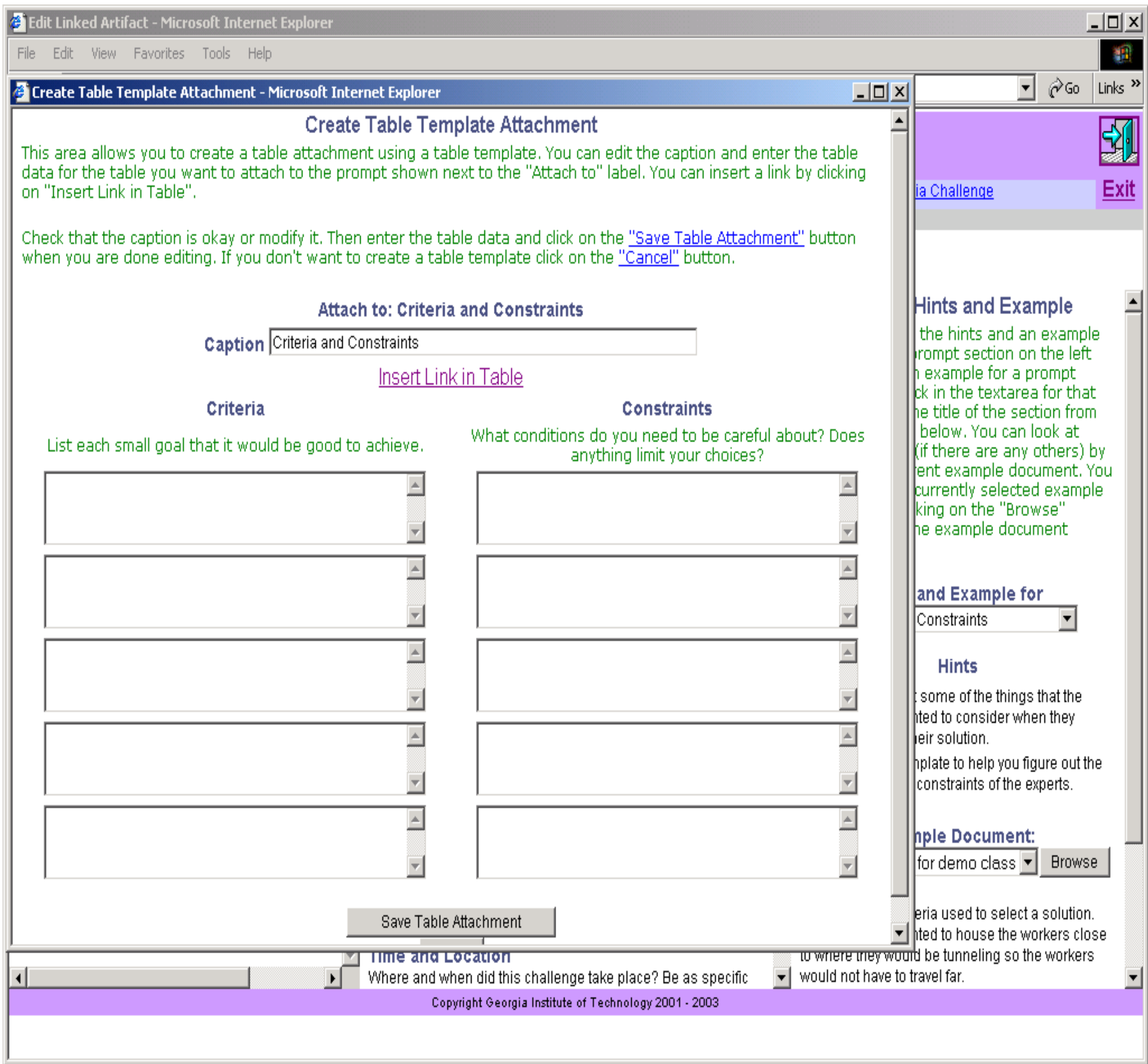


Figure 3.11: Criteria and Constraints Template

A link for the design rule of thumb template is included with the 'Lessons Learned' prompt which is also in the Case Interpretation Tool. This template, shown in Figure 3.12, is the same as the design rule of thumb template described earlier that is used in classrooms by teachers to help students articulate design rules of thumb and connect their experiences to the science content they are learning. However, in place of the list of options in parentheses, there are drop down menus where students and student groups can select the options that makes sense.

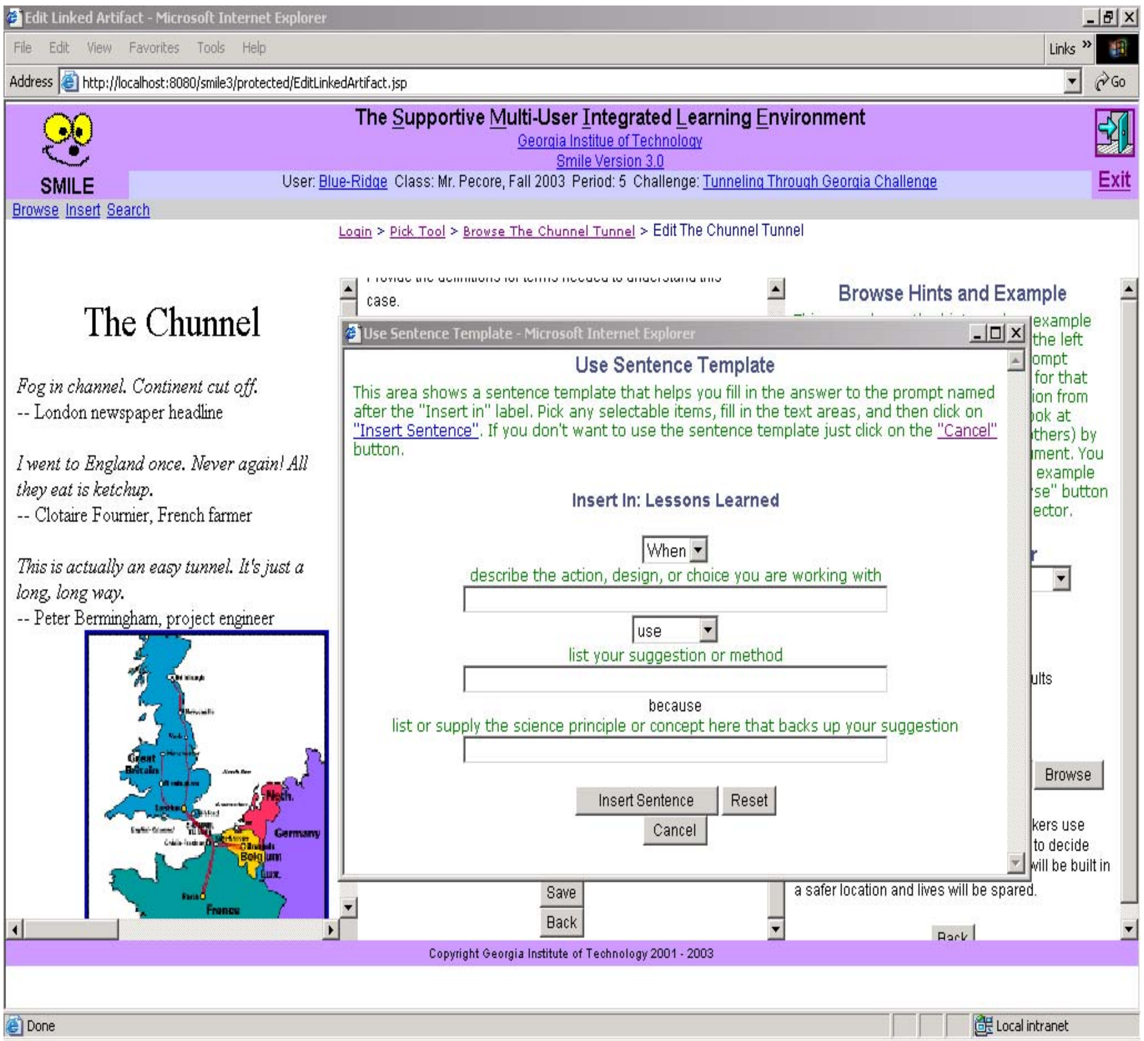


Figure 3.12: Rule of Thumb Template

As mentioned earlier, understanding criteria and constraints in a challenge is important when making design decisions. As such, the Case Application Tool's 'Our Criteria and Constraints' prompt includes a link to a Criteria and Constraints chart that looks like the one in Figure 3.11. However, unlike the Criteria and Constraints chart described earlier which is used to identify and understand the criteria and constraints in the expert case, this Criteria and Constraints chart is used to help students and student groups identify and understand the criteria and constraints in their challenge so that they can use those criteria and constraints to analyze the design rules of thumb gleaned from their interpretation of an expert case to determine which are applicable and how they can be applied.

During the application phase, this template helps groups analyze the design rules of thumb gleaned from the interpretation of an expert case and to determine which are applicable and how they can be applied, the Applying Our Rules of Thumb template is included as a link to the 'Rule(s) of Thumb' prompt in the Case Application Tool. As Figure 3.13 shows, this template contains 5 columns. The first column, *Rule of Thumb*, contains design rule(s) of thumb gleaned from the interpretation of the expert case. The second column, *Criteria addressed by rule of thumb*, helps students and student groups match the problem a design rule of thumb addresses to a criterion identified in their challenge identified in the criteria and constraints template. The third column, *Predictions the rule of thumb makes*, helps students and student groups think about the suggestions this rule of thumb could make for their challenge and the outcomes that might result if this design rule of thumb were not taken into account based on the criteria they wanted to address and the constraints they had to address in their challenge. The fourth column, *Is this rule of thumb applicable*, provides an at glance understanding of which design rules of thumb the group found useful and which they abandoned. The fifth column, *Ways the rule of thumb applies*, helps students and student groups explore and brainstorm all of the possible ways this rule of thumb could be incorporated into their design solution. The idea is that after brainstorming, the group will discuss which ideas make the most sense for their challenge solution. The Solution Assessment Tool does not contain any charts or templates.

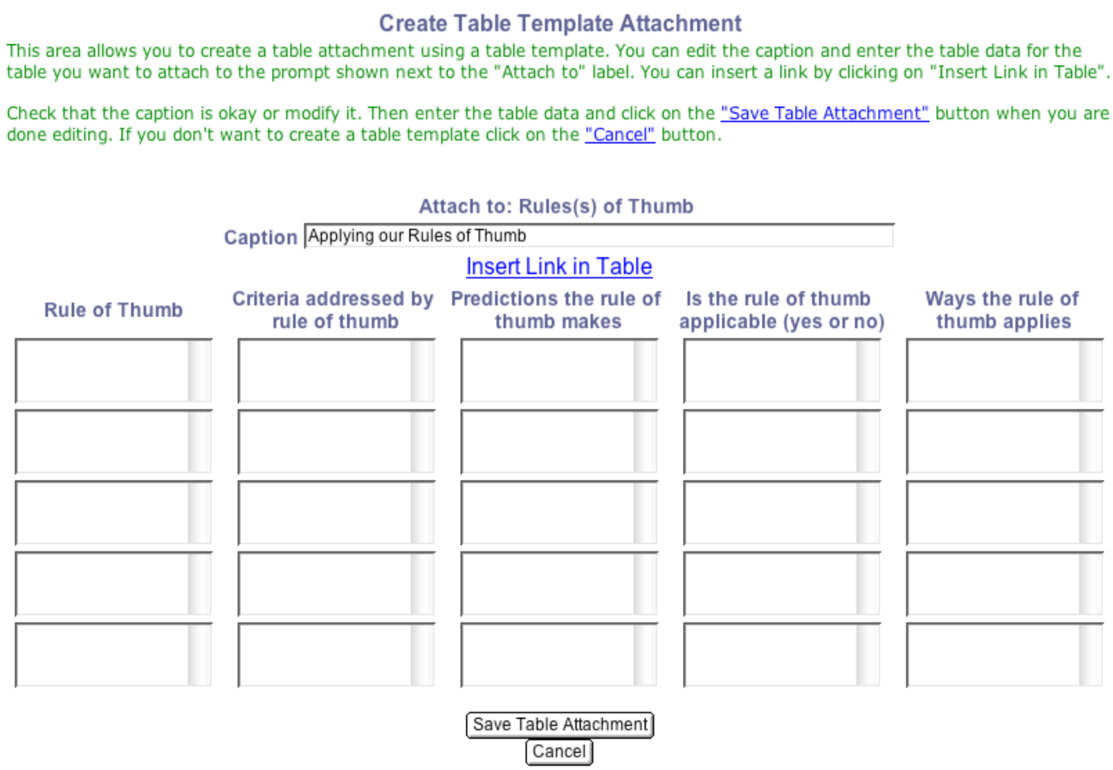


Figure 3.13: Applying Our Rules Of Thumb Template

3.6.5 Use Of The Case Application Suite

Integrating the Case Application Suite into the activities of Learning By Design is an important aspect of supporting and helping students develop their ability to interpret and apply expert cases. As we'll show in more detail later, students begin learning case use skills as they interpret cases during the Managing Erosion challenge, using design diary pages and scaffolding from the teacher to learn the complexities and grapple with the difficulties of interpreting and beginning to apply expert cases [Reiser, 2000].

Student groups are introduced to the Case Application Suite for the first time when they are interpreting their first tunnel cases as a group from the St. Gotthard, Frejus/Mt. Cenis, Queens Midtown, and Hoosac Tunnel cases. This is after the teacher has modeled case interpretation skills using the Lotschberg Case. Integrating the Case Application Suite too soon may prevent students from understanding the complexities and difficulties associated with interpreting and applying expert cases, why it is useful, and whether the support it provides is helpful, while integrating it too late may hinder students from taking full advantage of its system of scaffolds through repeated use.

After use of the tool for each stage of expert case use, the intention is that groups will share their work with the class, and the teacher will facilitate a discussion about what can be learned from the full range of cases and the reasoning the most successful students engaged in to do their work. Students may then refine their write-ups and publish them for others to read and comment on.

3.6.6 Managing the Relationship Between Specific Examples and General Principles

In Chapter 2, we examined three projects that use software in support of complex cognitive skill development. For each project, we described both the system of scaffolds they employ to support students as well as how they seem to manage the relationship between teaching complex cognitive skills in the context of specific experiences and helping students interpret those experiences in such a way that they can glean more general principles from them.

The Case Application helps students interpret specific expert cases to identify design rules of thumb. Students then refine those design rules of thumb by either analyzing them in the context of their design challenge or in the context of another specific experience, making the design rules of thumb more general and describing how they might be applicable to more situations over time. The teacher can also help students make the leap from specific experiences to more general principles by coaching them during small group and whole-class discussions. The teacher can prompt them to reflect on specific examples, hinting and reminding them in ways that help them make connections between those specific examples. He/she can also help the class refine design rules of thumb in light of new LBD experiences, helping them glean more general principles from the expert cases. For example, after each group interprets an expert case, the teacher can facilitate a whole class discussion about each of the cases, helping the class understand the similarities and differences across the expert cases. If similar design rules of thumb were gleaned by two different groups for two different expert cases, the teacher can prompt the class in such a way that they can begin to understand why similar design rules of thumb were gleaned from the different cases, and he/she can help them create a more general design rule of thumb based on the similar design rules of thumb gleaned from the two expert cases.

3.7 Summary

This chapter presented Learning By Design, SMILE, and the Case Application Suite. LBD provides affordances for students to be successful in project-based inquiry learning, and it serves as our enactment of a cognitive apprenticeship. SMILE supports students as they are engaging in project-based inquiry employing a system of scaffolds to help students achieve project-based inquiry tasks. The Case Application Suite uses the system of scaffolds to coach students and student groups as they interpret and apply expert cases to their design solutions. As helpful as the Case Application Suite sounds, its design and effectiveness were not discovered and determined overnight. Instead, investigations, designs and re-designs, and studies were conducted to understand how the Case Application Suite should be designed, what it should look like, what kinds of help it should provide, and how well it supports students in interpreting and applying expert cases. In other words, the Investigate & Explore as well as the Design & Redesign cycles of the LBD cycle were employed to design and study the Case Application Suite. The next chapter will return to the research questions for this study and describe the methodology used to answer them.

CHAPTER 4

STUDYING THE DEVELOPMENT OF A COMPLEX SKILL SET: DATA COLLECTION AND ANALYSIS

Our research goal revolves around understanding and describing how middle-schoolers in a project-based inquiry environment develop case use skills over time. We also want to understand how this development might impact and influence students' ability to use expert cases well in activities where use of cases is appropriate.

In particular, we want to answer the following research questions:

1. How do small-group case use capabilities develop over time?
2. How well are students able to apply case use skills in new situations over time?
3. What difficulties do learners have as they learn case use skills and as they apply case use skills in new situations? What do these difficulties suggest about how software might further support complex cognitive skill development using a cognitive apprenticeship framework?

To help students develop expert interpretation, application, and assessment skills, we designed the Case Application Suite that coaches middle school students as they read an expert case for understanding, identifying the lessons they can learn from the experts, apply those lessons to their design solution, and assess how well their solution addresses the challenge's goals, criteria, and constraints. This is accomplished using the Case Application Suite's system of scaffolds integrated within Learning By Design's project-based inquiry activities. In particular, LBD affords opportunities for students to interpret their project-based inquiry experiences in such a way that they can be used in the future. LBD also provides opportunities for case use skills learning and development through teacher modeling and coaching as well as coaching from more capable peers. LBD's units provide multiple opportunities for students to develop case use skills while working collaboratively. The Case Application Suite adds affordances for supporting collaborative discussion and negotiation of meaning, serving as a repository and history of group work and change, and helping students to engage successfully in project-based inquiry science learning and scientific reasoning tasks like designing and analyzing and experiments, planning a design solution, and interpreting and applying expert cases.

4.1 Setting And Participants

To study the answers to our research questions, we put SMILE in the classrooms of two LBD teachers enacting the *Digging In* and *Tunneling Through Georgia* Units, and we collected data in two middle schools in the Atlanta area. The target students in the public suburban middle school were 6th grade LBD students, while the target students in the private suburban middle grades section were 7th grade LBD students. There were no wholly learning-disabled, average, or gifted classrooms. Instead, students of all levels were present in all of the classrooms. Both the 6th and 7th grade LBD students engaged in the *Digging In* and *Tunneling Through Georgia* Units. Students worked in small groups of three or four for both units, switching groups between units. They were introduced to and practiced case use during *Digging In*, and they used the Case Application Suite to help with case use during the *Tunneling Through Georgia* Unit. In addition, the 7th grade classes engaged in the Immune and Reproductive System Unit (IRSU), a teacher-created, project-based inquiry unit that taught students about sexually transmitted diseases (STDs) in the context of making predictions about the diagnosis of a mock patient. Students worked in groups of two and used 5 software tools, which did not explicitly focus on the same case use skills as the *Digging In* Unit, *Tunneling Through Georgia* Unit, and the Case Application Suite did.

4.2 Data Sources

Within the context of LBD enactments, we were able to collect data from 5 sources:

Observations –During our classroom observations, we observed teachers as they modeled and coached students through applying cases to their challenge. We also observed students as they presented their case interpretations and as they used the software, collecting their discussions as they answered the prompts in the Case Application Suite and as they discussed their ideas during performance assessments before writing up individual answers. Teacher observations allowed us to understand the type of modeling and coaching the teacher provided before the software's system of scaffolds was introduced and integrated, and they helped us understand the sequence of activities and context in which teacher modeling and coaching took place. Student observations allowed us to understand how well students could interpret and apply cases using the Case Application Suite's system of scaffolds, and it helped us to describe the effects of the software on the small group's development of case use skills. In addition, student observations allowed us to understand and describe how the software and teacher distributed scaffolding responsibilities as students interpreted and applied expert cases. Students interpreted expert cases during three class periods spanning three months (one case in October, one case in November, and one case in December), and they applied expert cases during one class period (in November). They did not assess their challenge solutions using the Solution Assessment Tool.

Student Artifacts – Student artifacts allowed us to understand how the development of case use skills occurred in individuals and groups over time. There were two types of student artifacts: individual student My Case Summary Design Diary Pages and group Case Application Suite Artifacts. Students' My Case Summary Design Diary Pages provided starting points for describing the development of case use skills as a result of teacher modeling. We were able to collect 1-2 My Case Summary Design Diary Pages for each student: One for either the Dust Bowl or Landslide Cases (interpreted during teacher modeling in the *Digging In* Unit) and one for the Lotschberg Case (interpreted during teacher modeling in the *Tunneling Through Georgia* Unit). Group artifacts created from the Case Application Suite's tools allowed us to describe the development of case use skills as a result of additional coaching provided by our system of scaffolds. Each group had three (3) Case Interpretation Tool artifacts and one (1) Case Application Tool artifact. There were no Solution Assessment Tool artifacts.

Performance Assessments – Performance assessments allowed us to understand how well students were able to transfer case use skills to a new situation. They also allowed us to describe the effects of the Case Application Suite by understanding where students' skill development (without software scaffolding) lay at the end of the *Tunneling Through Georgia* Unit and the IRSU. The two performance assessments given were the Bald Head Island Challenge and the Snowshoe Hare/Lynx Challenge. The Bald Head Island Challenge involved student groups of three or four (the same groups from the *Tunneling*

Through Georgia Unit) making recommendations about whether and how a set of sub-divisions should be constructed on an island off the coast of Georgia similar to the Bald Head Island [Appendix A]. The Snowshoe Hare/Lynx Challenge involved student dyads (the same groups from the IRSU) making recommendations about how to prevent the cheetah from becoming extinct [Appendix B]. These performance assessments were not related to the content that the students learned in the *Tunneling Through Georgia* Unit and the IRSU. Instead, we wanted to understand how well students could apply case use skills in the absence of the Case Application Suite's system of scaffolds (e.g., identify relevant aspects of a case, create design rules of thumb based on the lessons they learned from the case, and apply those design rules of thumb to address the goal of the challenge).

Student Interviews – Two sets of individual interviews with students were used to understand what students understood about the processes involved in case use. In the first set of interviews, conducted following the *Tunneling Through Georgia* Unit, students talked about their tunneling solutions focusing on where they derived their solution. They also talked about the first performance assessment, focusing on what they thought was important in the expert case and how the rules of thumb they created (if any) impacted their solution. They talked about their use of the Case Application Suite, focusing on the scaffolds they used and their perceptions of the Case Application Suite's helpfulness in creating a solution to the Tunneling challenge. Finally, students described the steps they would take to use an example or case to help them solve a problem. Appendix H shows the questions that the students were asked in their individual interviews.

In the second set of individual interviews, conducted following the IRSU, students were asked about their groups' goals during the unit, focusing on how they were able to use the research they had conducted previously on STDs to help them make predictions about their patient. Students also talked about the second performance assessment, focusing on what they thought was important in the expert case and how the rules of thumb they created impacted their solution. They talked about their use of SMILE, focusing on the scaffolds they used and their perceptions of SMILE's helpfulness in creating predictions for the IRSU challenge. Finally, students described how they would use an example or case to help them solve a problem.

Teacher Interviews – Teacher interviews, conducted at the end of the Tunneling Through Georgia Unit (6^{th} and 7^{th}) as well as at the end of IRSU (7^{th}) allowed us to understand how the software was integrated into activities, how teachers felt about the software's role as coach within the learning environment, how scaffolding responsibilities were distributed across teacher and software, what aspects of integration and distribution were easy, and what aspects of integration and distribution were difficult.

4.3 Data Collection And Use

Table 4.1 provides an overview of the data sources and, for each source, describes whether the source informed individual or group performance/development, and when the source was collected. Video observations of whole class discussions and the teacher modeling case use skills for the whole class were collected during interpretation of the Dust Bowl and Landslide cases in *Digging In* as well as during interpretation of the Lotschberg Case in *Tunneling Through Georgia*. Video observations were also collected as small groups worked together during the Bald Head Island Performance Assessment

(Performance Assessment 1), given at the conclusion of Tunneling Through Georgia, as well as the Snowshoe Hare/Lynx Performance Assessment (Performance Assessment 2), given at the conclusion of the IRSU.

Student work was collected for both individuals and groups. Individual My Case Summary Design Diary Pages were collected as students and teacher interpreted the Dust Bowl and Landslide cases during *Digging In* and as they interpreted the Lotschberg case during *Tunneling Through Georgia*. Case Application Suite artifacts, produced as groups interpreted and applied expert cases during *Tunneling Through Georgia* were also collected. Individual work was collected for both the Bald Head Island Performance Assessment and the Snowshoe Hare/Lynx Performance Assessment.

Individual student and teacher interviews, conducted once at the conclusion of *Tunneling Through Georgia* and again at the conclusion of the IRSU, were video-recorded.

Table 4.1: Overview Of Data Sources

Data Source by Type	Individual or Group	When Source Was Collected
Observations	Group	During Digging In/Tunneling Through Georgia/Immune and Reproductive System Units / Performance Assessments 1 & 2
Student Work: My Case Summary Design Diary Page	Individual	During Digging In Unit
Student Work: Case Application Suite	Group	During Tunneling Through Georgia Unit
Student Work: Performance Assessment 1 – Bald Head Island Challenge	Individual	Following Tunneling Through Georgia Unit

Table 4.1: Overview Of Data Sources (Continued)

Student Interview 1	Individual	Following Tunneling Through Georgia Unit
Teacher Interview 1	N/A	Following Tunneling Through Georgia Unit
Student Work: Performance Assessment 2 – Snowshoe Hare/Lynx Challenge	Individual	Following Immune and Reproductive System Unit
Student Interview 2	Individual	Following Immune and Reproductive System Unit
Teacher Interview 2	N/A	Following Immune and Reproductive System Unit

4.4 Describing Case Use Skill Development Over Time: Developing A Coding Scheme

To study the development of case use skills over time using all of the data sources described, we needed an instrument that would allow us to qualitatively and quantitatively compare different types of data sources consistently and uniformly. The instrument needed to allow us to compare these data from different sources in a way that could help us to describe the development of middle-schooler's case use skills over time as they engaged in project-based inquiry activities, each of which provided slightly different evidence. For example, for student group work, we wanted to be able to line up Case Interpretation Tool artifacts for a group, compare the quality of answers from expert case interpretation to expert case interpretation, and both quantitatively and qualitatively describe changes that occurred in the group's ability to interpret those expert cases. To allow us to compare the quality of student work across three types of student artifacts (My Case Summary Design Diary Pages, Case Application Suite artifacts, and Performance Assessments), some group work and some individual work, we needed a coding scheme that could be used to code all student work. This approach is similar to

Law & Wong's [2003] use of a single coding scheme to code several artifacts over time. Using this approach would provide a consistent way for us to talk about changes, if any, that might occur over time as students developed interpretation, application, and assessment skills, and it would also stand to make our findings more consistent and connected since we would be using the same set of dimensions and ranges across all artifacts.

4.4.1 Getting Started: Grounding The New Coding Scheme In The Old Ones

We began developing our coding scheme based on the scheme we used in our study of the effectiveness of the Case Application Suite conducted in Fall 2002. From that study, we learned that the Case Application Suite seemed effective at supporting student groups as they interpreted and applied expert cases. Recall that in that study, we found that even though the Case Application Suite was used to interpret and apply only one expert case, groups who were exposed to the Case Application Suite's system of scaffolds performed better at interpreting expert cases than groups who were not exposed. In addition, groups who were exposed to the Case Application Suite's system of scaffolds performed significantly better at using interpretation skills in the absence of the Case Application Suite's system of scaffolds, and they also performed better applying an expert case in the absence of the software. Students who were exposed to the Case Application Suite's system of scaffolds also perceived case use to be composed of steps that were very similar to the prompting and ordering used in the Case Application Suite, though students could not tell us what each tool was supposed to help them accomplish. This suggested that students exposed to the Case Application Suite had an almost intuitive high-level notion of how to interpret and apply expert cases, but not as clear or intuitive a notion about the specifics of any part of that process.

As such, we decided to use the high-level process students had given, and the prompting of the Case Application Suite to begin to articulate the steps involved in interpreting, applying, and assessing expert cases. This articulation took the form of a flowchart we call the Case Use Skills Tree [Appendix C]. This skills tree is not thought to be an absolute or complete description of case use, but it could serve as a way for us to begin to describe a process that has not been described before, helping us to make predictions about how the Case Application Suite's system of scaffolds, when integrated into the learning environment, might influence and help students develop interpretation, application, and assessment skills, informing possible developmental changes that may occur in students' ability to interpret and apply expert cases and informing the dimensions we should begin focusing on to create our coding scheme. Figure 4.1 shows the interpretation phase of the Case Use Skills Tree used to inform dimensions in the coding scheme that relate to interpreting an expert case.

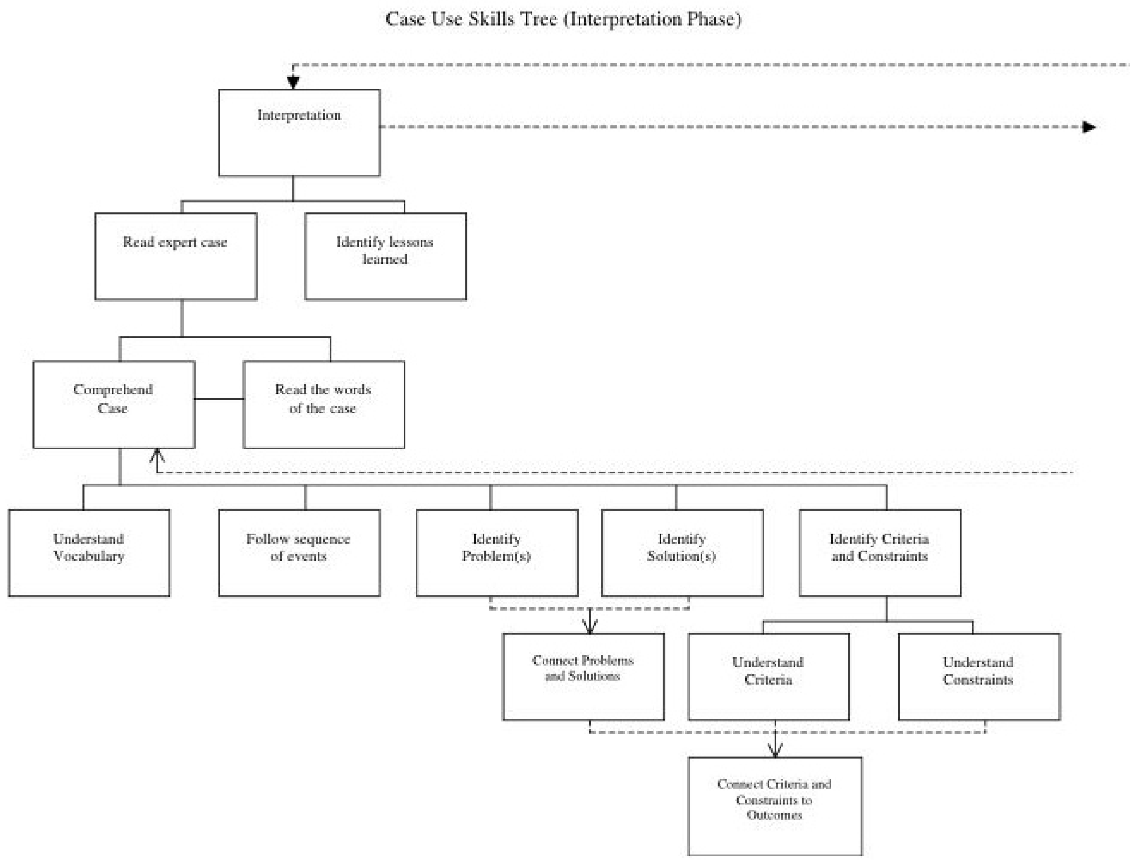


Figure 4.1: Case Use Skills Tree (Interpretation Phase)

4.4.2 Matching The Case Use Skills Tree With The Old Coding Scheme

To further inform possible changes that may occur in students' ability to interpret and apply expert cases, we also turned to the coding schemes used in our Fall 2002 study. These coding schemes were used to get an idea of what interpretation and application skills seemed to improve as a result of exposure to the Case Application Suite's system of scaffolds and to describe how well students were able to interpret and apply an expert case to create a design solution in the absence of the Case Application Suite's system of scaffolds. They were used to code group video and individual written results from the Bald Head Island Performance Assessment given at the end of the Fall 2002 semester.

We used a total of three coding schemes: two to analyze interpretation capability and one to analyze application capability.

The first coding scheme [Appendix D] was used to code group interpretation capability in the absence of the Case Application Suite's system of scaffolds using the video we recorded of the group as they engaged in Part 1 of the Performance Assessment. This coding scheme contained 10 dimensions describing groups' abilities to collaboratively interpret an expert case by rating how well groups identified risks, management methods, pros and cons for those management methods, and design rules of thumb from the Bald Head Island case. Each dimension consisted of a 5-point scale that described the degree of specificity for that dimension.

The second coding scheme [Appendix E] was used to code individual interpretation capability by coding the charts used by students during Part 1 of the performance assessment where they wrote the risks, management methods, pros, cons, and design rules of thumb they had discussed as a group as described above [Appendix A]. This coding scheme contained 5 dimensions describing how well individuals interpreted an expert case by rating how well they articulated the risks, management methods, pros and cons, and design rules of thumb discussed by the group on their individual charts. The coding scheme was a combination of 5-point scales (from 0 to 4) that described the range for each of the 5 dimensions as well as characterization elements that were tied to dimensions and used to classify pieces of the artifact being coded. Figure 4.2 shows a segment of the second coding scheme, namely a characterization element, **Origin of Risk**, that classifies whether a risk identified was taken directly from the case or not, and **Risk**, a 5-point scale dimension that describes the quality of a risk identified by a student.

Origin of Risk – This measure is used to categorize where the risk identified comes from. Enter a 1 or a 2 if a risk is present.

1 – Risk identified is taken directly from the case
2 – Risk identified is not mentioned in the case

Risk – Code for the following only if Origin of Risk is a 1.

No risk identified	Risk identified	Risk is identified and is relevant to the task	Risk is identified, is relevant to the task, and is justified (via the Why is it a risk column)	Risk is identified, is relevant to the task, and contains a correct justification of the risk
0	1	2	3	4

Figure 4.2: Characterization Element And Dimension From Fall 2002 Coding Scheme For Performance Assessment Part 1

The third coding scheme [Appendix F] was used to code group application capability in the absence of the Case Application Suite's system of scaffolds using the video we recorded of the group as they engaged in Part 2 of the Performance Assessment. This coding scheme contained 9 dimensions describing groups' abilities to collaboratively apply an expert case by rating how well they articulated a plan for constructing the two subdivisions and how well they articulated and justified the recommendations made to the construction company based on the risks, management methods, pros, cons, and design rules of thumb described in Part 1. Each dimension consisted of a 5-point scale that described the degree of specificity for that dimension.

To create a coding scheme for case use that could be consistent across spoken and written work but that could be used for student work created during interpretation, application, and assessment, we continued by looking for similarities in dimensions across the two. For example, **Able to identify expert problems** was an important dimension in the Fall 2002 coding scheme for results for Part 1 of the Performance Assessment. Students exposed to the Case Application Suite' system of scaffolds performed significantly better at identifying expert problems in the absence of the Case Application Suite's system of scaffolds during the performance assessment (Bald Head Island Challenge) than students who were not exposed to the Case Application Suite's system of scaffolds. **Identifies Problems** was a node in the Case Use Skills Tree. Due to the focus of this dimension and this node on identifying expert problems, **Identifies Problems** was included as a dimension in the coding scheme for this research and the range that was used in the coding scheme for the Fall 2002 study was used as an initial range for the new coding scheme. The Fall 2002 data provided grounding for developing the coding scheme to understand and describe how well individuals and groups could interpret, apply, and assess the application of the Bald Head Island case during the Performance Assessment, providing suggestions about what was important for a particular dimension. We revised the range for dimensions in the new coding scheme that matched dimensions from the Fall 2002 coding scheme by comparing the range for a dimension with the new data. In some cases, like with **Identifies Problems**, there was little refinement needed, and in other cases, a great deal of modification was needed, but the Fall 2002 study's coding scheme provided a starting point for revision.

This matching process was repeated for every node in the Case Use Skills Tree. If there was a node in the Case Use Skills Tree that was not in the coding scheme for the Fall 2002 study, that dimension was added to the new coding scheme with a sentence description of what that dimension should capture, but no initial range was included. If there was a dimension in the coding schemes for the Fall 2002 study that was not in the Case Use Skills Tree, that dimension's usefulness was examined. For example, in the coding schemes used for the Fall 2002 study, **Able To Negotiate** was a dimension used to show how well students were able to handle conflict or divergent ideas within the group. These moments were captured by our video observations. However, the current coding scheme for this research is only used to code written data not video data. As a result, this dimension no longer seemed useful since small group negotiations could not be determined by looking at written artifacts. This dimension was removed from the set of dimensions for the current coding scheme.

4.4.3 - Fleshing Out The Coding Scheme

Following the identification of all of the dimensions to be included in the new coding scheme and the initial ranges for those dimensions that matched across the Fall 2002 coding schemes and the Case Use Skills Tree, we turned to the data sources to create the actual ranges that would describe what was seen in the data for this study.

An iterative process was used to generate the range of descriptions for each dimension. A variation of an approach known as grounded theory [Glaser & Strauss, 1967; Strauss & Corbin, 1998] was used to generate this range of descriptions for the coding scheme. In our approach, the literature and the dimensions identified from the process described above provided the dimensions of the coding scheme while the data itself provided a gradient or range of descriptions for that dimension. This approach allowed interesting relationships between existing theory and the data to emerge while grounding analysis in both theory and the data. In creating the coding scheme, the suggestions from the skills acquisition, case-based reasoning, transfer, and cognitive apprenticeship literatures as enacted in the Case Application Suite provided some of the dimensions (reflected in the skills tree), while student work provided the range of descriptions of those dimensions. Figure 4.3 shows a pictorial flow of the iterative process used to create the coding scheme. Remember that the initial range of descriptions taken from descriptions for matched nodes in the Case Use Skills Tree and dimensions from the Fall 2002 coding schemes were compared against the current data set to create the final range of descriptions.

First, the My Case Summary Design Diary pages were analyzed to create descriptions of what the data showed for the relevant dimensions. For example, My Case Summary Design Diary Pages focus on case interpretation and creation of design rule(s) of thumb. These correspond to Dimensions I-VIII in the coding scheme; so we analyzed the My Case Summary Design Diary pages to create and/or refine descriptions for those dimensions. After creating descriptions for the relevant dimensions, a set of My Case Summary Design Diary Pages that were not a part of the target data set were coded to ensure that the range of descriptions for those dimensions was as inclusive and as descriptive as the data set showed.

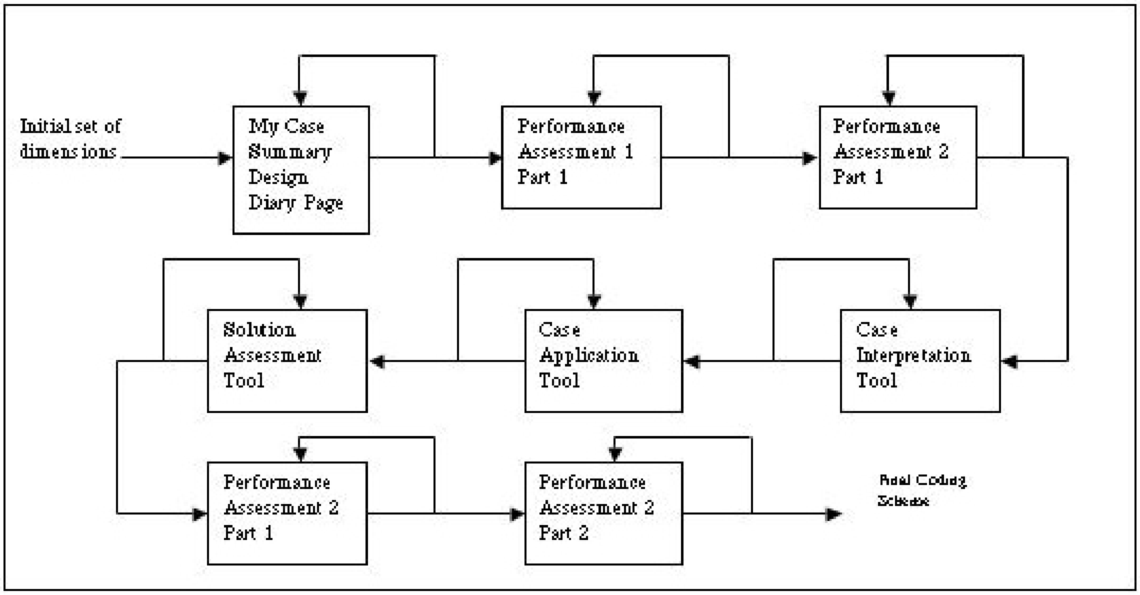


Figure 4.3: Pictorial Flow Of Iterative Process Used To Create Coding Scheme

Once this was achieved, the coding scheme was used to analyze artifacts from Performance Assessment 1 Part 1 (Bald Head Island Challenge). This data set was chosen next because it is a chart similar to the My Case Summary Design Diary Page, and because it prompts students for the same information as the My Case Summary Design Diary Page [Appendix A]. This analysis involved two parts: First, the dimensions that were relevant to Performance Assessment 1 Part 1 (i.e. Dimensions I-VIII) were used to perform an initial coding of the Performance Assessment 1 Part 1 artifacts. This was done to determine if each dimension was already describing what the artifacts showed or whether the range of descriptions for a dimension needed to be refined or modified to reflect what the data set showed. Second, if any dimension in the coding scheme did not already fully describe what the Performance Assessment 1 Part 1 artifacts showed for Dimensions I-VIII, that dimension was amended to reflect what the data set showed. Then, a set performance assessment artifacts that were not a part of the target data set were coded to ensure that the range of descriptions for the relevant dimensions were as inclusive and descriptive as the data set showed. This process was repeated sequentially for Performance Assessment 2 Part 1, Case Interpretation Tool, Case Application Tool, Performance Assessment 1 Part 2, and Performance Assessment 2 Part 2, respectively.

For some dimensions in the coding scheme that came from the Case Use Skills Tree, like **Makes Predictions About Which Constraints are Addressed**, there were no data available to flesh out the range of descriptions. However, this did not suggest that the dimension's relevance to the coding scheme should be called into question. Instead, it seemed to suggest that individuals and/or groups had not yet developed all of the skills involved in case use mostly due to lack of experience using those particular skills. In situations such as these where there were no data available to flesh out the range of descriptions, we made predictions about the types of descriptions the data could provide if it described that dimension and used those to flesh out the range of descriptions for those dimensions.

4.4.4 The Resulting Coding Scheme

The resulting coding scheme has three main parts. Dimensions I-VIII are dimensions that relate to interpreting an expert case. Dimensions V-XII are dimensions that relate to applying an expert case to the present challenge. There is overlap between Dimensions V, VI, VII, and VIII for both interpretation and application because during interpretation, these dimensions address individual and group performance with respect to an expert case, while during application, the dimensions address individual and group performance with respect to the group's challenge. Dimensions XIII-XVI are dimensions that relate to assessing how well the present challenge's solution addresses the challenge itself by examining the predictions made about the criteria and constraints that are addressed by the challenge solution and those that are overlooked by the challenge solution. The determination of the grouping of these dimensions was determined in part by the Case Use Skills Tree and in part by the Case Application Suite's design, both of which are divided in three major parts: interpretation, application, and assessment. These parts correspond to the high-level steps we have broken the case use process into. We present the pieces of the final coding scheme in the pages that follow. The full coding scheme is shown in Appendix G.

4.4.4.1 Identifying Expert Problems

Dimensions I-IV describe how well students and student groups are able to identify expert problems and solutions as well as how well they are able to explicitly connect the expert problems and solutions they identify. Each expert problem a student or student group identifies is given a Problem Number and then given a rating for **Dimension I - Identifies Problems**. If no expert problem is identified by a student or student group, a Problem Number is Not Given, and Dimension I is given a rating of 1, which is the lowest rating possible and corresponds to no expert problems identified. If an expert problem is identified, this dimension codes for whether the expert problem identified is a general problem (e.g., Erosion (rating of 2)), describes a specific aspect of an expert problem (e.g., The shoreline was eroding (rating of 3)), or describes a specific aspect of an expert problem and includes correct causality (e.g., The channel was dredged causing the island to accrete very rapidly (rating of 4)). Each expert problem identified is also categorized using the **Nature of Problem** characterization element, which describes whether the expert problem identified is one that occurs in nature of which the experts have no control (e.g., The shoreline was eroding (N)), one that occurred as a result of the experts implementing a solution (e.g., The channel was dredged causing the island to accrete very rapidly (E)), or one that does not fall in either of the first two categories (O).

Problem Number – Enter a number for each problem listed in the "Problems That Arose" or "Risk" column of the student chart in the problem number column. For each problem, in the Problem column, enter a rating for the problem and a number for the Nature of Problem (if applicable).

I. Identifies problems – Provide a rating for each problem listed

No problem identified	Provides a general description of problem	Provides a description about a specific aspect of a problem	Provides a description about a specific aspect of a problem and includes correct causality
1	2	3	4

Nature of Problem – This measure is used to categorize the problem(s) identified. Enter a number for each risk, and only a N or E if the problem identified comes from the case. If no problem is present, enter a O.

N-Nature-student writes about a problem that occurs in nature and of which the experts have no control.
Example: "The shoreline was eroding"
E-Expert-student identifies a problem that occurred as a result of the experts implementing a solution.
Example: "The channel was dredged causing the island to accrete very rapidly"
O-Other-student writes about a problem that does not fall in either of the first two categories.

Figure 4.4: Dimension 1 – Identifies Problems

4.4.4.2 – Identifying Expert Solutions

Each expert solution a student or student group identifies is given a **Solution Number** and then given a rating for **Dimension II - Identifies Solutions**. If no solution is identified, Dimension II is given a rating of 1, which corresponds to no solution identified. If a solution is identified, but it either does not address a problem identified by the student or student group or it does not address a problem found in the expert case, Dimension II is also given a rating of 1, which corresponds to solution identified not addressing a problem listed or a problem related to the expert case. If a solution is identified and it does relate to some problem identified by a student or student group or described in the expert case, this dimension codes for whether the solution identified is a general solution (e.g., Retaining wall (rating of 2)), describes a solution that includes who or what the solution would benefit or the criterion or constraint it should address (e.g., Put the houses on stilts to help flooding (rating of 3)), or describes a solution that includes who or what the solution would benefit, the criterion or constraint it should address, and some detail about how the solution was implemented (e.g., For the solution to the sinking of the walls, they laid down a granite floor and worked from the top of the tunnel to the bottom (rating of 4)).

Solution Number – Enter a number for each solution listed in the "How Problems Were Managed", "Ways To Manage This Risk", or artifact column/text box. This should be a two digit number—the first digit should be the Problem Number that the solution addresses, and the second digit should be a chronological numbering of the solution (1 for the first solution listed, 2 for the second, etc.). So, enter 11 in the Solution Number column if the solution is matched up with the 1st problem and if this solution is the 1st in the list of solutions.

II. Identifies solutions – Provide a rating for each solution listed

No solution identified or solution identified does not address problem listed or problems related to the case	Provides a general description of solution	Provides a description of a solution that includes the benefit it was supposed to have or the criteria/constraint it was supposed to address.	Provides a description about a solution that includes the benefit it was supposed to bring or the criteria/constraint it was supposed to address, and some detail about how it was implemented
1	2	3	4

Figure 4.5: Dimension II – Identifies Solutions

4.4.4.3 Specifies Implementation

If an expert solution identified includes details about the implementation (i.e. if it receives a rating of 4), it is also given a rating for **Dimension III - Specifies Implementation**. This dimension describes whether the implementation details described in the expert solution are general (e.g., When fissures were found small holes were dug out and filled (rating of 1)), provide a description of the implementation steps with no description of the tools/technology used or vice versa (e.g., For the solution to the sinking of the walls, they laid down a granite floor and worked from the top of the tunnel to the bottom (rating of 2)), provide a description of the implementation steps as well as the tools/technology used (e.g., A tunnel boring machine was used to inch through hard rock by cutters on the arms chewing away at the rock while the arms rotated (rating of 3)), or provide a description for the implementation steps, tools/technology used, and includes justification for that implementation (e.g., A tunnel boring machine was used to inch through hard rock by cutters on the arms chewing away at the rock while the arms rotated—this was used because it could cut through various types of rock (rating of 4)). If a rating is given for Dimension III, then a rating is also given for the characterization element, **Implementation Type**, which characterizes the implementation details as focusing either on the technology used (T), the process used (P), or focusing equally on both (H). If an expert solution does not receive a rating of 4 for Dimension II, then Dimension III is not given a rating.

III. Specifies Implementation– Describes the implementation provided. Code only if rating of 4 is given for Identifies Solution. Provide a rating for each solution listed

General Implementation given with no description of tools/technology or implementation steps.	Implementation provided with implementation steps but no description of tools/technology or with description of tools/technology but no implementation steps	Implementation provided with implementation steps and tools/technology used	Implementation provided with implementation steps, tools & technology used & justification for steps, tools, and technology used
1	2	3	4

Implementation Type – This measure is used to characterize the type implementation students describe. Enter a number for each rule of thumb, and only enter a T, P or H if the Specifies an Implementation column contains a 2, 3, or 4. If the Specifies and Implementation column contains a 1, enter a 0 for the Implementation Type.

> **T**—Technology – Implementation focuses more on the tools that were used in the solution than it does on a sequence of steps being carried out. Ex: "The scientists used shields to dig through rock that had been broken up by blasts. They also inserted pressurized air to push water out of the tunnel."
> **P**—Process—Implementation focuses more on the sequence of steps being carried out than the tools used in the solution. "Ex: "The solution that they came to for the filling of the water inside the tunnel was that they used two drainage tunnels that carried the water that was filling the tunnel up." Or "Due to high water pressure on the tunnel, holes were drilled into the tunnel walls that led to pipes to carry the water away."
> **H**—Hybrid—Implementation includes the sequence of steps carried out to implement the solution and includes the tools that were used at each step in the solution.

Figure 4.6: Dimension III – Specifies Implementation

4.4.4.4 Connecting Problems And Solutions

Next, problems and solutions are given a rating for **Dimension IV - Connects Problems And Solutions to Apply to Challenge**. This dimension describes whether a problem identified by a student or student group exists with no solution or a solution exists with no description of how it is connected to a problem (rating of 1), a solution is described that explicitly states how the solution addresses the problem (e.g., Put the houses on stilts to help flooding (rating of 2)), a solution is described that explicitly states how the solution addresses the problem and includes justification (e.g., Fissures were filled prevent flooding (rating of 3)), or a solution is described that explicitly states how the solution addresses the problem, includes justification is, and gives implementation details (e.g., For the solution to the sinking of the walls, they laid down a granite floor and worked from the top of the tunnel to the bottom (rating of 4)).

The characterization element **Vocabulary Identified** describes whether a student or group has identified and/or defined words in the expert case that they feel others might not understand. If such words have been identified, a plus symbol (+) is given for this characterization element; if no vocabulary has been identified and/or defined, a minus (-) symbol is given for this characterization element.

IV. Connects problems and solutions to apply to challenge

No connection of problems and solutions—either list a problem or a solution without explicitly stating how the solution addresses the problem	Solution is described and it is stated explicitly how the solution addresses the problem	Solution is described explicitly stating how the solution addresses the problem and justification is provided	Solution is described explicitly stating how the solution addresses the problem, justification is provided, and implementation details are given
1	2	3	4

Vocabulary Identified – **Enter a + if vocabulary has been identified. Enter a ++ if vocabulary has been identified and defined. Otherwise, enter a -.**

Figure 4.7: Dimension IV - Connect Problems And Solutions To Apply To Challenge

4.4.4.5 Understanding Expert And Group Criteria

Dimensions V and VI describe how well students and student groups are able to identify and describe criteria and constraints that the experts took into account (as students or student groups interpret an expert case) or criteria and constraints that the group takes into account for their challenge. Dimension VII describes how well students and student groups are able to describe the outcomes that result if constraints are addressed or not addressed. Each criterion identified by students or student groups is given a Criterion Number. If no criterion is identified by a student or student group, a Criterion Number is not given and Dimension V – Understands Criteria is given a rating of 1 which corresponds to no criteria mentioned. Each criterion that is correctly identified as such is given a rating for Dimension V, which describes whether the criterion is general (e.g., Safety (rating of 2)), describes an objective the experts or student group would like to address (e.g., Including a service tunnel (rating of 3)), or describes an objective the experts or student group would like to address that also includes justification (e.g., A service tunnel was proposed to be used for ventilation and escape from disasters such as fires (rating of 4)).

Criterion Number – Enter a number for each criterion listed. For each criterion in the Understands Criteria column, enter a rating for the criterion.

V. Understands criteria

No criteria mentioned	Provides general description of criteria	Describes objective that the experts/group would like to address	Describes objective that the experts/group would like to address and provides justification for choosing that criteria
1	2	3	4

Figure 4.8: Dimension V – Understands Criteria

4.4.4.6 Understanding Expert And Group Constraints

Each constraint identified by students or student groups is given a **Constraint Number**. If no constraint is identified by a student or student group, a **Constraint Number** is not given and **Dimension VI – Understands Constraints** is given a rating of 1, which corresponds to no constraints mentioned. If a constraint is identified by a student or student group, but the constraint is actually a criterion (e.g., The tunnel diameter had to be 7 feet), Dimension VI is also given a rating of 1 which corresponds to the listing of a criterion as a constraint. Each constraint that is correctly identified as such is given a rating that describes whether the constraint is general (e.g., Time (rating of 2)), describes a specific constraint and what the constraint affected (e.g., The cost of tunneling determined the budget (rating of 3)), or describes a specific constraint, what the constraint affected, and includes justification (e.g., Because it is expensive to tunnel, the budget was created after the cost of tunneling was determined (rating of 4)).

Constraint Number – Enter a number for each constraint listed. For each constraint in the Understands Constraints column, enter a rating for the constraint.

VI. Understands constraints

No constraints mentioned or lists criteria as a constraint	Describes a general constraint	Describes a specific constraint and what the constraint affected	Describes a specific constraint, what the constraint affected, and provides justification for choosing that constraint
1	2	3	4

Figure 4.9: Dimension VI – Understands Constraints

4.4.4.7 Describing The Outcomes That Occur As A Result Of Addressing (Or Not Addressing Constraints)

Each constraint identified by students or student groups is also given a rating for **Dimension VII-Connects Constraints to Outcomes**. If outcomes are not described, this dimension is given a rating of 1, which corresponds to not providing a description of an outcome that results if a constraint is addressed (or unaddressed) by the experts or group. This dimension describes whether the constraint described also describes an outcome that results if the constraint is addressed or not addressed (e.g., To prevent damaging the tunnel, it had a minimum of 13 feet of cover (rating of 2)), or whether it describes an outcome that results if a constraint is addressed or not addressed and why that constraint is addressed or not addressed (e.g., The budget needs to be raised to complete the project because the cost to build is high (rating of 3)). This is also an example of a dimension that has a 3-point scale instead of a 4-point scale. Because the range of descriptions for the coding scheme dimensions was taken from the data, the cases represent examples where only three types of variation were present in the data.

VII. Connects constraints to outcomes

Does not describe the outcome if a constraint is addressed (or not addressed)	Describes the outcome if a constraint is addressed (or not addressed)	Describes the outcome if a constraint is addressed (or not addressed) and why that constraint is addressed
1	2	3

Figure 4.10: Dimension VII – Connects Constraints To Outcomes

4.4.4.8 Articulating Design Rules Of Thumb

Dimension VIII describes how well students and student groups are able to identify and articulate design rules of thumb. Each design rule of thumb identified by students or student groups is given a Rule of Thumb Number. If no design rules of thumb are identified, a Rule of Thumb Number is not given and Dimension VIII – Rule of Thumb is given a rating of 1, which corresponds to no rule of thumb identified. Each design rule of thumb identified is given a rating for Dimension VIII, which describes whether the design rule of thumb is general (e.g., Take core samples (rating of 2)), includes correct causality and/or justification (e.g., Take core samples because they can tell you what is underneath the ground and prevent potential problems like flooding (rating of 3)), or includes correct causality and/or justification as well as suggestions for ways that the design rule of thumb can be applied (e.g., Make sure that the hill next to the basketball court has trees because trees help prevent erosion (rating of 4)).

Rule of Thumb Number – Enter a number for each rule of thumb listed. For each rule of thumb, in the Rule of Thumb column, enter a rating for the rule of thumb and a number for the Causality Type (if applicable).

VIII. Rule of Thumb

No rule of thumb identified	Rule of thumb identified	Rule of thumb is identified and includes correct causality and justification	Rule of thumb is identified, includes causality and justification, and suggestions for way(s) it can be applied
1	2	3	4

Rule of Thumb Carried Over From Interpretation – This measure is used to characterize whether a rule of thumb listed in a case application is one that was created during the case interpretation phase or whether it is a new rule of thumb. Enter a + if this rule of thumb is one that was carried over from the Case Interpretation. Otherwise, enter a minus (-)— (-) constitutes that this was a new rule of thumb not carried over from case interpretation.

Figure 4.11: Dimension VIII – Rule Of Thumb

Each design rule of thumb identified is also categorized using three characterization elements. The first is the Rule of Thumb Carried Over From Interpretation characterization element, which describes whether the design rule of thumb identified is a design rule of thumb that was identified during the interpretation phase of an expert case. If so, a plus symbol (+) is noted for the characterization element; if not, a minus symbol (-) is noted.

The second characterization element is the Rule of Thumb Type characterization element, which describes whether the design rule of thumb describes a kind of characteristic that should or should not be present (e.g., More porous rocks are more permeable (K)), a situation that signals a potential problem (e.g., Pressure against rock around you could be a sign of a lot of water, which is likely caused by faults or fissures

(S)), a technology that can be used to address a problem (e.g., If water somehow seeped through the permeable rock, you could use compressed air to pump it out of the tunnel (T)), a process that can be used to address a problem (e.g., We should always go under major cities when having to pass them in a tunnel building project. This way, the city is not disturbed (P)), or a design rule of thumb that does not fit into either of the previously described categories (e.g., When trying to find the answers, use highlighting because it makes it easier (O)).

The third characterization element is the Causality Type characterization element, which is coded only if the design rule of thumb receives a rating of 3 or 4 (i.e. the design rule of thumb includes causality and/or justification (3) or the and/or suggestions for ways it can be applied (4)). This characterization element describes whether the design rule of thumb's causality and/or justification describes some process that should be used to accomplish a task (e.g., Build a model to test a management method before building because errors can be discovered before building begins (P)), describes how to satisfy some criterion or constrain (e.g., Build a model to test a management method before building because making changes during planning is less expensive and time consuming than making changes while building (C)), or describes something other than the two categories just described (O).

Rule of Thumb Type – This measure is used to characterize the type of rules of thumb students have created. Enter a number for each rule of thumb, and only enter a K, S, T, P, or O if the Rule of Thumb column contains a 2, 3, or 4. If the Rule of Thumb column contains a 1, enter a 0 for the Rule of Thumb Type Type.

> **K**—Kind – Rule of Thumb Describes a Characteristic that should or shouldn't be present. Ex: "More porous rocks are more permeable" or "Harder rocks are preferred for digging"
> **S**—Signal—Rule of Thumb Describes a Situation that signals a potential problem. Ex: "Pressure against the rock around you could be a sign of a lot of water, which is likely caused by faults or fissures."
> **T**—Technology—Rule of Thumb Describes a Technology that can be used to address a problem
> Ex: "If water somehow seeped through the permeable rock, you could use Compressed air to pump it our of the tunnel." Or "Use sheilds to keep back mud so it won't overflow the tunnel."
> **P**—Process—Rule of Thumb Describes a process that can be used to address a problem
> Ex: "We should always go under major cities when having to pass them in a tunnel building project. This way, the city is not disturbed.
> **O**—Other—Rule of thumb does not describe one of the above

Causality Type – This measure is used to characterize the type of causality present in student created rules of thumb. Enter a number for each rule of thumb, and only enter a P, C, or O if the Rule of Thumb column contains a 3, or 4. If the Rule of Thumb column contains a 1 or 2, enter a 0 for the Causality Type.

> **P**—Process—The rule of thumb involves describing some process that should be used to accomplish a task. Ex: "Build a model to test a management method before building because errors can be discovered before building begins."
> **C**—Criteria or Constraint—The rule of thumb involves describing how to satisfy a criteria or constraint. Ex: "Build a model to test a management method before building because making changes during planning is less expensive and time consuming than making changes while building."
> **O**—Other—The rule of thumb does not describe one of the above types.

Figure 4.12: Dimension VIII – Rule Of Thumb Characterization Elements

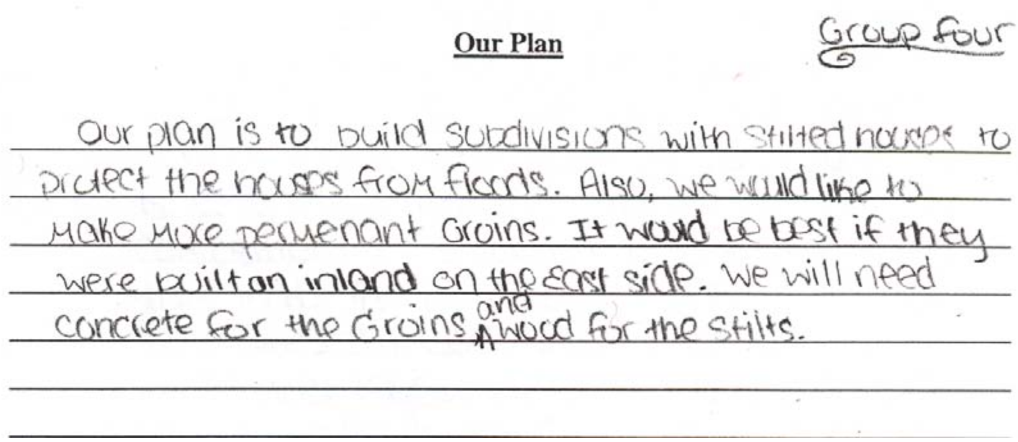
4.4.4.9 Judging The Applicability Of A Design Rule Of Thumb Or A Design Plan

Dimension IX describes how well students and student groups are able to judge whether a design rule of thumb is applicable to their challenge. There are two dimensions each labeled Dimension IX – Judges Applicability. However, the first describes how well students and student groups judge the applicability of design rules of thumb during their use of the Case Application Tool, while the second describes how well students and student groups judge the applicability of solutions that they propose during the planning phase of their Performance Assessments. Two instances of this dimension were created because while both instances are coding for the same capability, the artifacts from which these instances are coded are extremely different. For example, Figure 4.13 shows an Applying Our Design Rules of Thumb template that would be coded using the first instance of Dimension IX, while Figure 4.13 shows a plan created by a student during Part 2 of a Performance Assessment. As you can see, the two figures are drastically different in the information that they convey, but the underlying skill required to judge whether a design rule of thumb or a proposed solution are applicable is the same.

Applying our Rules of Thumb

Rule of Thumb	Criteria addressed by rule of thumb	Predictions the rule of thumb makes	Is the rule of thumb applicable (yes or no)	Ways the rule of thumb applies
We should always know what type of rock we are drilling through.	Our desire to to have a safe environment for our workers and the future people using our tunnel.	This rule of thumb suggests that we should learn about the types of rocks we drill through for an efficiently built and safe tunnel.	Yes	We could use part of our budget to pay people to take core samples so we can know about what we're drilling through.
We should always go under major cities when having to pass them in a tunnel building project. This way, the city is not disturbed.	Our desire to not harm traffic and not have to wreck people's homes to build the tunnel is met by going under the city.	This rule suggests that by being underground can make little to no difference above.	yes	We could use much of our budget to use on equipment for drilling and more things vital to an underground tunnel.

Figure 4.13: Applying Our Rules Of Thumb Template



Our Plan

Group four

Our plan is to build subdivisions with stilted houses to protect the houses from floods. Also, we would like to make more permenant Groins. It would be best if they were built on inland on the east side. We will need concrete for the Groins and wood for the stilts.

Figure 4.14: Our Plan From Performance Assessment Part 2

For the first instance of **Dimension IX – Judges Applicability of Rule of Thumb**, each design rule of thumb whose applicability is considered by students or student groups is given a two-digit **IX Judges Applicability Number**. The first digit corresponds to the **Criterion Number** that the design rule of thumb addresses, while the second digit corresponds to the chronological ordering of the design rule of thumb. The Criterion Number is the same as described for **Dimension V – Understands Criteria**. For example, if the design rule of thumb whose applicability is being considered is the first in the Applying Our Design Rules of Thumb Template, and it is judged by a student or student group to address criterion number 4 in their list of criteria, its IX Judges Applicability Number would be 41. Each design rule of thumb considered is given a rating for Dimension IX, which can describe four different scenarios.

The first describes the case where a student or group incorrectly identifies the criterion addressed by the design rule of thumb and the predictions made by the design rule of thumb, but still judges the design rule of thumb as being applicable to their challenge, as shown in Figure 4.15. In this scenario, the design rule of thumb is inaccurate in that it seems to describe one of the goals of the group's challenge rather than a design rule of thumb. Moreover, it is not clear whether the criterion the group says their design rule of thumb addresses (We want the tunneler's information to be accurate and precise) states they want the information they give the tunnelers to be accurate and precise or whether they want the information that the tunnelers give them to be accurate and precise. In addition, the predictions that the group feels this design rule of thumb makes (A prediction that our rule of thumb makes is that the information that we got from the tunnelers will be right) is an incorrect prediction because the tunnelers because the challenge states that the team should submit design plans that could potentially be carried out, not the other way around. As such, the criterion addressed by the design rule of thumb is incorrect and the predictions made are incorrect, yet the design rule of thumb is still judged by the group as being applicable to their challenge.

Applying our Rules of Thumb

Rule of Thumb	Criteria addressed by rule of thumb	Predictions the rule of thumb makes	Is the rule of thumb applicable (yes or no)	Ways the rule of thumb applies
We have to get the information that the tunnelers need to apply to the challenge.	We want the tu nneler's information to be accurate and precise.	A prediction that our rule of thumb makes is that the information that we got from the tunellers will be right.	Yes	

Figure 4.15: Judges Applicability of Rule of Thumb - Scenario One

The second scenario describes the case where a student or group either correctly identifies that the design rule of thumb addresses a criterion they have previously mentioned, but the predictions made by the student or group regarding the design rule of thumb are incorrect or vice versa, as shown in Figures 4.16 and 4.17, respectively. In this scenario, the criterion addressed by the design rule of thumb (We do not want this to happen) is incomplete because it is not clear whether the "this" referred to is not wanting water to seep through or not wanting to encounter permeable rock. However, the prediction this group feels the design rule of thumb makes (That we will run into water problems because of this rock) is correct and the design rule of thumb is still judged as being applicable to the group's challenge.

Applying our Rules of Thumb

Rule of Thumb	Criteria addressed by rule of thumb	Predictions the rule of thumb makes	Is the rule of thumb applicable (yes or no)	Ways the rule of thumb applies
Water can seep through permeable rock.	We do not want this to happen.	That we will run into water problems because of this rock.	YES!	If we drill through permeable rock, water will leak through the tunnel and may cause

Figure 4.16: Judges Applicability Of Rule Of Thumb – Scenario Two

The third scenario describes the case where a student or group correctly identifies that a design rule of thumb addresses a criterion they have not previously mentioned, but the predictions made by the student or group regarding the design rule of thumb are correct, as shown in the second entry in the Applying Our Rules of Thumb template shown in Figure 4.13. This scenario shows the group identifying a criterion not previously mentioned in their Criteria and Constraints template (Our desire to not harm traffic and not have to wreck people's homes to build the tunnel…) as being addressed by the design rule of thumb. However, the design rule of thumb does address this criterion, and the prediction made (This rule suggests that by being underground can make little to no difference above) is correct and based on the previously unmentioned criterion.

The fourth scenario describes the case where a student or group correctly identifies that a design rule of thumb addresses a previously mentioned criterion, and the predictions made by the student or group regarding the design rule of thumb are correct, as shown in the first entry in the Applying Our Rules of Thumb template in Figure 4.13. In this example, the previously mention criterion is safety of workers. The group has correctly identified that the design rule of thumb (We should always know what type of rock we are drilling through) addresses a previously mentioned criterion listed in the Criteria and Constraints template (safety of workers). The group's predictions (This rule of thumb suggests that we should learn about the types of rock we drill through for an efficiently built and safe tunnel) are correct, and the group judges the design rule of thumb to be applicable to their challenge.

IX Judges Applicability # – Enter a number for each solution proposed. Number should be a 2 digit number—first digit matches the criterion (from V) that the proposed solution addresses and the second digit signifies the order in which the solution was encountered chronologically.

IX. Judges Applicability of Rule of Thumb (Case Application Tool Artifacts) – Rate for each rule of thumb.

The criterion addressed by rule of thumb is incorrect and the predictions made are incorrect, but the rule of thumb is judged as being applicable.	Notices that rule of thumb satisfies a previously mentioned criterion (states how it satisfies the criteria), but provides an incorrect prediction based on that criterion OR Criterion addressed by rule of thumb is incomplete or incorrect, but predictions made are correct	The criterion addressed by rule of thumb is not previously mentioned, but group notices that rule of thumb satisfies that criterion and provides a correct prediction based on that criterion	Notices that rule of thumb satisfies a previously mentioned criterion (states how it satisfies the criterion) and provides a correct prediction based on that criterion
1	2	3	4

Figure 4.17: Dimension IX (First Instance) – Judges Applicability of Rule Of Thumb

For the second instance of Dimension IX – Judges Applicability of Plan, each solution proposed in the plan is given a two-digit IX Solution Number. The first digit corresponds to the Criterion Number that the proposed solution addresses, while the second digit corresponds to the chronological ordering of the proposed solution within the design plan. The Criterion Number is the same as described for Dimension V – Understands Criteria. For example, if the proposed solution whose applicability is being considered is the second solution proposed in the Our Recommendations section of Part 2 of the Performance Assessment, and it is judged by a student or group to have addressed criterion number 4 in the list of criteria, its IX Solution Number would be 42. If there is neither a plan nor recommendations described for Part 2 of the Performance Assessment, no IX Solution Number is given, and Dimension IX is given a rating of 1, which corresponds to the Our Plan section being empty (i.e. no plan exists) or the Our Recommendations section being empty (i.e. no proposed solutions exist). If both a plan and recommendations are described, but the recommendations are not connected to the plan, Dimension IX is also given a rating of 1, which corresponds to a proposed solution does not apply to the plan. Otherwise, each proposed solution considered is given a rating for Dimension IX, which can describe three different scenarios.

The first describes the case where a proposed solution is considered, but the usefulness of that proposed solution is not considered (e.g., We could make changes in how much interaction you have with these animals (rating of 2)). The second scenario describes the case where a proposed solution is considered and found to be useful, useful with modifications, or not useful at all (e.g., We would like to take an animal census (rating of 3)). The third scenario describes the case where a proposed solution is considered, found to be useful, useful with modifications, or not useful at all, and includes justification for its use, modification, or abandonment (e.g., First of all, we ask for several million dollars for an advertising campaign, to decrease demand for cheetah and gazelle products (rating of 4)).

IX Solution # – Enter a number for each solution proposed. Number should be a 2 digit number—first digit matches the criterion (from V) that the proposed solution addresses and the second digit signifies the order in which the solution was encountered chronologically.

IX. Judges Applicability of Plan (Performance Assessments Part 2) – Code for each solution proposed.

Applicability of plan is not judged or no plan or proposed solution exists.	Proposed solution is considered, but the usefulness of the proposed solution is not considered.	Proposed solution is considered and found to be useful, useful with modifications, or not useful at all.	Proposed solution is considered and found to be useful, useful with modifications, or not useful at all. Justification is provided for its use, modification, or abandonment
1	2	3	4

Figure 4.18: Dimension IX (Second Instance) – Judges Applicability Of Plan

<u>4.4.4.10 Describing The Quality Of Design Rule Of Thumb Application</u>

Dimension X describes the quality of the application of a design rule of thumb by student groups. The quality is determined by looking at how student groups explore the different ways that they can use a design rule of thumb in their design solution, as they do using the Applying Our Design Rules of Thumb Template during their use of the Case Application Tool. Each design rule of thumb identified by students or student groups is given a rating for **Dimension X – Quality of Application of Rule of Thumb**, which describes whether the ways that a design rule of thumb can be applied are not explored (rating of 1), the design rule of thumb is applied in the form of a prediction or a justification, but is not incorporated into a design solution (i.e., If we drill through permeable rock, water will leak through the tunnel and may cause destruction.), the design rule of thumb is applied in the form of a suggestion for implementation of the design rule of thumb that follows from the correct identification of both a criterion that the design rule of thumb addresses and predictions that the design rule of thumb makes (i.e., We could use much of our budget to use on equipment for drilling and more things vital to an underground tunnel), or the design rule of thumb is applied in the form of a suggestion for implementation of the design rule of thumb that follows from the correct identification of a criterion that the design rule of thumb addresses and the predictions the design rule of thumb makes, and includes justification for the implementation (i.e., We could use part of our budget to pay people to take core samples so we can know about what we're drilling through).

X. Quality of Application of Rule of Thumb

Ways that rule of thumb can be applied are not explored.	Rule of thumb is applied as a prediction or a justification for applying rule of thumb, but rule of thumb is not incorporated into a solution or a suggestion for a solution.	Suggestion for implementation of rule of thumb is given that follows from the criterion rule of thumb addresses and the predictions rule of thumb makes.	Suggestion for implementation of rule of thumb is given (that follows from the criterion rule of thumb addresses and the predictions rule of thumb makes), and justification is given for implementation.
1	2	3	4

Figure 4.19: Dimension X – Quality of Application Of Rule Of Thumb

4.4.4.11 Understanding The Group's Challenge

Dimension XI describes how well student groups understand the challenge they are trying to achieve. This dimension is coded for Case Application Tool artifacts where students describe the goals of their challenge. Their description is given a rating for **Dimension XI – Understands the Challenge**, which describes whether the challenge is not described (rating of 1), the challenge is described incorrectly (e.g., Our challenge is to design a tunnel that runs from Kennesaw to McDonough that must go through the city of

Atlanta (rating of 2)), the challenge is described correctly, but the description is general (e.g., To design a tunnel (rating of 3)), or the challenge is described correctly, including specific goals and details like the route a tunnel will follow, the predator to be saved, etc (e.g., To design a tunnel that runs from Kennesaw to McDonough and must go underneath the city of Atlanta (rating of 4)).

XI. Understands the Challenge

No description of the challenge provided	Incorrect description of the challenge provided	General, but correct description of the challenge is provided	Specific description of the challenge is provided including specific details (i.e. route to take, predator to be saved, etc.) and design goals.
1	2	3	4

Figure 4.20: Dimension XI – Understands The Challenge

<u>4.4.4.12 Finding A Match Between A Criterion And A Problem Addressed By A Design Rule Of Thumb</u>

Dimension XII describes how well student groups are able to correctly connect the problem that a design rule of thumb addresses and a criterion present in their challenge, and how their ability to make that connection impacts the predictions the student group makes about the design rule of thumb. Each design rule of thumb considered for application is given a rating for **Dimension XII – Finds a Match Between Criterion and Problem Rule of Thumb Addresses**. At first glance, there may appear to be very little difference between Dimension XII and the first instance of **Dimension IX – Judges Applicability of Rule of Thumb**. However, unlike the first instance of Dimension IX, which examines how student groups arrived at concluding whether a design rule of thumb was applicable or not, this dimension examines the relationship between the problem that the design rule of thumb addresses, the criterion that the student group states is addressed by the design rule of thumb, and the predictions that are described as a result of that relationship. While Dimension IX looks at the connection between the criterion and the prediction made, Dimension XII looks at the connection between the design rule of thumb and the prediction made, namely, how well the predictions made follow from the design rule of thumb. As such, Dimension XII describes four possible scenarios.

The first scenario describes the situation where no match between a criterion and a problem that the design rule of thumb addresses exists. The second scenario describes the situation where a match exists between a criterion and a problem the design rule of thumb addresses, but no predictions or suggestions that the group thinks the design rule of thumb might make for their design solution are included. Although we never saw this scenario in our target data, an example of an answer in the second scenario would be like that shown in Figure 4.21.

Applying our Rules of Thumb

Rule of Thumb	Criteria addressed by rule of thumb	Predictions the rule of thumb makes	Is the rule of thumb applicable (yes or no)	Ways the rule of thumb applies
When building a structure to house workers use information (warnings, terrain info, etc.) to decide where to build it because the structure will be built in a safer location and lives will be spared.	This addresses our desire to build the facility close to where the workers will be working.		yes	We can include money in our budget to conduct a survey of the townspeople to get their input about where we should build the facility. We can also include time in our plan to research historical records to find out if any natural disasters have taken place.

Figure 4.21: Dimension XII – Scenario 2

Scenario three describes a situation where a match exists between a criterion and a problem the design rule of thumb addresses, but the predictions or suggestions that the group thinks the design rule of thumb makes for their design solution are incorrect and do not follow directly from the design rule of thumb.

Applying our Rules of Thumb

Rule of Thumb	Criteria addressed by rule of thumb	Predictions the rule of thumb makes	Is the rule of thumb applicable (yes or no)	Ways the rule of thumb applies
We have to get the information that the tunnelers need to apply to the challenge.	We want the tu nneler's information to be accurate and precise.	A prediction that our rule of thumb makes is that the information that we got from the tunellers will be right.	Yes	

Figure 4.22: Dimension XII – Scenario 3

The fourth scenario describes a situation where a match exists between a criterion and a problem the design rule of thumb addresses that also includes correct predictions or suggestions that the group thinks the design rule of thumb makes for their design solution.

Applying our Rules of Thumb

Rule of Thumb	Criteria addressed by rule of thumb	Predictions the rule of thumb makes	Is the rule of thumb applicable (yes or no)	Ways the rule of thumb applies
Water can seep through permeable rock.	We do not want this to happen.	That we will run into water problems because of this rock.	YES!	If we drill through permeable rock, water will leak through the tunnel and may cause

Figure 4.23: Dimension XII – Scenario 4

XII. Finds a match between criteria and problem rule of thumb addresses (generally found in Criteria addressed by rule of thumb and Predictions the rule of thumb makes column)

No match between criteria and problem rule of thumb addresses is made	A match between criteria and problem rule of thumb addresses is made, but predictions about rule of thumb are not present.	A match between criteria and problem rule of thumb addresses is made, and prediction about rule of thumb is present BUT it is incorrect (i.e. prediction does not directly follow from the rule of thumb)	A match between criteria and problem rule of thumb addresses is made, and predictions about rule of thumb are present and correct.
1	2	3	4

Figure 4.24: Dimension XII – Finds A Match Between Criteria And Problem Rule Of Thumb Addresses

4.4.4.13 Making Predictions About The Criteria Addressed By Design Solution Or Recommendations

Dimensions XIII-XVI describe how well students or student groups are able to assess the completeness of their design solutions or recommendations by making predictions about the criteria and constraints addressed as well as those overlooked by their design solutions or recommendations. For a given challenge, each prediction that relates to a criterion addressed by a student or student group is given a two-digit XIII Prediction Number. The first digit corresponds to the Criterion Number that the prediction addresses, while the second digit corresponds to the chronological ordering of the prediction within the design plan or recommendations. The Criterion Number is the same as described for Dimension V – Understands Criteria. For example, if a prediction made in the Our Recommendations section of Part 2 of the Performance Assessment is the first prediction made, and it pertains to criterion number 3 in the list of criteria, its

XIII Prediction Number would be 31. If no prediction is made that relates to a criterion addressed by a student or student group, no XIII Prediction Number is given, and Dimension XIII – Predicts Which Criteria Are Addressed is given a rating of 1, which corresponds to no match being present between a criterion identified by a student or student group and the problem a design rule of thumb addresses.

Otherwise, each prediction that relates to a criterion addressed by a student or group is given a rating for Dimension XIII. This dimension codes for whether the prediction describes a potential problem that could arise that relates to a particular criterion the group wants to address without proposing a solution to the potential problem (e.g., Their cycle will then be protected from humans, poachers, and other activities which would otherwise interfere with their living environment (rating of 2)), describes a potential problem that could arise that relates to a particular criterion the group wants to address including a proposed solution to the potential problem (e.g., We believe that reducing logging will increase the vegetation population which will increase the gazelle population (rating of 3)), or describes a potential problem that could arise that relates to a particular criterion the group wants to address, includes a proposed solution to the potential problem, and provides justification for the proposed solution (e.g., A decrease in backcountry trails will help prevent other predators attacking the gazelles because the backcountry will limit their access to the gazelles (rating of 4)).

XIII Prediction # – Enter a number for each prediction that matches a criterion. Number should be a 2 digit number—first digit matches the criterion (from V) that the prediction addresses and the second digit signifies the order in which the prediction was encountered chronologically.

XIII. Predicts which criteria are addressed – Rate for each occurrence of a prediction that addresses a criteria

No predictions about which criteria are addressed are made in challenge solution	Prediction of possible problems that could arise that address a particular criteria are given, but no solution is proposed	Prediction of possible problems that address a particular criteria are given and a solution is proposed	Prediction of possible problems that address a particular criteria are given, a solution is proposed, and justification is given for that solution
1	2	3	4

Figure 4.25: Dimension XIII – Predicts Which Criteria Are Addressed

4.4.4.14 Making Predictions About The Constraints Addressed By Design Solution Or Recommendations

Each prediction that relates to a constraint addressed by a student or student group is given a two-digit XIV Prediction Number. The first digit corresponds to the Constraint Number that the prediction addresses, while the second digit corresponds to the chronological ordering of the prediction within the design plan or recommendations. The Constraint Number is the same as described for Dimension VI – Understands Constraints. For example, if a prediction made in the Our Recommendations section of Part 2 of the Performance Assessment is the third prediction made, and it pertains to constraint number 1 in the list of criteria, its XIV Prediction Number would be 13. If no prediction is made that relates to a constraint addressed by a student or student group, no XIV Prediction Number is given, and Dimension XIV – Predicts Which Constraints Are Addressed is given a rating of 1, which corresponds to the lack of predictions concerning which constraints are addressed. Otherwise, each prediction that relates to a constraint addressed by a student or group is then given a rating for Dimension XIV. This dimension codes for whether the prediction explicitly describes a constraint that is addressed (e.g., We estimate security improvements will cost roughly $10 million (rating of 2)), explicitly describes a constraint that is addressed including justification about why the constraint was addressed (e.g., We estimate security improvements will cost roughly $10 million because of the cost to pay guards to secure the reserve (rating of 3)), or explicitly describes a constraint that is addressed, includes justification about why the constraint was addressed, and includes outcomes that may occur as a result of addressing this constraint (e.g., We estimate that security improvements will cost roughly $10 million because the cost to pay guards to secure the reserve will ensure the safety of the cheetahs as they are being bred).

XIV Prediction # – Enter a number for each prediction that matches a constraint. Number should be a 2 digit number—first digit matches the criterion (from VI) that the prediction addresses and the second digit signifies the order in which the prediction was encountered chronologically.

XIV. Predicts which constraints are met – Rate for each occurrence of a prediction that addresses a constraint

No predictions about which constraints are addressed are made in challenge solution	Constraints that are addressed are explicitly stated	Constraints that are addressed are explicitly stated and justification is given	Constraints that are addressed are explicitly stated, justification is given, and predicted outcomes are given
1	2	3	4

Figure 4.26: Dimension XIV – Predicts Which Constraints Are Met

4.4.4.15 Making Predictions About Criteria Overlooked In Design Solution Or Recommendation

Each prediction that describes a criterion identified by a student or group that was overlooked is given a two-digit XV Prediction Number. The first digit corresponds to the Criterion Number that the prediction describes, while the second digit corresponds to the chronological ordering of the prediction within the design plan or recommendations. The Criterion Number is the same as described for Dimension V – Understands Criteria. For example, if a prediction made in the Our Recommendations section of Part 2 of the Performance Assessment is the second prediction made, and it describes criterion number 3 in the list of criteria, its XV Prediction Number would be 32. If no prediction is made that relates to a criterion described by a student or student group that was overlooked, no XV Prediction Number is given, and Dimension XV – Predicts Which Criteria Are Overlooked is given a rating of 1, which corresponds to a lack of predictions by a student or student group that addressed criteria that were overlooked in the design solution or recommendation.

Otherwise, each prediction that describes a criterion described by the group that was overlooked is given a rating for Dimension XV. This dimension codes for whether the prediction explicitly describes a criterion that was overlooked, but provides no means of addressing the criterion (e.g., Building taller, stronger, groins will prevent tourists from seeing the beach (rating of 2)), explicitly describes a criterion that was overlooked including justification for why the criterion was overlooked, but provides no description concerning how the overlooked criterion might be addressed in the future (e.g., Building taller, stronger groins will prevent tourists from seeing the beach but will keep the shoreline from eroding further inland (rating of 3)), or explicitly describes a criterion that was overlooked, includes justification for why the criterion was overlooked, and provides a description of how the overlooked criterion might be addressed in the future (e.g., Building taller, stronger groins will prevent tourists from seeing the beach but will keep the shoreline from eroding further inland. You might want to look into designing and building a bridge or walkway for tourists to use to get over the groins to the beach (rating of 4)).

XV Prediction # – Enter a number for each prediction that matches a criterion that was mentioned but not addressed by the proposed solution(s). Number should be a 2 digit number—first digit matches the criterion (from V) that the prediction refers to and the second digit signifies the order in which the prediction was encountered chronologically.

XV. Predicts which criteria are overlooked – Rate for each occurrence of a prediction that describes a criterion that was not addressed

No predictions about which criteria are overlooked in challenge solution are made	Criteria that are overlooked are explicitly stated, but no means of addressing overlooked criteria is proposed	Criteria that are overlooked are explicitly stated, valid justification for overlooking criteria is given, but a means of addressing overlooked criteria is not proposed	Criteria that are overlooked are explicitly stated, justification for overlooking criteria is given, and a means of addressing overlook criteria is given
1	2	3	4

Figure 4.27: Dimension XV – Predictions Which Criteria Are Overlooked

4.4.4.16 Making Predictions About Constraints Overlooked In Design Solution Or Recommendations

Each prediction that describes a constraint identified by a student or group that was overlooked is given a two-digit XVI Prediction Number. The first digit corresponds to the Constraint Number that the prediction describes, while the second digit corresponds to the chronological ordering of the prediction within the design plan or recommendations. The Constraint Number is the same as described for Dimension VI – Understands Constraints. For example, if a prediction made in the Our

Recommendations section of Part 2 of the Performance Assessment is the first prediction made, and it describes criterion number 1 in the list of criteria, its XVI Prediction Number would be 11. If no prediction is made that relates to a constraint described by a student or student group that was overlooked, no XVI Prediction Number is given, and Dimension XVI – Predicts Which Constraints Are Overlooked is given a rating of 1, which corresponds to a lack of predictions by a student or student group that addressed constraints that were overlooked in the design solution or recommendation.

Otherwise, each prediction that describes a constraint described by the group that was overlooked is then given a rating for Dimension XVI, which codes for whether the prediction describes a constraint that was not addressed by the design solution created or recommendations made by a student or student group (e.g., Building the reserve will restrict tourism (rating of 2)), describes a constraint that was not addressed by the design solution created or recommendations made by a student or student group and includes justification for why that constraint was not addressed (e.g., Building the reserve will restrict tourism to protect the endangered cheetahs and gazelles (rating of 3)), or describes a constraint that was not addressed by the design solution created or recommendations made by a student or student group, includes justification for why that constraint was not addressed, and describes outcomes that may occur as a result of that constraint not being addressed (e.g., Building the reserve will restrict tourism to protect the endangered cheetahs and gazelles, possibly causing a decrease in money available to maintain the reserve).

XVI Prediction # – Enter a number for each prediction that matches a constraint that was mentioned but not addressed by the proposed solution(s). Number should be a 2 digit number—first digit matches the constraint (from VI) that the prediction refers to and the second digit signifies the order in which the prediction was encountered chronologically.

XVI. Predicts which constraints are not met – Rate for each occurrence of a prediction that describes a constraint that was not addressed.

No predictions about which constraints have not been addressed in challenge solution are made	Describes which constraints that may not have been met by challenge solution	Describes which constraints may not have been met by challenge solution and gives justification for why those constraints were not met in challenge solution	Describes which constraint may not have been met by challenge solution, gives justification for why those constraints were not met in challenge solutions, and predicts specific outcomes that may result
1	2	3	4

Figure 4.28: Dimension XVI – Predicts Which Constraints Are Not Met

4.5 Using The Coding Scheme To Code Student Work

The coding scheme just described was used to code all student work. Table 4.2 shows all of the data sources coded using the coding scheme. For each data source, the dimensions that the data source informs are listed.

Table 4.2: Coding Scheme Dimensions Informed By Types Of Student Work

Type of Student Work	Coding Scheme Dimensions Informed by Student Work															
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
My Case Summary Design Diary Pages	X	X	X	X	X	X	X	X								
CAS - Case Interpretation Tool	X	X	X	X	X	X	X	X								
CAS – Case Application Tool					X	X	X	X	X	X	X	X				
CAS – Solution Assessment Tool												X	X	X	X	X
Performance Assessment I – Part 1	X	X	X	X	X	X	X	X								
Performance Assessment I – Part 2					X	X	X		X				X	X	X	X
Performance Assessment II – Part 1	X	X	X	X	X	X	X	X								
Performance Assessment II – Part 2					X	X	X		X				X	X	X	X

The My Case Summary Design Diary Pages were designed to help students interpret expert cases. In particular, they were designed to help students identify problems the experts faced, identify solutions to those problems, explore if and how those solutions might be useful for their challenge, and identify learning issues and questions they still need to answer in order to move forward with their challenge. As such, these artifacts were coded for Dimension I (Identifies Problems) through Dimension VIII (Rules of Thumb).

The Case Interpretation Tool was designed and used to help small groups interpret expert cases and articulate design rules of thumb gleaned from those cases. In particular, the Case Interpretation Tool helped student groups identify problems the experts faced, identify solutions to those problems, identify and understand criteria and constraints, identify learning issues and questions, and create design rules of thumb to describe the lessons learned from the experts. As such, artifacts generated using this tool were coded for Dimension I (Identifies Problems) through Dimension VIII (Rules of Thumb).

The Case Application Tool was designed and used to help small groups assess the fitness of a design rule of thumb for their group's design challenge and explore the ways that applicable design rules of thumb might be incorporated into the group's solution. In particular, the Case Application Tool helped student groups describe the goals, criteria, and constraints of their challenge, refer back to and/or generate design rules of thumb, and for each design rule of thumb, consider what criteria a design rule of thumb addresses, make predictions about how the design rule of thumb might inform their design, and explore how the design rule of thumb might be incorporated into the groups solution. As such, artifacts generated using this tool were coded for Dimension IX (Judges Applicability of Rule of Thumb) through Dimension XII (Finds a Match Between Criteria and Problem Rule of Thumb Addresses).

The Solution Assessment Tool was designed to help small groups make predictions about how well their solution might or might not work if carried out and what next steps the group could take to make their design solution better. In particular, the Solution Assessment Tool was designed to help student groups describe their design solution, predict the criteria and constraints their design solution addressed, predict the criteria and constraints their design solution did not address and why those criteria and constraints went unaddressed, and explore how they might address the weaknesses of their design solution in another iteration. As such, were artifacts generated using this tool, they would have been coded for Dimension XIII (Predicts Which Criteria are Addressed) through Dimension XVI (Predicts Which Constraints Are Not Met).

For each Performance Assessment, there were two parts: the first part (Part 1) asked students to identify problems, ways to address those problems, and the pros and cons of each; the second part (Part 2) asked students to design a plan for addressing the challenge and then make recommendations about if and/or how the challenge should be solved. In particular, Part 1 of both Performance Assessments provided opportunities for students to interpret a case in the absence of the Case Application Suite's system of scaffolds, namely, to identify problems the experts faced, identify solutions to those problems, understand the pros and cons of each of those solutions (i.e. understand the criteria and constraints of the experts' challenges), and identify design rules of thumb. As such, Part 1 for both Performance Assessments dealt with interpreting the expert case and articulating rules of thumb. For each Performance Assessment, Part 1 was coded for Dimension I (Identifies Problems) through Dimension VIII (Rules of Thumb).

Part 2 for both Performance Assessments dealt with applying what was learned from the expert case by incorporating the design rules of thumb during the interpretation phase (Part 1) into a design solution and/or using what was learned from the expert case to justify the recommendations suggested and making predictions about how the resulting application informs the recommendations made. As such, for each Performance Assessment, Part 2 was coded for Dimension IX (Judges Applicability) and Dimension

XIII (Predicts Which Criteria Are Addressed) through Dimension XVI (Predicts Which Constraints Are Not Met).

4.6 Answering Our Research Questions: Data Analysis

All of our data, including the coding of student work, were used to help us in achieving our goal of understanding the development of middle-school students' case use skills by exploring our research questions.

We started by looking at the data to determine which data to code. From the full set of Case Application Suite artifacts across Mr. A's 6th grade classes and Mr. J's 7th grade classes, only Mr. J's 7th grade classes used the Case Application Suite more than once to interpret expert cases. Mr. A used the Case Interpretation Tool twice in his classes, but he changed the groups after the first use of the Case Interpretation Tool due to behavioral problems, so each group permutation only used the Case Interpretation Tool once. As a result, while data from Mr. A's class can provide examples of how the Case Application Suite's system of scaffolds can support students as they are working in different small groups to interpret an expert case, only Mr. J's 7th grade classes have data that can help us understand how interpretation, application, and assessment skills develop over time as students work in the same small groups and have multiple opportunities to use the Case Application Suite. Therefore, the results presented in the following chapters will be from Mr. J's 5th and 6th period classes.

From there, we identified the groups we would target. Mr. J's 5th and 6th period classes had four groups each, for a total of eight groups across both periods. Of those eight groups, one group could not be videotaped because permission to videotape one of the members of that group was denied. From the remaining seven groups, we chose three groups to study in detail. These groups, our target groups, were selected because they had the most complete set of student work out of the seven groups.

Next, we wrote three case studies, to be presented in the next three chapters. The first case study describes development for one group from 5th period. The second and third case studies describe development for two groups in 6th period, noting differences from 5th period episodes (if any). In all case studies, episodes where case interpretation and/or application skills were modeled, developed and supported using the Case Application Suite, application of case use skills in the absence of the Case Application Suite's system of scaffolds during Performance Assessments I and II, and applicable excerpts of transcribed video-recorded group discussions needed to help explain the coding results are described.

All written data was coded in the same way by two raters. Both raters independently coded 1/3 of the target data set to establish reliability, and then one rater coded the entire set of target data. Discrepancies in ratings given during the reliability phase were resolved by negotiation.

From there, we selected from the case studies the kind of data that could help us describe three things. First, we selected data that could help us describe the development of interpretation, application, and assessment skills by understanding and describing the kinds of changes that occurred as individuals worked in small groups interpreting and applying expert cases. Second, we selected data that could help us describe how well individuals could use interpretation, application, and assessment skills in the absence of the Case Application Suite's system of scaffolds by describing how individuals' abilities to carry out case use skills seems to develop over time. Third, we selected data that could help us describe how small group case use skill development and application of case use skills by individuals could further inform the Case Application Suite's system of scaffolds. We also wanted to understand how we could better support individuals and small groups while learning case use skills and while applying those skills in new situations where their use is appropriate. Table 4.3 shows which data sources were used to address each research question and how those data sources helped us address our research questions.

Table 4.3: Data Sources Used To Investigate Each Research Question

Research Question	Data Sources Used to Address Research Question	What Data Source Shows
How do small-group case use capabilities develop over time?	Observations	• Teacher observations show the type of modeling and coaching the teacher provides, sequence of activities, and context in which teacher modeling and coaching took place • Student observations show how well student groups interpret and apply expert cases using CAS
	Student Work	• CAS artifacts show the development of case use skills as a result of CAS's additional coaching via scaffolding
How well are students able to apply case use skills in new situations over time?	Student Work	• My Case Summary Design Diary Pages provide starting points for describing individual development • IRSU Tool artifacts show us dyads' ability to use some interpretation sub-skills when not explicitly prompted to use them

Table 4.3: Data Sources Used To Investigate Each Research Question (Continued)

	Observations	• Observations of Mr. J. facilitating class discussions during the IRSU allow us to understand the activities/practices dyads engaged in that impacted their performance on Performance Assessment 2
	Performance Assessments	• Bald Head Island Challenge shows how well students could use case use skills at the end of LBD • Snowshoe Hare/Lynx Challenge shows how well students could use case use skills at the end of IRSU
	Student Interviews	• Student Interviews gauge students' individual understanding of the processes and skills involved in case use
What difficulties do learners have as they learn case use skills and as they apply case use skills in new situations? What do these difficulties suggest about how software might further support complex cognitive skill development using a cognitive apprenticeship framework?	Observations	• Student Observations show how software and teacher distribute scaffolding responsibilities as student groups interpret and apply cases
	Teacher Interviews	• Teacher Interviews describe how software was integrated into class activities, teacher's perception of CAS, and teacher's perceptions of software integration and shared scaffolding responsibilities

4.6.1 Analyzing Data For Research Question 1

To answer this question, we started with the coding results from the Case Application Suite group artifacts tables presented in the case studies, focusing on the two best answers given for each dimension. Tables were lined up, and for each dimension, changes across Case Interpretation Tool artifacts were identified and described. For example, if Group 1's coding results tables for their first use of the Case Interpretation Tool show ratings of 2 and 2 for **Dimension V – Understands Criteria** and coding results tables for their second use of the Case Interpretation Tool show ratings for the same dimension, we would consider this a change in performance.

We then analyzed the video observations to provide context for the changes we saw in group Case Interpretation Tool artifacts. In particular, we transcribed group discussions to understand how changes in group discussion related to changes in group capabilities and changes in group performance through Case Interpretation Tool artifacts. From there, we characterized changes in group discussion and described the impact they had on group capability and performance during Case Interpretation Tool use. We described trends that were revealed during our analysis of the data.

4.6.2 Analyzing Data For Research Question 2

While research question 1 addresses describing changes in group interpretation capabilities and performance over time, research question 2 addresses changes in individual interpretation, application, and assessment performance and capabilities over time. To answer this research questions, we began coding My Case Summary Design Diary Pages to understand individual interpretation performance before Case Application Suite use. This analysis would allow us to understand individual capabilities before using the Case Application Suite in small groups.

Then, we compared individual interpretation, application, and assessment performance from Performance Assessment 1 to Performance Assessment 2. Performance Assessment data would allowed us to do two things. First, coding results helped us understand the effects of the Case Application Suite by analyzing how well individuals could use interpretation, application, and assessment skills without the software's scaffolds. Second, this analysis allowed us to understand how well individuals retained interpretation, application, and assessment skills over a five month period. During this five month period, Mr. J.'s 5th and 6th period classes engaged in the IRSU. Given the changes we saw in individual interpretation, application, and assessment performance across performance assessments, we looked at the enactment of the IRSU and informally analyzed IRSU Tool artifacts to understand what activities and/or practices dyads engaged in that may have impacted coding results across performance assessments. We also identified trends about individual performance and compared group performance and capability to individual performance and capability, identifying factors that seem to influence them the most.

4.6.3 Analyzing Data For Research Question 3

For the third question focuses on explaining the difficulties involved in learning and applying case use skills in new situations and how those difficulties might inform our system of scaffolds and what we know about the development of complex reasoning skills. To answer this question, we looked at the case studies and our analysis of the first two research questions to identify difficulties groups face when learning and developing case use skills as well as difficulties individuals face when using expert cases in new situations. Based on these difficulties, we gleaned more general lessons we could learn about designing software in support of complex cognitive skill development. By identifying the lessons learned, our intention is to offer suggestions about supporting not only the learning of reasoning skills associated with case interpretation and application and also, as much as possible, but also to develop more general suggestions about software-realized scaffolding in support of the development of complex reasoning skills.

4.7 Summary

This chapter presented the method we used to answer our research questions. Three different aspects were presented. First, our use of the coding schemes from our Fall 2002 study and the Case Use Skills Tree to create a coding scheme that could be used to code different kinds of student work and help us describe the development of case use skills over time was presented. Second, this chapter presented our initial approach to answering each of our research questions. Third, for each research question, the data analyzed and the procedure of analysis used to answer that research question was presented. In order to answer each of our research questions, we must first present Mr. J.'s enactments of case use skills learning and development during his 5th and 6th period classes.

CHAPTER 5

CASE STUDY 1: GROUP CASE USE SKILL ENACTMENTS AND DEVELOPMENT IN THE BLUE RIDGE GROUP

The case studies presented in this chapter and the next one are designed to describe episodes of case use skill development and enactment during and following the Digging In and Tunneling Through Georgia Units. For each episode, four parts are described: Mr. J's emphasis on case use skills, our predictions for case use capability for that episode, coding results for group or individual performance of case use skills, and excerpts of group discussions that provide context for coding results. This chapter presents Case Study 1 for the Blue Ridge Group, while Chapter 6 presents Case Studies 2 and 3 for the Ridge and Valley and Coastal Plain groups, respectively.

As coding results in the case studies will reveal and as Tables 5.1 and 5.2 summarize, there was variation across case use capability over time for groups and individual students. Students started out with different case use capabilities and, as we'll see in our interpretation of results in later chapters, while both groups and individuals were able to develop case use skills, that development was not uniform. Table 5.1 shows that during Case Application Suite use, the Blue Ridge group's interpretation results decreased and then increased over group case interpretation activities. The Ridge and Valley group's interpretation results were best in the first episode and decreased from there. The Coastal Plain group's interpretation results increased from the first to the second episode and then remained the same. In addition, the kinds of discussions groups had as they worked also varied and changed across case interpretation activities. In our interpretation of results, those differences and their impact on group case use capability will be discussed.

Table 5.1 – Summary Of Changes in Performance of Group Interpretation Skills Over Time

Name of Group	Cases Interpreted (in order of interpretation)	Changes in Performance For Case Interpretation Across First and Second Uses of Case Interpretation Tool (Episodes 4 and 5)	Changes in Performance For Case Interpretation Across Second and Third Uses of Case Interpretation Tool (Episodes 5 and 7)
Blue Ridge	St. Gotthard (Episode 4) Tecolote (Episode 5) Chunnel (Episode 7)	Decrease	Increase
Ridge and Valley	Queens Midtown (Episode 4) Mono Craters (Episode 5) Simplon (Episode 7)	Decrease	Decrease
Coastal Plain	Frejus (Episode 4) Tecolote (Episode 5) Hudson (Episode 7)	Increase	No Change

In addition to variation in the development of case use skills, there was also variation in students' ability to carry out case use skills both before and after being exposed to the Case Application Suite. Table 5.2 shows that when carrying out case use skills before being exposed to the Case Application Suite's system of scaffolds, there was variation across student interpretation performance. Some students performed better, some worse, and some neither better nor worse. When enacting case use skills during Performance Assessment 1 after using the Case Interpretation and Case Application Tools in small groups, that variation in student performance persisted. However, when carrying out case use skills almost five months later during Performance Assessment 2, most students performed just as well or better than they had during Performance Assessment 1. In our interpretation of results, the suggestions our results make with respect to skill development and designing software in support of development of complex cognitive skills will be discussed.

Table 5.2 – Summary Of Changes In Student Performance Of Case Use Skills Time

Name of Student	Group Membership	Type of Change in Performance of Interpretation Capability Across Teacher Introduction and Modeling Episodes (Episodes 1 and 3)	Type of Change In Performance of Case Use Skills From Teacher Introduction and Modeling To Performance Assessment 1 (Episodes 1/3 and 8)	Type of Change in Performance of Case Use Skills Across Performance Assessment 1 and Performance Assessment 2 (Episodes 8 and 9)
Theresa	Blue Ridge	Increase	Decrease	Increase
Margaret	Blue Ridge	Inconsistent	Inconsistent	Increase
Billy	Blue Ridge	N/A	Decrease	Increase
David	Blue Ridge	N/A	Inconsistent	Increase
Michelle	Ridge and Valley	Increase	Increase	Decrease (for interp.)/ Increase (for app.)
Sam	Ridge and Valley	Decrease	Increase	Decrease (for interp.)/ Increase (for app.)
Daniel	Ridge and Valley	Inconsistent	Increase	No Change
Kenny	Ridge and Valley	N/A	Inconsistent	Decrease
Sandy	Coastal Plain	N/A	Decrease	Increase
Chris	Coastal Plain	N/A	Inconsistent	Increase
Chad	Coastal Plain	N/A	Decrease	Increase
Melissa	Coastal Plain	Increase	Decrease	Increase

5.1 Description of Target Group(s) /Target Students – Blue Ridge Group - 5th Period

The Blue Ridge group was made up of four students: Billy, Theresa, Margaret, and David. Working together on the *Tunneling Through Georgia* Unit, they were responsible for designing a tunnel that would run from Kennesaw to McDonough, going through the Blue Ridge Mountains. The Blue Ridge group interpreted three (3) cases using the Case Interpretation Tool (St. Gotthard, Tecolote and Chunnel) and applied one case using the Case Application Tool (Tecolote). Descriptions of the cases can be found in Chapter 3.

Mr. J judged each of his students based on how well they behaved (behavior and attitude), how well they engaged in inquiry (science inquiry), how capable they were at thinking critically (unifying themes and science and society), their ability to display a knowledge of the historical development of the science content they were learning (history of science), their understanding of the content they learned (science content), and their ability to use different kinds of tools to investigate science phenomenon (e.g., computers, stopwatch, measuring stick, etc.) (technology). He described each student's capabilities in each dimension as either an "area of concern", an area where the student was "developing appropriately" or one where the student "demonstrated excellence." These areas correspond to below average (area of concern), average (developing appropriately), and above average (demonstrates excellence) performance. Mr. J. also listed homework and test letter grades for each student. Based on Mr. J.'s judgment of the members of the Blue Ridge group which is based on performance in the areas described above, David, Theresa, and Billy would be considered typical students while

Margaret would be considered an exemplary student. However, based on homework and test letter grades for each student, Billy would be considered below average.

Billy was judged by Mr. J. to be "developing appropriately," (i.e., average in development), in the areas of behavior and attitude, science inquiry, unifying themes and science and society (i.e. critical thinking), history of science, and science content. He demonstrated excellence only in the area of technology. Despite his average assessment, his homework and test grades were D and C, respectively. His reading ability was much lower than his team members.

Mr. J. judged Theresa as developing appropriately in the areas of behavior and attitude, science inquiry, unifying themes, and science content. She demonstrated excellence in the areas of technology and history of science, while unifying themes was judged as an area of concern for Theresa.

He judged Margaret as developing appropriately in the areas of technology and science content, and excellent in all other areas. Her homework and test grades were A and B, respectively. Margaret was very quiet and tended to express her ideas, but she did not push if she was not heard.

David was judged by Mr. J. to be developing appropriately in the areas of behavior and attitude, science inquiry, unifying themes, technology, and science content. He was judged as a student who demonstrated excellence in the areas of science and society and history of science (i.e. critical thinking). David's homework and test grades were C and B, respectively. He was very outspoken, always expressing his ideas, whether relevant or far-fetched. David developed the ability to articulate his ideas and justify them as he engaged in discussion with other members of the Blue Ridge group.

He was very confident in his ideas, and he pushed his point home until his group members agreed or gave up.

For all students, their first encounter with expert cases was while engaging in the Erosion Challenge (Episodes 1 and 2). They began working together in a group after the completion of that challenge and for the duration of *Tunneling Through Georgia*. (names of units should be italicized in all chapters)

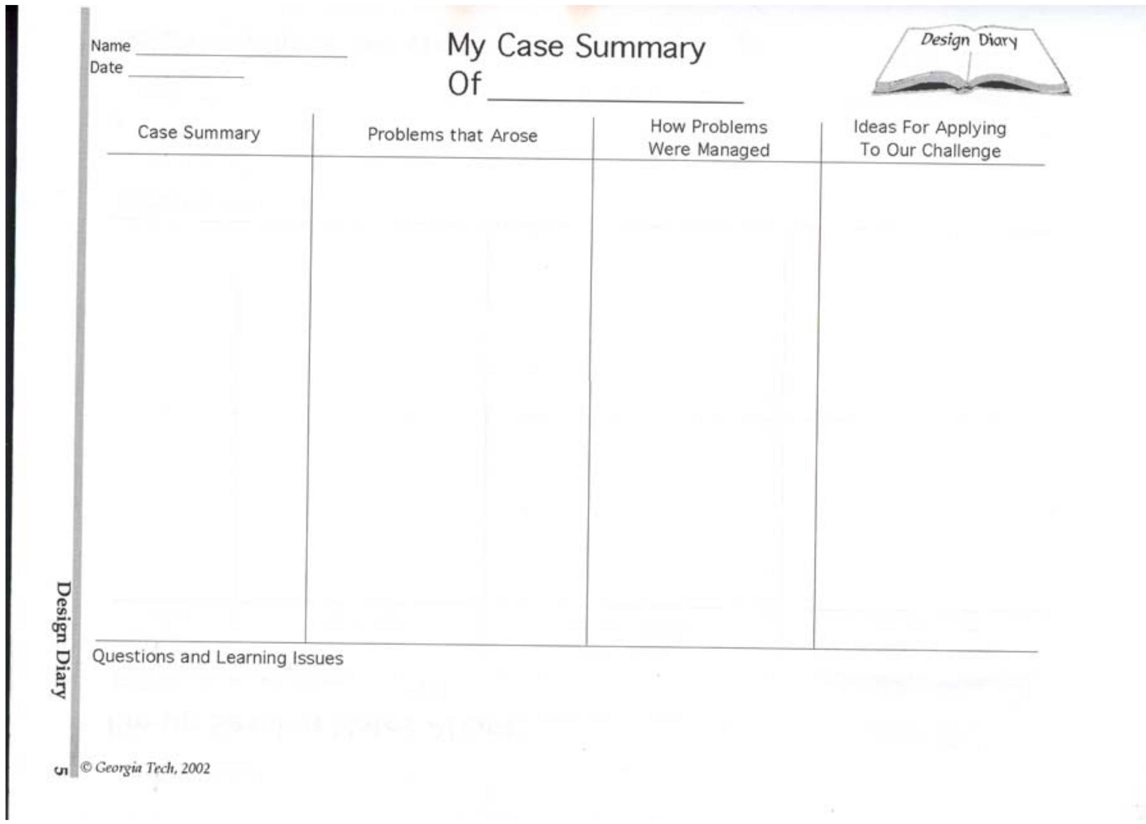
We present three types of episodes. The most common type (exemplified in Episodes 1, 3, 4, 6 and 7) has Mr. J making presentations to the class, interspersed with some participation by students, and followed by a student or group activity. For these, we first present the enactment, then our predictions about student capabilities and/or development, and then our analysis of the quality of student work. If group discussions are available (as they are for Episodes 4, 6, and 7), our analysis of those discussions will follow our analysis of student work. The second type (exemplified in Episodes 2 and 5) are whole-class presentation and/or discussion activities. They are done after small-group work and involve considerable discussion. Here, we present the purpose and if different from the actual enactment, the intended enactment of the activity, followed by its actual enactment, including in important snippets of student discussion that show student capabilities. The third type (exemplified in Episodes 8 and 9) are performance assessment activities, done after the completion of a unit. For these, we first present the enactment, then our predictions about student capabilities and/or development, followed by our analysis of student work. In Episode 8, we also include an analysis of group discussions.

5.2 Episode 1: Introduction To Case Use Skills – Landslide and Dust Bowl Cases

Mr. J introduced students to case use skills for the first time when the Landslide and Dust Bowl cases were introduced early in the Erosion Challenge (part of *Digging In*). He emphasized case interpretation and the beginnings of case application as he described the questions students should ask themselves as they used the My Case Summary Design Diary page to interpret the Dust Bowl and Landslide cases.

5.2.1 Enactment

Mr. J. introduced and modeled case interpretation and the beginnings of application skills to students by modeling the reasoning they should do when filling out the My Case Summary Design Diary Page. As he expected later from students, he organized this introduction and modeling around the prompts in the My Case Summary Design Diary Page, shown in Figure 5.1. Mr. J. began class by stating that the class was going to read a case and summarize it. He asked for a volunteer to read a poster hanging in the back of the room that described what Design Diary Pages were, and he passed out the My Case Summary Design Diary Pages to each student in the class.


Name ____________
Date ____________

My Case Summary
Of ____________

Design Diary

Case Summary	Problems that Arose	How Problems Were Managed	Ideas For Applying To Our Challenge

Questions and Learning Issues

Design Diary

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Figure 5.1 –My Case Summary Design Diary Page

Mr. J told the class that he wanted their summaries for the Case Summary column to be about two or three sentences long, and he solicited ideas about what might go in each column. For the Problems That Arose column, one idea was to identify problems about the case they were reading. For the What Problems Were Managed column, one student said that they were to figure out what the experts did to stop or manage erosion. For the Ideas for Applying to the Challenge column, one student said, “You might have ideas you want to try in the challenge” that come from the case.

Mr. J told the class they were going to read a story and the story or case they would be reading was about erosion. He told them they were not being asked to solve the challenge, but that they were looking for ideas they might want to investigate. For example, he asked, “What might be one way to solve the erosion problem we saw on our Erosion walk?” One student replied, “Don’t put the tractor or truck in the road.” Then, Mr. J asked them “What are ways to stop trucks from going through the path?” He helped the class come up with ideas for how they might answer that question, explaining that those ideas were actually management methods.

Then, Mr. J assigned two groups to read the Dust Bowl case and two groups to read the Landslide case, and he told the class that each group would teach the class about the case that they read. He solicited ideas from the class about how they planned to read and fill out the My Case Summary Design Diary Page. Answers ranged from highlighting and circling in the text as they read and then going back and filling in the My Case Summary Design Diary Page, to filling out the My Case Summary Design Diary Page as they read along, and having read one paragraph, to think about whether anything that was read could help them fill out their My Case Summary Design Diary Page, and then moving to the next paragraph. As student groups began reading their cases, they discussed the expert case as a group and completed the My Case Summary Design Diary Pages individually. As they worked, Mr. J told the class to let him know if they had any questions or ran across words they didn’t understand.

5.2.2 Predictions

We predicted that there would be variation in student case interpretation capability on the My Case Summary Design Dairy Pages for the Dust Bowl and Landslide cases. Because this was the first time students had interpreted an expert case, we predicted that most would either provide general or specific descriptions of problems and solutions. However, because they had not had much experience in class justifying their ideas or describing how solutions were implemented before this activity, we thought very few students to include causality, justification, or implementation details in their problem and solutions.

Understanding, identifying, and knowing the difference between criteria and constraints as well as understanding how they impact design decisions was a major part of the *Digging In* Unit. However, because every student may not have understood criteria and constraints equally well, we thought most students would identify either general criteria and constraints, or specific criteria and constraints. Because the My Case Summary Design Diary Page did not prompt students to describe outcomes that occurred because the experts either addressed or failed to address their constraints, we thought very few students would describe those outcomes. Because they had not had much experience justifying their ideas up to that point, we predicted that students would not include justification for choosing the criteria and constraints they identified.

Because they had not had much experience with identifying, creating, and using design rules of thumb in earlier activities, we thought students would either identify no design rules of thumb or identify only very general design rules of thumb, without causality or justification. We thought most students to attempt to tie design rule(s) of thumb to their challenge because they were prompted to do so. However, we thought few students would include causality or justifications in their design rules of thumb or explore multiple ways the design rule of thumb might be applied to their challenge. They had also experienced some trouble applying the things they knew from other classes to their activities, like memorizing the definition of erosion in World Geography, but being unable to describe how erosion played out real world situations where application of the definition made sense. Since this was the first time many of these students had been exposed to thinking about expert cases in this way, we knew that students would bring different prior knowledge, experience, development of critical thinking skills, and abilities to interpret cases to this activity.

5.2.3 Student Work[2]

Two students in the Blue Ridge group had My Case Summary Design Diary Pages for the Dust Bowl and/or Landslide cases that we could code: Theresa and Margaret. Figure 5.2 shows Margaret's My Case Summary Design Diary Page for the Landslide case, as written, while Figure 5.3 shows a recreation of Theresa's My Case Summary Design Diary Page for the Dust Bowl case. Table 5.5 shows how we coded the two best answers each of them gave for each dimension. Coding results for each episode will be presented using tables of two types. In the first type, the two best answers given for each dimension and the ratings that those two best answers received are presented, as Tables 5.3 and 5.4 show for Margaret and Theresa, respectively. In the second type, for each student or group (e.g. Theresa, Margaret, Blue Ridge Group), there are three columns: the first and second columns show the ratings given for a student or group for the two best answers for each dimension; and the third column shows the total number of answers that a student or group wrote on the artifact that applied to the dimension shown in the first column. Additional columns show the same information, but for another student or group. We see from Table 5.5 that for the dimension named Identifies

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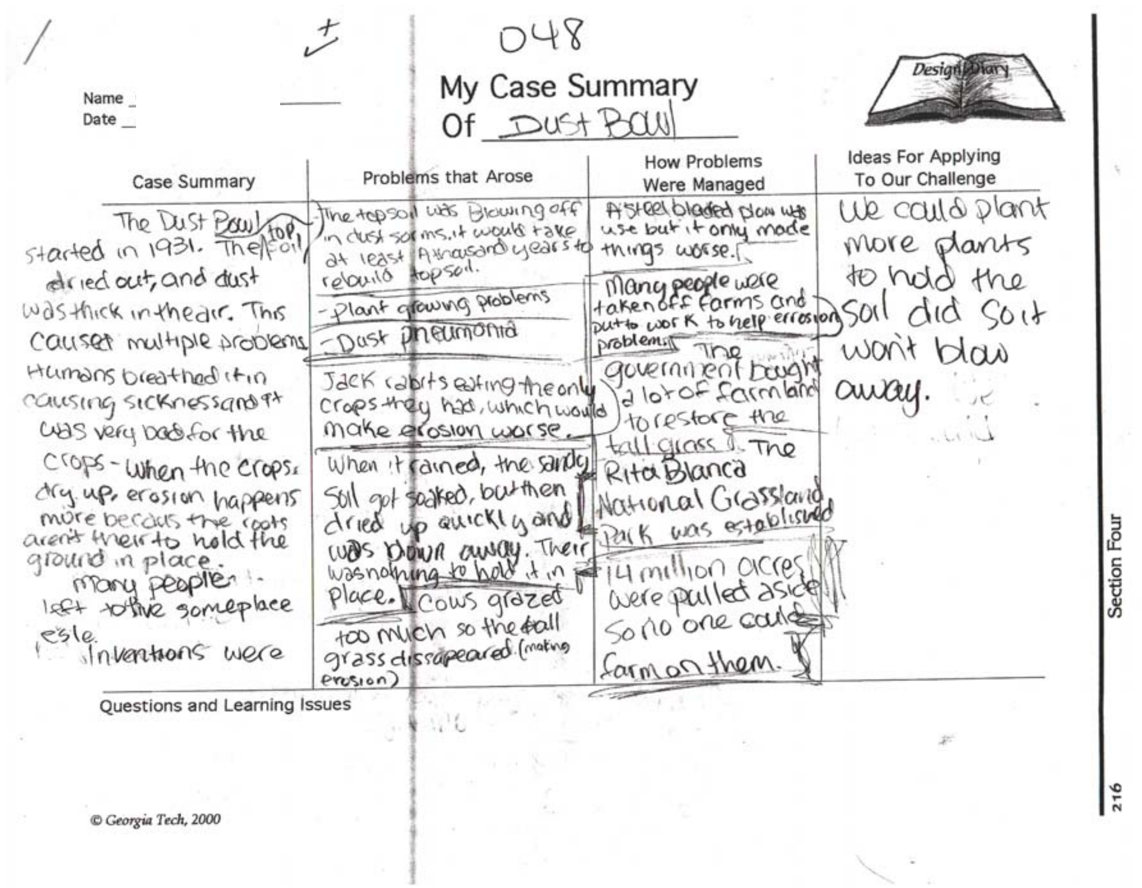
[2] This section presents the results of the coding for those students in the Blue Ridge group who completed a My Case Summary Design Diary page for the Dust Bowl or Landslide Case. This and the second episodes allow us to understand how well students are able to interpret and attempt to apply expert cases after having been exposed to teacher modeling but before being exposed to the Case Application Suite's system of scaffolds.

Problems (I), Theresa received ratings of 2 and 2 for her two best answers (columns 1 and 2) out of a total of 3 problems identified (column 3). For that same dimension, Margaret received ratings of 4 and 3 for her two best answers out of a total of 4 problems identified. For any dimension, 1 is the lowest score that can be given; there is no rating of 0.


048

My Case Summary

Of Dust Bowl

Name _

Date _

Case Summary	Problems that Arose	How Problems Were Managed	Ideas For Applying To Our Challenge
The Dust Bowl started in 1931. The top soil dried out, and dust was thick in the air. This causes multiple problems. Humans breathed it in causing sickness and it was very bad for the crops - when the crops dry up, erosion happens more becaus the roots aren't their to hold the ground in place. Many people left to live someplace esle. Inventions were	The topsoil was blowing off in dust storms. it would take at least A thousand years to rebuild topsoil. - Plant growing problems - Dust pneumonia. Jack rabits eating the only crops they had, which would make erosion worse. When it rained, the sandy soil got soaked, but then dried up quickly and was blown away. Their was nothing to hold it in place. Cows grazed too much so the tall grass dissapeared (making erosion)	A steel bladed plow was use but it only made things worse. Many people were taken off farms and put to work to help errosion problems. The government bought a lot of farmland to restore the tall grass. The Rita Blanca National Grassland Park was established. 14 million acres were pulled aside so no one could farm on them.	We could plant more plants to hold the soil so it won't blow away.

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Figure 5.2 – Margaret's My Case Summary Design Diary Page

As summarized in Table 5.3, Margaret was able to interpret the Dust Bowl case. She identified many problems, some with a great deal of detail and including correct causality (Identifies Problems (I)): *It* [erosion] *was very bad for the crops—when the crops dry up, erosion happens more because the roots aren't there to hold the ground in place.* She also identified expert solutions that included who or what the solutions were to benefit. When identifying solutions the experts considered in the Dust Bowl case (Identifies Solutions (II)), Margaret wrote: *The government bought a lot of farmland to restore the tall grass*.

While Margaret did not identify criteria for this case (Understands Criteria (V)), she did identify one general constraint (Understands Constraints (VI)): *It would take at least a thousand years to rebuild topsoil*. However, she did not describe outcomes that occurred as a result of this constraint being addressed or unaddressed by the experts (Connects Constraints to Outcomes (VII)). Margaret identified one general design rule of thumb: *We could plant more plants to hold the soil down so it won't blow away.*

Table 5.3 – Margaret's Two Best Answers From My Case Summary Design Diary Page – Landslide Case

Margaret		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	The topsoil was blowing off in dust storms. It would take at least a thousand years to rebuild topsoil.	4
	Jack rabbits eating the only crops they had, which would make erosion worse.	3
Identifies Solutions (II)	A steel bladed plow was used but it only made things worse.	3
	The government bought a lot of farm land to restore the tall grass.	3
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		2
		2
Understands Criteria (V)		1
Understands Constraints (VI)	It would take at least a thousand years to rebuild topsoil.	2
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	We could plant more plants to hold the soil down so it won't blow away.	2

047 – 5th Period – My Case Summary of Landslides

Case Summary	Problems That Arose	How Problems Were Managed	Ideas For Applying To Our Challenge	Questions and Learning Issues
The case discussed the many landslides that happen in the Cascades. It discussed some of the ways and things that could cause landslides. It also went over the many different methods and their history of keeping/preventing landslides.	Some of the problems were houses destroyed, lives lost. Also that none of the ways to stop erosion truly 100% work. Trees/roots.	Landslides are managed with retaining walls. Dewatering systems funding for watering systems, control development	How landslides could be a danger to the project of the court. Also how we could prevent/slow down erosion.	Is there room in the budget for dewatering system or retaining wall?

Figure 5.3 – Theresa's Re-Created My Case Summary Design Diary Page

Table 5.4 shows which parts of Theresa's page were analyzed as data. Recall that our practice has been to choose the two best examples along each coded dimension. As summarized in the table, Theresa seemed able to read the Landslide case for understanding and to identify important aspects of the case. She identified general problem/solution pairs, but did not include causality or justification: *Some of the problems were houses destroyed* and *lives were lost*. She also identified general expert solutions (Identifies Solutions (II)). For example, Theresa wrote *Landslides are managed with retaining walls*. Theresa did not explicitly connect the expert problems with the expert solutions she identifies (Connects Problems and Solutions To Apply To The Challenge (IV)), so it is not clear which solutions address which problems. Theresa also did not identify any criteria for this case (Understands Criteria (V)). However, she did identify two general constraints (Understands Constraints (VI)): *Also that none of the ways to stop erosion truly 100% work* and *Funding for watering systems*. She did not describe outcomes that occurred as a result of the expert addressing or failing to address these constraints (Connects Constraints to Outcomes (VII)) nor did she identify design rules of thumb (Rule of Thumb (VIII)).

Table 5.4 – Theresa's Two Best Answers From My Case Summary Design Diary Page – Landslide Case

Theresa		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Some of the problems were housed destroyed, lives lost.	2
	Also that none of the ways to stop erosion truly 100% work.	2
Identifies Solutions (II)	Landslides are managed with retaining walls.	2
	Dewatering systems	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		1
		1
Understands Criteria (V)		1
Understands Constraints (VI)	Also that none of the ways to stop erosion truly 100% work	2
	Funding for watering systems	2
Connects Constraints To Outcomes (VII)		2
		1
Rules of Thumb (VIII)		1

5.2.4 Summary Of Results

Inter-rater reliability for this episode was 99%. Table 5.5 shows that overall, Theresa's ability to interpret and attempt to apply the Landslide case was as we predicted, as she identified general problems, solutions, criteria, and constraints. Margaret's ability to interpret and attempt to apply the Dust Bowl case was better than predicted. She identified specific problems the experts faced that also included correct causality, and the solutions she identified in the expert case included the criteria or constraint it was supposed to address. As we will see later, this variation across students will continue as students continue to use case use skills.

Table 5.5 – Coding Results for My Case Summary Design Diary Pages – Dust Bowl and Landslide Cases

	Theresa's Coded Results			Margaret's Coded Results		
Identifies Problems (I)	2	2	Total - 3	4	3	Total – 4
Identifies Solutions (II)	2	2	Total – 3	3	3	Total – 6
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	1	1	Total – 3	2	2	Total – 6
Identifies Criteria (V)	1		Total – 0	1		Total – 0
Identifies Constraints (VI)	2	2	Total – 2	2		Total – 1
Connects Constraints To Outcomes (VII)	2	1	Total – 2	1		Total – 1
Design rules of Thumb (VIII)	1		Total - 0	2		Total - 1

5.3 Episode 2: Learning from the Dust Bowl and Landslide Cases

Episode 2 took place the day after students completed their first interpretations of the Dust Bowl and Landslide cases. Its purpose was to again review how to interpret expert cases and to go over the interpretations students had attempted of the two cases and as a class identify their important aspects and usefulness and make causal connections between their parts. During this episode, Mr. J. and the class collaboratively discussed and wrote on the whiteboarded the facts, ideas, and learning issues gleaned from the Dust Bowl and Landslide cases.

5.3.2 Intended Enactment

We wanted Mr. J to help students understand what they had read about the Dust Bowl and Landslide cases (e.g., plants help root the soil, water is not the only cause of landslides), help them tease apart any ideas they had about the cases (e.g., since loose, gravelly soil is easily blown away, maybe we should think about how to keep the soil tight and moist), and help them understand how they could turn questions about how something works into questions that they can investigate and learn from, helping them move forward in their challenge (e.g., what kinds of vegetation are effective to hold down loose, gravelly soil). We had also asked Mr. J. to use this class time as an opportunity to help students make and understand the causal connections in the expert cases (e.g., farmers overworked the soil removing nutrients from it, causing it to become dry and loose and easily blown around by wind). We expected that the class would offer up ideas and different perspectives by building on the ideas of others, identifying facts in the expert cases, and talking about the things they still wanted to learn more about and how they might accomplish that.

5.3.3 Actual Enactment and Results

As we had intended, Mr. J helped the class understand important ideas from the expert cases, make causal connections, and understand what lessons they could learn from the expert cases, while filling out the class whiteboard. During this discussion, for example, Mr. J helped students understand the role that the condition of the soil played in a resulting landslide:

(1) Mr. J: What, what about soil type?
(2) Student 1: Gravelly and loose…
(3) Mr. J: So, that means what about why-why is gravelly
(4) and loose soil—
(5) Student 1: It wouldn't hold together, so the house
(6) slid down.
(7) Mr. J: Soil type—but it doesn't hold a lot of

(8) moisture, right?

(9) Student 2: Right.

Excerpt 5.3.1: Class Discussion on Soil Type

Here, Mr. J. helped Student 1 not only understand what could be gleaned from his description of the soil type as being loose and gravelly (i.e., soil type is important in understanding erosion and loose gravelly soil doesn't hold a lot of moisture), but his prompting also pushed Student 1 to explain the connection between the soil type, the landslide, and the outcomes that occurred as a result of the landslide ("the house slid down"). During the class discussion, Mr. J also emphasized and helped students understand the importance and usefulness of expert cases:

(10) Mr. J: Alright, so we have all these facts, right?

(11) Facts, what are these facts about?

(12) Margaret: Landslides and Dust Bowls.

(13) Student 4: What's known about problems in our

(14) challenge.

(15) Mr. J: OK…so all these facts are related to our

(16) challenge. Right? Related to our problem, right?

(17) And we learned these facts from where?

(18) Student 5: [inaudible]

(19) Theresa: The cases.

(20) Mr. J: From our case studies, right?

(21) David: You.

(22) Mr. J: And where, what are case studies?

(23) David: Studies of cases.

Student 5: [inaudible]

Mr. J: [inaudible]

Theresa: Cases that you study.

Mr. J: Cases that you study…

Theresa: They are.

Student 4: Cases that have taken place.

Mr. J: Ahh! Cases that have taken place…

Student 6: In our world.

Theresa: And that you study.

Mr. J: So they're not cases that are going to take place, they're cases that have already taken place, right? So...anything else?

Student 4: I mean it's talking about stuff-

Student 3: They're, like, experiences and examples that suggest ideas.

Mr. J: OK—experiences and examples that suggest ideas. And where do those ideas come from? Or those experiences come from? They came from… [goes over to Student 4's book]

Student 5: The real world.

Mr. J: The real world, and the past, right?

Student 5: Things that have happened.

Mr. J: Good, things that have happened to other people and what they learned from them…you're learning from, right? OK.

Excerpt 5.3.3 – Class Discussion of Role of Expert Cases

Here, Mr. J. and the class described expert cases as being descriptions of events that have already taken place, experiences of others that provide real-world examples and provide suggestions of ideas that might be useful in the future, and descriptions of events that others have experienced and the lessons learned from those events. Mr. J. emphasized that the class should use expert cases to learn what the experts learned. During the remainder of class, they continued discussing the Dust Bowl and Landslide cases, and from that they created the whiteboard shown in Table 5.6.

Table 5.6 – 5th Period Class Whiteboard – Class Discussion of Dust Bowl and Landslide Cases

Facts	Ideas	Learning Issues
Wind blows soil	Hills with vegetation erode more slowly	
Plants hold soil in place	Retaining walls divert soil	
Water causes landslides	Underground water channels divert water	
Clear cutting loosens soil	Control development	
Animals destroy vegetation	Early warning	
Long periods of rain cause erosion	Irrigation techniques	
Soil type that does not hold moisture		
Erosion occurs more on steep slopes		
People's choice to live		

5.4 Episode 3: Modeling Case Use Skills A Second Time – Lotschberg Case In *Tunneling Through Georgia*

In Episode 3, Mr. J models processes involved in using cases a second time, this time in the context of the Lotschberg Tunnel case, the first case in the *Tunneling through*

Georgia unit. In this episode, he reinforces case interpretation skills and adds more to his presentation of application skills, again in the context of helping students use the scaffolding in My Case Summary Design Diary pages to guide their interpretation. We shall see that Theresa's ability to interpret and begin to apply the Lotschberg Tunnel case improved from her interpretation of the Landslide Case in Episode 1.. Instead of identifying more specific problems, solutions, and criteria and including justification in his design rules of thumb, Billy identified general expert problems, solutions, criteria, and design rules of thumb that did not include justification. David understood criteria in a very sophisticated way, as he described a specific objective that the experts wanted to address that included justification for choosing the criterion, but he identified expert problems, solutions, and design rules of thumb that were general..

5.4.1 Enactment

Three weeks after Episode 2, the class was ready to interpret the Lotschberg Case in the *Tunneling Through Georgia* Unit. Having asked the class to read the case for homework the night before, Mr. J. modeled the kinds of questions they should ask of themselves and their group members as they interpreted this case and other cases in the future. He asked what happened in the Lotschberg case, and responses ranged from noting that the experts had to build a restaurant so the workers would have a place to eat, to noting that digging took place on the north and south sides of the tunnel simultaneously. Mr. J emphasized that although both of those responses were correct, he preferred that the problems they cite on their My Case Summary Design Diary Pages be more like the latter response, specifically addressing tunneling or geological issues.

Mr. J explained that he wanted an overview of the case for the Case Summary column. For the Problems that Arose column, he said that he only wanted them to write down problems that had to do with tunneling or geology and to only include problems that were found in the expert case. For the How Problems Were Managed column, Mr. J told the class that he wanted them to describe solutions to the problems they identified in the Problems that Arose column. For the Ideas for Applying to Our Challenge column, he said that he wanted them to talk about how some of the problems could be avoided. For the Questions and Learning Issues section, he told the class to include things they may not have understood in the case or things they may have wanted to know more about. He gave the class 10 minutes to complete the My Case Summary Design Diary Page for the Lotschberg Case, and he told them if they didn't finish interpreting the case in class, they could complete it for homework that evening. As they had done in Episode 1, students discussed the expert case as a group, but completed individual My Case Summary Design Diary pages.

Following their interpretation of the Lotschberg Case, the class completed worksheets based on The Magic Schoolbus series, where the characters took a journey inside the earth to understand its composition as well as how different kinds of rock were formed. During this activity, Mr. J. helped the class connect what they saw in the video to their experience of going to a mine in Dahlonega, Georgia. The class had taken that field trip earlier in the school year prior to beginning the *Digging In* Unit. He helped to them understand how different kinds of conditions might exist in different kinds of areas and what may cause those different conditions. For example, Mr. J. reminded them that the tour guide in the Dahlonega mines told them that the mine was only 60 degrees and its comfortable temperature drew people to want to work there. He asked what the tour guide said about the South African diamond mines, and one student replied, "It's, like, 120 degrees, but they can get it to 100." When Mr. J. asked the class why it was so hot in the South African diamond mines, another student said, "Because the diamonds are igneous rocks and are the hardest to form," referring to the high temperatures necessary to form igneous rocks. Acknowledging the student's reference to diamonds being igneous rocks and being hard to form as correct, but not hearing what he was looking for as an explanation for the high temperature in South African diamond mines, he asked the class again why it was so hot. Another student responded that the South African diamond mines were so hot because they were deeper in the ground. Following the Magic School Bus Activity, each group continued creating their rock models by adding more sand and substrate, and they read about how they would test their rock models.

5.4.2 Predictions

As in Episode 1, we predicted that there would be variation in individual student capability for the My Case Summary Design Diary Pages for the Lotschberg case. However, we thought that variation would not be as large as predicted for Episode 1. Because students were familiar with the My Case Summary Design Diary Page and its role in helping them interpret expert cases, we thought most students would describe more specific problems and solutions, and we thought more students would include causality, justification, and implementation details in their descriptions of problems and solutions. In addition, as Mr. J. prompted students, they had begun justifying, explaining, and identifying cause-effect relationships during whole class discussions. As a result, they began prompting each other to justify their ideas. Because Mr. J. specifically stated that their problems and solutions should be specific to tunneling and geology, we predicted that students would identify more problems and solutions of that nature.

Because they had been prompted by Mr. J. to justify their ideas and make connections between events and the causes of those events, we thought students would identify more specific criteria and constraints including justification for choosing those criteria and constraints although the My Case Summary Design Diary page did not explicitly prompt students for criteria and constraints. However, because the My Case Summary Design Diary page prompted students to describe the outcomes that occurred because the experts either addressed or failed to address constraints, we thought students would not describe those outcomes. Because of their experiences justifying their ideas and identifying lessons they could learn from the Dust Bowl and Landslide cases during *Digging In*, we predicted more students would not only identify design rules of thumb that included justification and causality, but would also attempt to tie the design rules of thumb to their challenge.

5.4.3 Student Work

Three students in the Blue Ridge group had My Case Summary Design Diary Pages for the Lotschberg Case: Theresa, Billy, and David. As summarized in Table 5.7, Theresa seemed to be able to read a case for understanding. She was able to identify specific problem/solution pairs during this episode, but she still did not include causality nor justification. For example, when identifying problems the experts faced in the Lotschberg case, she wrote: *First workers had to set up a city which ended up in death and destruction*. In this episode, Theresa still identified one general expert solution, but she also identified a solution that included details about how the solution was implemented. For example, when identifying solutions the experts considered in the Lotschberg case, Theresa wrote *Built a small city,* and she also wrote *Sealed tunnel with wall and curved a new section to go to south end*. Theresa identified one specific criterion: *To make a train to go through Lotschberg Mountain through/under rivers*. However, she did not identify any constraints, and she did not describe any outcomes that occurred because the experts addressed or failed to address constraints. Theresa identified one general design rule of thumb that did not include causality: *We should test all ideas and rock before building or planning anything*.

Table 5.7 – Theresa's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case

Theresa's Coded Results		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	First workers had to set up a city which ended in death and destruction.	3
	The river came in people died sand filled the tunnel.	3
Identifies Solutions (II)	Built a small city.	2
	Sealed tunnel with wall and curved a new section to go to south end.	4
Specifies Implementation (III)		2
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		2
		2
Understands Criteria (V)	To make a train to go through Lotschberg Mountain through/under rivers	3
Understands Constraints (VI)		1

Table 5.7 – Theresa's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case (Continued)

Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	We should test all ideas and rock before building or planning anything.	2

As shown in Table 5.8, Billy identified general problem/solution pairs that included no causality or justification: *Sand and gravel farther down than thought* and *Thin rock layer roof*. Billy also identified general expert solutions that included no implementation details. For example, when identifying solutions the experts considered in the Lotschberg case, he wrote *Eventually went around sand and gravel* and *It caved in*. While Billy identified one general criterion, *Needed to build a tunnel through a mountain under river*, he did not identify any constraints. However, he identified two general design rules of thumb: *Send a test pipe to see what's down there in the ground* and *Dig or tunnel deeper* as design rules of thumb.

Table 5.8 – Billy's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case

Billy's Coded Results		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Sand and gravel farther down than thought	2
	Thin rock layer roof	2
Identifies Solutions (II)	Eventually went around sand and gravel	2
	It caved in.	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		2
		1
Understands Criteria (V)	Tunnel through a mountain under river	2
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	Send a test pipe to see what's down there in the ground.	2
	Dig a tunnel deeper.	2

As Table 5.9 shows, David described general problems the experts faced in the Lotschberg case: *Silt and mud avalanche* and *Hot springs*. He identified general expert solutions. However, one of his solutions did not seem to map to any expert problem when he wrote *Scientists found things out*. David also wrote *Only 575 feet long, curved path* as an expert solution, describing the length and orientation of the Lotschberg Tunnel. He identified one specific criterion that included justification for choosing the criterion when he wrote *The Simplon tunnel could not be accessed, a tunnel was proposed to be built through the mountain*. Although he identified no constraints, he did identify a general design rule of thumb: *Learn about terrain*.

Table 5.9 – David's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case

David		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Hot springs	2
	Silt and mud avalanche	2
Identifies Solutions (II)	Scientists found things out	2
	Only 575 feet long, curved path	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		1
		1
Understands Criteria (V)	Simplon Tunnel could not be accessed, a tunnel was proposed to be build through the mountain.	4
Understands Constraints (VI)		1

Table 5.8 – Billy's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case (Continued)

Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	Learn about terrain	2

5.4.4 Summary of Student Performance

Inter-rater reliability for this episode was 99%. As summarized in Table 5.10, overall Theresa's ability to interpret the Lotschberg case matched the predictions we had for this episode. In Episode 1, Theresa identified general expert problems, solutions, criteria, and constraints. In this episode, however, she identified more specific problems, solutions whose description included the criteria/constraint the solution was supposed to address, and a criterion that described a specific objective the experts wanted to address. Billy's ability to identify problems, solutions, criteria, and design rules of thumb was did not match our predictions because we expected students to be able to identify more specific problems, solutions, and criteria, and we expected students to begin including justification in their design rules of thumb. However, all of the problems, solutions, criteria, and design rules of thumb Billy identified or described were general. David performed inconsistently. His ability to identify expert problems, solution, and design rules of thumb was below our predictions (i.e., he identifies general expert problems solutions and design rules of thumb), but his ability to identify criteria was above our predictions. We had no design diary pages for Billy or David from the Landslide or Dustbowl cases, so we have no way of knowing how their performance changed over time.

Table 5.10 - Coding Results for My Case Summary Design Diary Pages – Lotschberg Case

	Theresa's Coded Results			Billy's Coded Results			David's Coded Results		
Identifies Problems (I)	3	3	Total – 3	2	2	Total – 2	2	2	Total – 4
Identifies Solutions (II)	4	2	Total – 3	2	2	Total – 2	1	2	Total – 2

Specifies Solution Implementation (III)	2	N/A	Total – 1	N/A	N/A	Total –0	N/A	N/A	Total – 0
Connects Problems and Solutions (IV)	2	2	Total – 3	2	1	Total – 2	1	1	Total – 2
Identifies Criteria (V)	3		Total – 1	2		Total – 1	4		Total – 1
Identifies Constraints (VI)	1		Total – 0	1		Total – 0	1		Total – 0
Connects Constraints To Outcomes (VII)	1		Total – 0	1		Total – 0	1		Total – 0
Rules of Thumb (VIII)	2		Total - 1	2	2	Total - 2	2		Total - 1

5.5 Episode 4: Using the Case Interpretation Tool – First Software-Scaffolded Case Activity

Episode 4 presents the first time student groups used the Case Interpretation Tool to interpret an expert case. Overall, the Blue Ridge group identified general and specific problems, specific criteria and general design rules of thumb in the St. Gotthard Tunnel case. They also identified two expert solutions that included detail about how the solution was implemented. However, the group's written work also reveals that there was some confusion about the difference between criteria and constraints because they identified one criterion as a constraint. Group discussions show that this group worked well together and tended to classify, support, and refute ideas using the definitions of the classifications in questions as justification or evidence.

5.5.1 Enactment

A week following Episode 3, student groups interpreted cases using the Case Interpretation Tool. This was the first time they used the Case Interpretation Tool and its system of scaffolds to support them as they interpreted an expert case in their small groups. Each group interpreted a different case from the following set of cases: Hoosac, Frejus, Queens Midtown, and St. Gotthard. Descriptions of these and the other cases in the Tunneling Through Georgia Unit were described in Chapter 3.

While using the Case Application Suite in their small groups, group members took on one of three roles described to the class by Mr. J.: typist, reader (text and/or screen), and facilitator. The typist was responsible for typing in the group's response into the software. Readers were responsible for reading through the expert case to help find information in the expert case the group would need to form a response and/or reading the prompt on the screen so that everyone would know the question they were being asked. However, as many episodes of the case studies will reveal, any member of a group could function in this capacity if they desired even if they were not playing the role of reader within their group. The facilitator was responsible for ensuring that the group stayed on task and that everyone participated in the group discussion. As this and the next two case studies will show, sometimes members within a group took on different roles for each case activity, sometimes they maintained the same roles across case activities, and sometimes, members changed roles within a case activity (e.g., a reader taking on the role of typist when the typist walks away from the group). Mr. J. logged all of the groups into the software, and they began working on their cases. The Blue Ridge group interpreted the St. Gotthard Tunnel case.

5.5.2 Predictions

For the first case interpretation activity using the Case Interpretation Tool, we predicted that were that there would be variation in group capabilities. Although this was not the first time students had interpreted expert cases, this was the first time that the students in the Blue Ridge group had interpreted an expert case together. Each student in the Blue Ridge group was in a different group during the Digging In Unit, and as coding results for Episodes 1 and 2 showed, each student in the Blue Ridge group came into this activity with different interpretation capability. We thought these different individual capabilities would affect the way the group would discuss ideas, negotiate meaning, and use the Case Interpretation Tool's system of scaffolds as they worked collaboratively. Because of the effect the variation of individual student capabilities might have on group capability, we predicted most groups would either provide general descriptions of problems and solutions or to provide more specific descriptions about problems and solutions. However, we did not think most groups would include causality, justification, or implementation details in their problem and solution descriptions. This was the first time the group had worked together around the computer, so we thought trying to negotiate and collaborate around a new tool with a relatively new group might impact the ease with which group members communicated with each other, perhaps preventing the group from engaging in the kinds of discussion that would encourage talk about causality, justification, and implementation.

Because student groups were prompted to use the Our Criteria and Constraints template and there was a column heading in the template for criteria and constraints (meaning student groups should enter something for each of the columns), we predicted most student groups would identify either general criteria and constraints or specific criteria and constraints. Because the software did not prompt student groups to talk about outcomes that may have occurred because the experts addressed or failed to address constraints, we did not expect student groups to describe those kinds of outcomes.

Because they had not had much experience identifying, articulating, and using design rules of thumb, we expected most groups to identify general design rules of thumb. Although Mr. J. had occasionally encouraged students and groups to create design rules of thumb during the *Digging In* Unit and during their early activities in *Tunneling Through Georgia*, he had not focused on including causality or on justifying design rule(s) of thumb.

5.5.3 Student Work

As the Blue Ridge group used the Case Interpretation Tool, every member of the group except Theresa, who was the designated typist for the group, had the written expert case in their student books in front of them. They looked back at what the cases said as needed while they worked. David dominated the discussion, though Billy and Theresa were both vocal, and Margaret was quiet. In general, they had an easy time with identifying expert problems, solutions, and using the rule of thumb template to generate design rules of thumb, but they required more discussion about criteria and constraints, spending most of their discussion time on this topic.

In this episode, summarized in Table 5.11, the Blue Ridge group identified general problems the experts faced, (Identifies Problems (I)). For example, they identified *Water stopped flowing through the tunnels* and *North end hit serpentine, south side hit mica* as expert problems. The Blue Ridge identified solutions the experts used to address the problems they encountered (Identifies Solutions (II)), providing a description of a solution that included the benefit the solution was supposed to have or the criteria or constraint the solution was supposed to address, and including some detail about how the solution was implemented for one of the three expert solutions they identified. They typed *For the solution to the sinking of the walls, they laid down a granite floor* and *They made airpower drill and they flipped the whole tunneling method upside down. They worked from the bottom to the top. They chose this solution because anything they put down (ex. Granite wall) sank beneath the floor* as solutions the experts used to address problems they encountered.

The Blue Ridge group also identified criteria (Understands Criteria (V)) and constraints (Understands Constraints (VI)) though most criteria and constraints were general. They typed *built two towns for workmen* and *water pumps* as criteria and *cost of work/tunnel building (budget)* and *type of rock/minerals (hardness etc.)* as constraints. However, this group seemed to identify a constraint that was actually criterion when they typed *cave-ins*, and this group did not identify outcomes that resulted because a constraint was addressed or not addressed (Connects Constraints To Outcomes (VII)). The Blue Ridge group used the Rule of Thumb template to create a design rule of thumb (Rule of Thumb (VIII)). Although this group attempted to include causality in their design rule of thumb, *When you hit unexpected water, use a water pump because it is the only effective way to get rid of water*, the justification was not tied to any scientific principle and despite being a successful solution, the expert case did not describe water pumps as the only effective way to get rid of water from flooding.

Table 5.11 – Blue Ridge Group's Two Best Answers From Case Interpretation Tool – St. Gotthard Tunnel case

Blue Ridge Group

Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Sinking of the walls	3
	Flooding water	2
Identifies Solutions (II)	They made air power drills and they flipped the whole tunneling method upside down. They worked from the bottom to the top. They chose this solution because anything they put down (ex. Granite wall) sank beneath the floor.	4
	They also used water pumps to pump out the flooding water.	4
Specifies Implementation (III)		2
		2
Understands Criteria (V)	Finished by October 1880 or pay fine	3
	Built two towns for workmen	2
Understands Constraints (VI)	Cost of work/tunnel building (budget)	3
	Type of rock/minerals (hardness, etc…)	2
Connects Constraints To Outcomes (VII)		1
		1
Rules of Thumb (VIII)	When you hit unexpected water, use a water pump because it is the only effective way to get rid of water.	2

Table 5.12 shows the coding results for this episode. Reliability was 98% for this case activity.

Table 5.12 – Blue Ridge Group Case Interpretation I Coding Results

	Blue Ridge Group's Coded Results Case Interpretation 1 – St. Gotthard Tunnel		
Identifies Problems (I)	3	2	Total – 2

Identifies Solutions (II)	4	4	Total – 3
Specifies Solution Implementation (III)	2	2	Total – 2
Identifies Criteria (V)	3	2	Total – 3
Identifies Constraints (VI)	3	2	Total – 5
Connects Constraints To Outcomes (VII)	1	1	Total – 5
Rules of Thumb (VIII)	2		Total - 1

5.5.4 Group Discussions

While previous to this, we captured only the products of student work and whole-class discussions, we were able to also capture the conversations groups had while using the software. While their products show group capability based on their answers (e.g. identifying expert problems, identifying expert solutions, identifying criteria and constraints, articulating design rules of thumb), their conversations show how those answers were derived, who contributed to generating, creating, and wording those answers, and what other ideas may have been suggested that did not make it into the final response. Their conversations provide context for understanding their written work.

The group began by discussing the goal the experts wanted to achieve, addressing criteria and constraints, the solution the experts chose, how they carried the solution out, science and technology used, vocabulary, and design rules of thumb. The group worked well together and shared ideas with each other well. Aside from criteria and constraints, the group's discussions are what we expected; a group member would offer up an idea and, if the group agreed, they talked about how they would articulate it; if the group didn't agree, they talked about why they didn't agree and figured out what they should do to move forward. However, the group's discussion about criteria and constraints was more in-depth than their discussions about the other prompts in the Case Interpretation Tool.

As far as we know, there had been no public conversation about criteria and constraints since they had begun working on cases nor had this group noticed the criteria and constraints template as they began identifying criteria and constraints. Toward the end of their discussion, Mr. J. showed them the link for the Criteria and Constraints template and told them he wanted them to use it. Nonetheless, this group spent most of their conversation time on the topics of criteria and constraints. From the point of view of their introduction to case interpretation, it's somewhat surprising that this group focused so much on criteria and constraints. On the other hand, from their activities in *Digging In* that focused on the importance of criteria and constraints in making informed decisions and choosing solutions, they knew that understanding the criteria and constraints of a situation is critical to understanding the problems arise in a situation, the solutions that are chosen to address those problems, and even the tools that are used to implement solutions.

For this reason, and because in later episodes, this group shifts in their ability to understanding criteria and constraints over time, it seems appropriate to present excerpts for this group that focus on those discussions. Many things might have influenced these changes, including their use of the case for idea generation, explanation, and justification, their use of the Case Application Suite's system of scaffolds, and their discussions.

While identifying criteria and constraints, a member of the Blue Ridge group would pose an idea and the group would spend time trying to classify whether it was a criterion or a constraint, as in the following example below. Notice the use of the definitions of criterion and constraint that are used to justify why an idea should or shouldn't be classified as a criterion or a constraint:

```
(1)  Billy: What limitations did the experts have to
(2)  address?
(3)  Well, with the machines…they…"
(3)  Theresa: Were there any criteria
(4)  Billy: Not anymore…let's see…where are we…wait…
(5)  Theresa: So there weren't any criteria?
(6)  David: Umm….well, it really doesn't tell you…
(7)  Billy: Wait…well, what…the limitations they were they
(8)  had to face?  I'm just saying…
(9)  David: Here's a criteria! I have a criteria!
(10) Theresa: Yes…
(11) David: The building of two towns to house the workmen.
(12) Billy: Right.
(13) Margaret: That's a constraint.
(13) David: It's not a constraint—they didn't have to do
(14) It, but it was something he did.
(16) Margaret: Yeah, but if you didn't do it, then the
(17) workers would die…
(18) Billy: Right…
(19) Theresa: Well…
(20) Billy: I don't know…
(21) Theresa: It's optional that they die.
(22) Billy: Yeah, you could be cold-hearted.
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(23) David: Yeah, I mean, if you think about it, you want
(24) the workers to not die, but you don’t have to have
(25) them not die-
(26) Margaret: But if (muffled), then no one would be
(27) able to work.
(28) Billy: No, see, you just bring in new people. See
(29) you could’ve done that, but it shows that it would be
(30) more efficient…
(31) Theresa: Is it a criteria or constraint?
(32) David: Criteria
(33) Billy: That’s OK…
(34) Margaret: Alright.

Excerpt 5.5.1: Blue Ridge Group Discussion of Criteria and Constraints

What’s going on in this discussion? After reading the Criteria and Constraints prompt, Billy attempted to offer a limitation or constraint for the group to consider (lines 1 and 2), but was not able to find the words to express his idea and was cut off by Theresa who prompted the group for a criterion (line 3). Billy seemed to be confused, as he was trying to figure out whether they were looking for criteria or constraints (line 4). He seemed to think they were focusing on constraints while Theresa seemed to be prompting for information in the order that it was asked for in the prompt (i.e. criteria first) (line 5). David suggested that there may not be any criteria described in this case (line 6). Billy, still seemingly confused about whether they were looking for criteria or constraints, seemed to be trying to get the group to look for constraints instead of criteria (lines 7 and 8), but they did not listen as David identified the criterion that the experts wanted to build two towns to house the workers (lines 9-11).

Billy, who seemed to be clear now that the group was discussing criteria, supported David's identification of a criterion (line 12), but Margaret did not support David's classification of the two towns to house the workers being a criterion (line 13). David disagreed with Margaret and used the definitions of criterion ("something the experts want to do") and constraint ("something the experts had to do") to justify classifying the building of the towns to house the workmen as a criterion (lines 14 and 15). Margaret retorted with the outcome that would result had the experts failed to build the towns for the workers (i.e. they would die) (lines 16 and 17). Billy seemed to have shifted his position and now seemed to support Margaret's position that David's idea was a constraint (line 18). Theresa expressed some uncertainty that housing the workers was a constraint (line 19), and Billy then seemed unsure about which classification he supported (line 20).

Theresa considered the outcome of the workers dying as a criterion (because it's an option) (line 21), and Billy and David piggy backed off of that statement tying in the ethics of the workers dying, but then noting that the ethics involved in the workers dying (i.e. being cold-hearted and not wanted the workers to die) did not pose a limitation for the experts (lines 22-25). Margaret identified a causal effect of the workers dying (i.e. no one would be able to work) (lines 26 and 27), but Billy proposed a remedy for that effect (i.e. to bring in new workers (lines 28-30). Theresa, who seemed to want some closure on the discussion, prompted the group to decide whether the idea of housing the workers was a criterion or a constraint (line 31). David, still holding to his original position said criterion (line 32), Billy agreed (line 33), and Margaret seemed to concede (line 34).

Notice that lines 14 and 15 show the first use of definitions as justification or support for a position when David used the definition of criterion, “something the experts want to do” to support his classification of building two towns to house the workers as a criterion and uses the definition of constraint, “something the experts had to do” to show why his idea should not be classified as a constraint. Lines 22 through 25 show David again using the definitions of criterion and constraint, “you want the workers to not die, but you don’t have to have them not die” to support the classification of his idea as a criterion by showing that the outcome that could result from not housing the workers properly (e.g. death of the workers), was not a limitation.

In fact, this approach of classifying generated ideas as criteria or constraints continued throughout the discussion:

(35) Billy: And also, (looking at David), didn’t the, umm,
(36) like, they didn’t have electricity, they had to wait a
(37) while before they got air powered generator thingys,
(38) they had to put to rivers to the air generators…
(39) David: It’s not really a constraint. Would you
(40) consider it a constraint if…
(41) Billy: If you didn’t have…
(42) David: You had to type a project and your computer
(43) crashes? No, because it’s…you never had to have your
(44) computer crash, but it’s not really a criteria either
(45) because you never really wanted your computer to
(46) crash, so that’s really not either.
(47) Margaret: It’s like a problem…

(47) David: (at the same time) It’s more like a problem
(48) they ran into, and it wasn’t really a criteria or a
(49) constraint.
(50) Margaret: Yeah.
(51) Billy: Alright.

Excerpt 5.5.2: Blue Ridge Discussion of Criteria and Constraints

Here, Billy asked David if the experts not having electricity (which resulted in the experts having to wait for generators to run the drills) was a constraint (lines 35-39). David said the idea posed by Billy was not really a constraint, and he began trying to think of an analogy to support his position (lines 39 and 40). Billy tried to justify his position (line 41), but David thought of an analogy to show that Billy’s idea was not really a constraint. He compared waiting to type a project because of a computer crashing to waiting for generators because of lack of electricity (lines 42 and 43). David used the definitions of criterion and constraint to situate his computer analogy and concluded that the computer analogy and therefore, Billy’s idea were neither constraints nor criteria (lines 43-46). Margaret expressed that Billy’s idea was more like a problem the experts faced (line 47). David, practically at the same time as Margaret, also reached the same conclusion (lines 48-51). Margaret agreed with David (line 52), and Billy seemed to concede (line 53).

Following these discussions, Mr. J came over to the group and showed them the link for the Our Criteria and Constraints template. The criteria and constraints discussed above in addition to others were typed into the template.

5.5.5 Summary Of Results

This episode represents the first time student groups interpreted cases in their small groups using the Case Interpretation Tool. Overall, the Blue Ridge group's performance for interpretation was as predicted for identifying problems, criteria, connecting constraints to outcomes, and identifying design rules of thumb. They identified general and specific problems, specific criteria, general design rules of thumb, and they did not connect constraints to outcomes (a skill the Case Interpretation Tool does not support). In addition, the Blue Ridge group's ability to identify expert solutions was better than we predicted for this episode, as they identified two expert solutions that included detail about how the solution was implemented. Although the group identified general and specific constraints, they seemed to confuse one criterion as a constraint. However, their discussions of criteria and constraints showed that they consistently relied on the definitions of criterion and constraint to classify their ideas as such. We will show later how we think discussion of this topic impacted later capability for this group.

5.6 Episode 5: Using the Case Interpretation Tool: Second Software-Scaffolded Case Activity and Discussing the First Software-Scaffolded Case Activity

This episode presents the second time groups used the Case Interpretation Tool to interpret an expert case. Overall, the Blue Ridge identified expert solutions that included the criteria/constraint the solution was supposed to address as well as some detail about how the solution was implemented. However, the problems, criteria, constraints, and design rules of thumb they identified were general. While the group's discussions were very similar to Episode 4 in that the group continued to classify, support, and refute ideas using the definitions of the classifications in question as justification or evidence, they did not use the expert case to inform their discussions and written work. Instead, they tended to rely mostly on their memories of the Tecolote Tunnel case when generating, supporting, and refuting ideas.

5.6.1 Enactment

Six days after Episode 4, Mr. J. introduced topographic and relief maps. He focused on what each map was useful for and how each map should be read, and he handed out topographic and relief maps that had been used for his previous job. These maps were of actual job sites, and Mr. J. helped the class read and understand the maps, telling them that he wrote geologic reports using those maps, and that they would write geologic reports for their tunnel sections as a culminating activity.

He had previously assigned the reading of both the Tecolote Tunnel and the Mono Craters Tunnel cases as homework for the night before, so students were expected to have already read the assigned expert case. Therefore, during class, he led a discussion to help students begin thinking more about what they should be focusing on as they interpret an expert case. For example, he asked the class if anyone could give a one-sentence summary of each of the cases. For the Tecolote Tunnel case, one student stated, "In California, they had to get water supply, so they built a tunnel to bring the water down. Everything that could've happened did. It caved in, it burned, it flooded…" For the Mono Craters Tunnel case, another student stated, "People [were] trying to build aqueducts—they had to build 400 mile aqueducts through the mountains. They encountered volcanic ash and water. The volcanic ash was good for the tunnel because it holds the tunnel up and it's easier to dig through." Then, students began interpreting either the Tecolote Tunnel case or the Mono Craters Tunnel case in their small groups using the Case Interpretation Tool; the Blue Ridge group interpreted the Tecolote Tunnel case. As groups used the Case Interpretation Tool, Mr. J. went from group to group occasionally answering questions. Students interpreted their second cases for 30 minutes of the 50 minute class period. Following their use of the Case Interpretation Tool, groups used the Library Tool in SMILE to comment on the interpretations of other groups in their class. They commented on things they didn't understand after reading the group's interpretation of the expert case, how an idea might be worded better, and things they the group to elaborate on more in their interpretations.

Following this, Mr. J. facilitated a class discussion that was supposed to pull together the lessons learned across the expert cases they had encountered up to that point. He had small groups go the Pick Tools Page and select the Rule of Thumb Tool, which served as a repository for design rules of thumb for each group, linking back to the artifact where the design rule of thumb was created. As a class, important design rules of thumb were compiled to create a table for the cases that had been interpreted before that day (Tecolote Tunnel and Mono Craters Tunnel cases were excluded from the discussion) as well as the sedimentary rock model lab that the class had been working on. They explored what those design rules of thumb might suggest for their challenge. As Table 5.13 shows, one column identified the lessons(s) learned from each expert case or activity. Another column, described how the lesson could be applied to the *Tunneling Through Georgia* challenge. However, some of the lessons that were articulated were not actually design rules of thumb. Instead, the entries in the Applies to Our Tunnel column seem to be general design rules of thumb, while entries in the Lessons column seem to be partial justifications for the design rules of thumb (i.e., Need to know what sedimentary rocks are at the tunnel site b/c different sedimentary rocks act differently).

Table 5.13 – Table of Expert Cases, Lessons Learned From Expert Cases, and Ideas for Applying to Tunnel Challenge

Source	Lessons	Applies to Our Tunnel
Lotschberg Case	Need to know the materials to be drilled through	Take core samples
	Need food, water, shelter, supplies	Location of nearest city/town
	Explosive cased cave-ins=death	Need to take safety conscious
Sedimentary Rock Models	Sedimentary rock particles fell apart	Some sedimentary rocks are poor tunneling material
	Different sedimentary rocks act differently	Need to know what sedimentary rocks are at the tunnel site
	Rocks change over time	
St. Gotthard Tunnel	Water can flood and destroy the tunnel	Loose sediments cause cave-ins
Hoosac Tunnel	Sandy/silt materials cause cave-ins	Need to correctly locate core samples
Frejus/Mt. Cenis Tunnel	Hit a cold spring	Watch out for water
Queens Midtown Tunnel	Had to filter out air from machine exhaust	Ventilation system
	Concern of dredging destroy	Land elevation necessary to dig
	The top of the tunnel	Tunnel deeper

5.6.2 Predictions

We predicted that there would be variation in group capability as groups used the Case Interpretation Tool to interpret the Tecolote Tunnel and Mono Craters Tunnel cases. However, we thought there would be less variation than we predicted in Episode 4. Because groups had experienced using the Case Interpretation Tool to collaboratively interpret an expert case and because Mr. J. had been prompting them to justify their ideas, we thought they would describe more specific problems and solutions, and include more causality, justification, and implementation details in those descriptions. Also, because of their previous experience using the Case Interpretation Tool, we thought groups would identify more problems and solutions than they had in Episode 4.

Because most groups spent a lot of time discussing criteria and constraints and because groups used the Criteria and Constraints template during Episode 4, we thought groups would use the template again to identify criteria and constraints in the expert cases, and we predicted most groups would identify more specific criteria and constraints in the expert cases, including more justification for choosing those criteria and constraints. Because student groups used the design rule of thumb template during Episode 4, and because students were beginning to justify their ideas without being prompted to do so, we predicted groups would identify design rules of thumb including correct causality and/or justification. Justifying ideas seemed to be becoming more a part of the way students talked about science. Because students were prompted to think about how they might apply design rules of thumb to their challenge during the class discussion and creation of Table 5.13, we expected groups to describe how their design rules of could be applied to the *Tunneling Through Georgia* challenge. However, because the software did not scaffold the connection between the outcomes that occur as a result of addressing or not addressing constraints, we did not think group's ability to connect outcomes to constraints would improve.

5.6.3 Student Work

As the Blue Ridge group used the Case Interpretation Tool, only Margaret had her student book open to the written expert case. She was also the only group member who continuously referred to it during the entire episode. David referred to the expert case during the group's discussion of an expert solution, and Theresa grabbed David's book during that same discussion to find evidence in the case to support her idea. Billy, served as the group's typist, and did not have his student book open during the episode. David, Theresa, and Billy dominated the discussion, while Margaret remained relatively quiet. As in the last use of the Case Interpretation Tool, the required more discussion about criteria and constraints, spending most of their discussion time on this topic.

In this episode, summarized in Table 5.14, the Blue Ridge group identified a problem the experts faced, but did not include causality (Identifies Problems (I)): *A lot of water flooded the tunnel*. For one of the three expert solutions identified (Identifies Solutions (II)), *A lot of water flooded the tunnel, so they diverted the water into two drainage tunnels. This was the fastest and most efficient way to make the water go away from the construction,* they provided a description of a solution that included the benefit the solution was supposed to have or the criteria or constraint the solution was supposed to address, and including some detail about how the solution was implemented for one of the three expert solutions they identified.

The Blue Ridge group also identified a criterion (Understands Criteria (V)) and two constraints (Understands Constraints (VI)). They typed *The builders wanted concrete lining* as a criterion and *The tunnel had to be seven feet in diameter* and *The builders had a budget* as constraints. Though the criterion and one of the constraints (The builders had a budget) were general, the other constraint was actually a criterion, as the experts designed the tunnel to be seven feet in diameter but were not limited to seven feet for the diameter of the tunnel. This group did not identify outcomes that resulted because a constraint was addressed or not addressed (Connects Constraints To Outcomes (VII)), but they did identify two general design rules of thumb (Rule of Thumb (VIII)). They were not able to open the design rules of thumb template, so they generated these design rules of thumb without using the template. Their design rules of thumb were *If there is a high pressure and great quantity of water, divert it with two tunnels* and *If you line the tunnel with concrete and use perforated pipes, you keep water pressure from building up.*

Table 5.14 – Blue Ridge Group's Two Best Answers From Case Interpretation Tool – St. Gotthard Tunnel case

Blue Ridge Group		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	A lot of water flooded the tunnel	2
Identifies Solutions (II)	A lot of water flooded the tunnel, so they diverted the water into two drainage tunnels. This was the fastest and most efficient way to make the water go away from the construction.	4
Specifies Implementation (III)		3
		2
Understands Criteria (V)	The builders wanted concrete.	2
Understands Constraints (VI)	The tunnel had to be seven feet in diameter.	1
	The builders had a budget.	2
Connects Constraints To Outcomes (VII)		1
		1
Rules of Thumb (VIII)	If there is a high pressure and great quantity of water, divert it with two tunnels.	2
	If you line the tunnel with concrete and use perforated pipes, you keep water pressure from building up.	2

Table 5.15 shows the coding results for this episode. Reliability was 98% for this case activity.

Table 5.15 – Blue Ridge Group Case Interpretation 2 Coded Results

	Blue Ridge Group's Coded Results Case Interpretation 2 – Tecolote Tunnel		
Identifies Problems (I)	2		Total – 1
Identifies Solutions (II)	4		Total – 2
Specifies Solution Implementation (III)	3	2	Total – 2

Table 5.15 – Blue Ridge Group Case Interpretation 2 Coded Results (Continued)

Identifies Criteria (V)	2		Total – 1
Identifies Constraints (VI)	1	2	Total – 2
Connects Constraints To Outcomes (VII)	1	1	Total – 2
Rules of Thumb (VIII)	2	2	Total - 2

5.6.4 Group Discussions

The Blue Ridge group's discussions in this episode were very similar to their discussions in Episode 4. Again, their discussions of the expert's goals, problems and solutions, science and technology, and design rules of thumb were what we expected. One group member posed an idea and if there was disagreement, the group discussed the disagreement until intersubjectivity was reached. In certain instances, the expert case was used to settle the disagreement or to elaborate further on a proposed idea; in other instances, disagreements were settled without referring to the Tecolote Tunnel case.

Looking at the group's discussions of criteria and constraints as we did in Episode 4, we find that again, most of the group's discussion time was spent discussing criteria and constraints. However, unlike Episode 4, many of the ideas generated in Episode 5 come from group members' memories instead of the expert case. For example, Theresa began by stating that the tunnel had to be 7 feet in diameter, a constraint she drew from memory. Only Margaret had a student book open, but she was reading the Tecolote case for the first time because she "read the wrong case…I read Mono Craters." As a result, she did not participate as much in group discussions. Because the expert case was not used to support or refute Theresa's idea, her criterion was accepted as a constraint without discussion.

Also, unlike Episode 4, the Blue Ridge group used the Criteria and Constraint template throughout the entire discussion of criteria and constraints in this episode. However, like Episode 4, the discussion of criteria and constraints in this episode continues to focus on using words that implicitly conjure the definition of criterion and constraint to classify ideas. For example, Theresa identified from memory that "they [the experts] wanted the tunnel to be lined in concrete" as a criterion. Although, in this instance, there is no disagreement about Theresa's classification of the idea as a criterion, she does use the term "wanted" to signify that her idea is a criterion:

```
(1)  Billy:  Next, criteria.  What?  They-
(2)  Theresa: Criteria.  It had to be lined in concrete.
(3)  David: Yeah, lining in concrete.
(4)  Billy:  Alright.  Uh…um…who wanted it to be lined in
(5)  concrete?  The builder dudes?
(6)  Theresa:  They thought it would be smoother.
(7)  Billy:  Who's they?
(8)  Theresa:  The builders-
(9)  David:  The builders thought that concrete would be
(10) smoother.  Thus, concrete lining was a criteria.
(11) Theresa:  The builders wanted concrete lining.
```

Excerpt 5.6.1 – Discussion of Criteria

In this excerpt, Billy identified that they were looking for a criterion. He prompted the group for a criterion, and hearing none offered, he began to articulate one (line 1). Theresa's offering of a criterion (the tunnel had to be lined in concrete) cut off Billy (line 2). Despite her use of the word "had," which usually signifies a constraint, David agreed that Theresa's idea was classified correctly (line 3). Billy accepted David's support of Theresa's idea, but wanted to be clear about who wanted the tunnel to be lined in concrete (lines 4 and 5). Theresa seemed think that Billy was asking her to justify her classification of the tunnel being lined in concrete as a criterion, so she offered a justification (they "thought it would be smoother") (line 6). Billy again prompted for clarification of who "they" is (line 7), and Theresa clarified the ambiguity by saying that the builders wanted the concrete lining (line 8). David, looking to establish an understanding and tie everything together stated why the builders wanted concrete lining and established concrete lining as a criterion (lines 9 and 10). Theresa restated her original idea (line 11).

The group continued their discussion of criteria and constraints, using the definitions of criterion and constraint to classify their ideas or to support or refute the ideas of others. For example, Theresa identified that the tunnel had to carry water, and stated that her idea was a constraint, but David disagreed, saying "That's more of a criteria…it didn't HAVE to carry water." Theresa dismissed the idea and suggested that the group move on. David suggested "keeping in budget…that's always a good criteria," but he quickly asked if keeping in budget was more of a constraint. Theresa answered his question by saying, "That's a constraint. Budget is always a constraint."

One interesting aspect of the group's discussion occurred when David asked Mr. J. if they had to draw their criteria and constraints directly from the expert case or if they could "make something that logically we think would be a good criteria?" Mr. J. told him that the criteria and constraints had to come from the passage and that they could infer a little bit on the criteria and constraints, but not a lot. He then said, "I don't want you to spend a whole lot of time on this," and he began reading the criterion and constraints they had listed. He said what they had was good, and he walked away. The interesting aspect of this exchange is that although Mr. J told the group that the criteria and constraints had to come from the expert case, this did not prompt them to use the expert case to insure that their criteria and constraints were correct. Instead, Billy asked the group if there were other criteria and constraints, and Theresa said there were none, so the group moved on to describing the solution the experts chose.

The only time the group referred to the expert case was during their discussion of the Solution Chosen prompt. As the group worked to identify the problems the experts encountered and the solutions they chose to address those problems, David identified that the experts encountered a lot of water in the tunnel. Theresa suggested that to fix that problem, they built a separate tunnel. David disagreed, and he and Theresa went back and forth. As David grabbed his student book to look at the expert case, Theresa did also, and in the end, they were able to collaboratively articulate the solution the experts used to address the problem of water flooding the tunnel:

(1) Theresa: What were some of the problems they

(2) encountered and how did they fix them?

(3) David: OK, they encountered a lot of water in the (4) tunnel.

(5) Theresa: And to fix that they built a separate

(6) tunnel.

(7) David: No, to fix the water, they…

(8) Theresa: Built separate tunnels.

(9) Billy: Wait a minute. The problem is they…

(10) Theresa: A lot of water flooded the tunnel-

(11) David: A lot of water flooded the tunnel, and to

(12) fix it, they-

(13) Theresa: Built two separate-

(14) David: No-

(15) Theresa: tunnels on the side of it to carry water

(16) away.

(17) David: [Reading from the expert case] Holes were

(18) drilled ahead of the tunnel, and concrete grout was

(19) pumped in under high pressure to fill the holes in the

(20) rock so water would not come through.

(21) Theresa: Yeah, but they also, they like, built two

(22) separate tunnels to drain it.

…

(23)David: I thought they built two separate tunnels

(24) and they pumped in concrete grout.

(25) Theresa: No, they [looking at the expert case] built

(26) two separate tunnels to drain the water from the rock

(27) ahead of the main tunnel so it does not flood.

(28) Billy: So they-

(29) David: Diverted the water into two drainage

(30) tunnels.

(31) Theresa: [at same time] Diverted the water into two

(32) drainage tunnels.

(33) David: Diverted the water into two drainage tunnels

(34) which would carry the excess water and then they

(35) [inaudible].)

Excerpt 5.6.2 – Use of Expert Case For Classification of Idea

Here, Theresa prompted the group to identify some of the problems the experts encountered and solutions they used to address those problems (lines 1 and 2). David stated that the experts "encountered a lot of water in the tunnel," (lines 3 and 4) and Theresa noted that to address the water problem, the experts built a separate tunnel (lines 5 and 6). David attempted to disagree and provided a different solution (line 7), but Theresa interrupted him and gave the same solution she gave in lines 5 and 6 (line 8). Billy prompted the group to restate the problem (line 9) and both Theresa and David restated that the problem was that a lot of water flooded the tunnel (lines 10 and 11). As David attempted to provide the solution, Theresa cut him off and restated her idea (line 12). David disagreed (line 13), and Theresa stated that the tunnels were built on the side and used to carry water away (lines 14 and 15). David read an excerpt that said that holes were drilled in the tunnel and grout was pumped in under high pressure to cover the holes in the rock to prevent the water from reentering the tunnel (lines 16-19). Theresa agreed, but stated that the experts also built two separate drains (lines 20 and 21). David, seeing where the difference in their answers was, stated that he thought they built two separate tunnels and pumped in concrete grout (lines 23 and 24), but Theresa looked to the expert case to explain that two separate tunnels were built to drain the water from the rock so it wouldn't flood (lines 25-27). Billy, looking to type an answer into the prompt, prompted the group for what he should type (line 28), and David and Theresa began describing the answer at the same time (lines 29-32). David finished articulating the answer (lines 33 and 34), and Billy typed it in.

5.6.5 Summary Of Results

This episode represents the second time student groups interpreted cases in their small groups using the Case Interpretation Tool. Overall, the Blue Ridge group's performance for interpretation was below what we predicted for this episode. While they identified expert solutions that included the criteria/constraint the solution was supposed to address and some detail about how the solution was implemented, the problems, criteria, constraints, and design rules of thumb they identified were general. The Blue Ridge group also identified fewer expert problems and solutions as well as criteria and constraints during this episode than they did in Episode 4. Although the group's discussion about criteria and constraints continued to focus on using the definitions of criterion and constraint to classify, support or refute ideas generated by the group, the group's identification of a criterion as a constraint continued during this episode. In addition, fewer group members used the expert case in the student book to generate, support, and refute ideas. In fact, only Margaret had the expert case open during the entire episode, but because she was reading the expert case as the others were working, she did not begin contributing to the group's discussion until the Time and Location prompt toward the end of the Case Interpretation Tool. Theresa and David used the expert case in the student book one time to settle a dispute over an idea Theresa presented for a solution the experts chose, and they ended up using the expert case to elaborate on Theresa's idea; however, following that discussion, Theresa and David did not refer to the student book again.

5.7 Episode 6: Using the Case Application Tool

This presents the first time student groups used the Case Application Tool to analyze and apply design rules of thumb gleaned from a previously interpreted expert case. Overall, the Blue Ridge group's ability to apply the Tecolote was better than we predicted for this episode. However, they did not apply the design rules of thumb they identified and articulated during their interpretation of the Tecolote Tunnel case. Instead, they identified, articulated, and analyzed new but relevant design rules of thumb.

5.7.1 Enactment

A week following their second use of the Case Interpretation Tool, groups applied a case that they had previously interpreted. Between these two episodes, they engaged in a rock lab and built and tested a core sample model. The rock lab gave student groups an opportunity to investigate the permeability of rock; it involved placing drops of water on several different rocks and noting either how long it took for the water to seep in (i.e. the range of permeability) or that the water did not seep in at all (i.e. the rock was impermeable).

The core sample modeling activity helped groups understand how core samples are collected, graphed, and used to understand the composition of the ground underneath. In this activity, Mr. J. gave each student group a model rock whose layers were made out of different colors of play-doh. Using a straw as a core sampler, groups took samples out of the model rock and drew the composition of those samples on the board. Mr. J. was able to help students make the connection that the more core samples they took, the more accurate their pictures could be.

Following the core sample modeling activity, groups re-read their previous case interpretations and decided which of those cases they wanted to apply using the Case Application Tool. As student groups worked, Mr. J. went from group to group reminding them to read the hints and examples for each prompt and helping them figure out what the goals, criteria and constraints of their challenge were.

Groups had 10-15 minutes to complete the first two prompts of the Case Application Tool (Table 4.1). Mr. J. encouraged them to spend the remainder of the 50 minute class period filling out the Applying Our Rules of Thumb template (Figure 5.2). Remember, this template was designed to help student groups analyze the applicability of their design rules of thumb by understanding the criteria in the group's challenge that each design rule of thumb might address, describing the potential impact or benefit each design rule of thumb could have on the group's solution in progress, and incorporating applicable design rules of thumb into the group's solution. Mr. J. directed each student group's attention to the example accompanying the Rule(s) of Thumb prompt (Figure 5.3) and told them to be sure to look at the example to understand how to use the template and to understand what information the template was reminding and hinting them for. One group asked if they could use rules of thumb from other cases or from their modeling experiences, and Mr. J. told them that was fine as long as they noted where the design rule of thumb came from.

5.7.2 Predictions

Because this was the first time student groups used the Case Application Tool to apply an expert case to their challenge, we predicted that there would be variation across group application capability. We designed the Case Application Tool to support student groups as they carried out a particular process for both analyzing a design rule of thumb to determine it's applicability for their challenge and incorporating applicable design rules of thumb into their design solution. That process involved several steps:

- Making a connection between a criterion the group would like to address and a problem that a design rule of thumb addresses - The group may have identified using dynamite as a criterion. A design rule of thumb that states: "Take core samples to know the composition of rock that will be tunneled through to ensure the proper use of tools for tunneling" provides a clear connection between the group's criterion (using dynamite—a tool used for tunneling) and the problem this design rule of thumb addresses (using the right tools for tunneling).
- Identifying predictions a design rule of thumb could make for their solution - The design rule of thumb described in the previous bullet suggested that taking core samples would inform which tools should be used for tunneling through different kinds of rock. Applying this design rule of thumb may result in fewer problems related to use of improper tools given a certain kind of rock. Not applying this design rule of thumb may result in an increase in problems related to improper use of tools given a certain kind of rock.
- Deciding whether a design rule of thumb is applicable to the group's challenge based on the previous two bullet points, and
- Exploring ways that the design rule of thumb might be applied - Using the same design rule of thumb described in the first bullet, ways that this design rule of thumb might be applied include taking core samples, not purchasing tools for the tunneling

project until the results of the core samples are known, and taking core samples in places where the composition of rock is not already known.

Because Mr. J described the *Tunneling Through Georgia* challenge to the whole class several times and because a description of the challenge and the different sets of tunnels that needed to be designed was included in the student book, we predicted student groups would provide either a general description of their challenge or specific information about their challenge including the goals of their challenge and details about their challenge like what route they were asked to take. Because this was the first time student groups had considered the criteria and constraints for their challenge, we predicted groups would identify either general criteria and constraints or specific criteria and constraints, but we thought few groups would include justification for choosing those criteria and constraints. Because the Case Application Suite did not prompt groups to describe outcomes that might occur as a result of addressing or failing to address constraints, we did not think their ability to describe those outcomes would improve.

However, we expected groups would attempt to apply design rules of thumb that they had created during the interpretation phase of the case use process. We also thought they would include design rules of thumb not originally created during the interpretation phase because they had been told that was acceptable as long as they noted where those design rules of thumb originated.

Because of the different perspectives and abilities that individuals in the student groups would be bringing to this case activity, we predicted most groups would either (a) connect the design rule of thumb to the wrong criterion and make incorrect predictions about how the design rule of thumb could impact their solution, but still judge the design rule of thumb as being applicable (even though it most likely would not be), (b) connect the design rule of thumb to the correct criterion, but make incorrect predictions about how the design rule of thumb could impact their solution or vice versa, or (c) correctly connect the design rule of thumb to a criterion previously mentioned and provide a correct prediction based on that criterion.

When applying design rules of thumb that the group judged to be applicable to their challenge, we predicted most groups would either (a) fail to explore the ways that the design rule of thumb could be applied, (b) apply the design rule of thumb as a prediction or a justification, but fail to incorporate the design rule of thumb into an actual solution or suggestion for a solution, or (c) make a suggestion for implementing of the design rule of thumb that follows from the criterion the rule of thumb addresses and the predictions the design rule of thumb makes. Because student groups had not experienced applying design rules of thumb in this way up to this point, we did not think most groups would provide justification for those implementation suggestions. Furthermore, we did not think student groups would include justifications during application for other reasons. First, student groups applied lessons learned from the experts since their experiences in the *Digging In* Unit, so we thought their ability to apply them would be a little rusty. Second, the Fall 2002 study data suggested that the application phase of the case use process involved skills that may not be as well developed as the skills needed for the interpretation phase. Therefore, even if groups had recently had the opportunity to apply design rules of thumb to another challenge prior to this activity (which they had not), the difficulty and novelty of applying design rules of thumb in this way may still have caused groups to fail to include justifications for applying a design rule of thumb in a particular way.

Because of the different abilities individual students would bring to this group activity, when finding a match between a criterion and the problem a rule of thumb addresses, we predicted student groups would either (a) find there was not a match between their criteria and the problem a design rule of thumb addresses, (b) find a match between their criteria and the problem a design rule of thumb addresses, but make no prediction about how using (or not using) the design rule of thumb could impact their solution (c) find a match between their criteria and the problem a design rule of thumb addresses, but make an incorrect prediction about how using (or not using) the design rule of thumb could impact their solution, or (d) find a match between their criteria and the problem the design rule of thumb addresses and make a correct prediction about how using (or not using the design rule of thumb could impact their solution. For this episode, the Blue Ridge group applied the Tecolote Tunnel case.

5.7.3 Student Work

As summarized in Table 5.16, the Blue Ridge group seemed to understand their challenge. They provided a specific description of their challenge including specific details when they typed (Understands Challenge (XI)) *Our design goals are 1) to build a tunnel from Kennesaw to McDonough and 2) to go under Atlanta*. The Blue Ridge group also identified general criteria (Understands Criteria (V)), *ventilation systems* and *concrete lining*, and general constraints (Understands Constraints (VI)), *we have to go under the city of Atlanta* and *time to build tunnel*.

They identified two design rules of thumb, neither of which were carried over from the group's interpretation of the Tecolote Tunnel. Despite the fact that the group read their case interpretation for the Tecolote Tunnel case immediately before using the Case Application Tool and despite the Case Interpretation Tool artifact for the Tecolote Tunnel case being available in Browse mode in the left frame, the group did not seem to recognize that they should use the design rules of thumb they created during their interpretation of the Tecolote Tunnel case (Episode 5). Instead, they typed (Rule of Thumb (VIII)) *We should always know what type of rock we are drilling through* and *We should always go under major cities when having to pass them in a tunnel building project. This way, the city is not disturbed*.

When analyzing their design rules of thumb to not only determine whether they were applicable, but to also explore how they might be incorporated into their design solution, the resulting Applying Our Rules of Thumb template was generated:

Rules(s) of Thumb
Use the "Applying Rules of Thumb" chart to figure out which rules of thumb apply to your challenge.

Applying our Rules of Thumb

Rule of Thumb	Criteria addressed by rule of thumb	Predictions the rule of thumb makes	Is the rule of thumb applicable (yes or no)	Ways the rule of thumb applies
We should always know what type of rock we are drilling through.	Our desire to to have a safe environment for our workers and the future people using our tunnel.	This rule of thumb suggests that we should learn about the types of rocks we drill through for an efficiently built and safe tunnel.	Yes	We could use part of our budget to pay people to take core samples so we can know about what we're drilling through.
We should always go under major cities when having to pass them in a tunnel building project. This way, the city is not disturbed.	Our desire to not harm traffic and not have to wreck people's homes to build the tunnel is met by going under the city.	This rule suggests that by being underground can make little to no difference above.	yes	We could use much of our budget to use on equipment for drilling and more things vital to an underground tunnel.

Browse Artifact Main Page 2 of 2

Figure 5.4 Blue Ridge Group's Applying Our Rules of Thumb Template

As the template shows, the Blue Ridge group was able to judge whether their design rules of thumb were applicable (Judges Applicability of Rule of Thumb (IX)), noticing that the first design rule of thumb satisfied a previously mentioned criterion (safety) and then identifying a correct prediction or suggestion that this design rule of thumb could make for their challenge. The second design rule of thumb addressed a criterion not previously mentioned, but the group nonetheless identified a correct prediction or suggestion that the design rule of thumb could make for their challenge.

This group was also able to integrate their design rules of thumb into the beginnings of a challenge solution (Quality of Application of Rule of Thumb (X)). The quality of the integration and application of the first design rule of thumb shows that the group identified a suggestion for implementing the design rule of thumb including justification about why the rule of thumb should be implemented in that way. The suggestion for implementing the design rule of thumb, *We could use part of our budget to pay people to take core samples so we can know about what we're drilling through*, followed directly from the criterion the design rule of thumb addressed and the predictions the design rule of thumb made. The quality of the integration and application of the second design rule of thumb shows that the group was able to identify a suggestion for implementing the design rule of thumb but did not include justification for the implementation. The suggestion for implementing the second design rule of thumb was *We could use much of our budget to use on equipment for drilling and more things vital to an underground tunnel*, and this suggestion for implementation also followed directly from the criterion the design rule of thumb addressed and the predictions the design rule of thumb made. Given the group's ability to judge their design rules of thumb as applicable and given the quality of the integration and application of those design rules of thumb, it follows that the Blue Ridge group was able to find a match between some criterion in their challenge and a problem that these design rules of thumb addressed (Finds A Match Between Criteria And Problem Rule of Thumb Addresses (XII)), and they were able to identify correct predictions or suggestions these design rules of thumb made for their challenge.

Table 5.16 – Blue Ridge Group's Two Best Answers From Case Application Tool – Tecolote Tunnel Case

Blue Ridge Group		
Dimension	Answer(s) Given	Rating(s) Given
Understands Criteria (V)	Ventilation systems	2
	Concrete lining	2
Understands Constraints (VI)	We have to go under the city of Atlanta	2
	Time to build tunnel in	2
Connects Constraints To Outcomes (VII)		1
		1
Rule of Thumb (VIII)	We should always know what type of rock we are drilling through.	2
	We should always go under major cities when having to pass them in a tunnel building project. This way the city is not disturbed.	3
Judges Applicability of Rule of Thumb (IX)		4
		3
Quality of Application of Rule of Thumb (X)		4
		3
Understands the Challenge (XI)		4
Finds a Match Between Criteria and Problem Rule of Thumb Addresses (XII)		4
		4

Table 5.17 summarizes coding results for group performance for Case Application Tool use to apply the Tecolote Tunnel case. Reliability was 97% for this case activity. Margaret was the only student who directly used the expert case in the student book as she referred to the expert case as the group identified the goals of their challenge and their criteria and constraints. However, the expert case was not used during their analysis of their design rules of thumb.

Table 5.17 – Blue Ridge Group Case Application I Coding Results

	Blue Ridge Group's Coded Results Case Application I – Tecolote Tunnel		
Understands Criteria (V)	3	2	Total – 3
Understand Constraints (VI)	2	2	Total - 4
Connects Constraints to Outcomes (VII)	1	1	Total – 4
Rule of Thumb (VIII)	3	2	Total – 2
Judges Applicability of Rule of Thumb (IX)	4	3	Total – 2
Quality of Application of Rule of Thumb (X)	4	3	Total – 2
Understands the Challenge (XI)	4		N/A

5.7.4 Group Discussion

During their use of the Case Application Suite, the Case Application Tool was only used once. As a result, we were unable to compare the group's ability to apply design rules of thumb to their challenge over time. Because our analysis of group performance and capability presented in Chapter 8 only involves comparing student work and group discussions from episodes where groups interpreted expert cases using the Case Interpretation Tool, group discussions were not included for this episode of Case Application Tool use.

5.7.5 Summary Of Results

This episode presented groups' first time applying expert cases to their *Tunneling Through Georgia* challenge using the Case Application Tool. Overall, the Blue Ridge group understood the criteria and constraints that informed their challenge, and they identified and articulated both a general design rules of thumb as well as one that included correct causality or justification. In addition, they were able to judge design rules of them as being applicable to their challenge, and they suggested ways these design rules of thumb could be incorporated into their solution, sometimes justifying that incorporation. They were able to make connections between the criteria in their challenge and the problems the design rules of thumb made, and they were able to figure out how they could actually integrate and apply the design rules of thumb into their design solution, justifying their connections, integrations, and applications along the way.

5.8 Episode 7: Using the Case Interpretation Tool: Third Software-Scaffolded Case Interpretation Activity

Episode 7 presents the third and final time student groups used the Case Interpretation Tool to interpret an expert case. Overall, the Blue Ridge Group identified specific problems that included correct causality as well as solutions that included both the criteria/constraint the solutions were supposed to address and details about how the solutions were implemented in the Chunnel Tunnel case. The group described specific objectives the experts wanted to address, sometimes including justification for identifying a criterion. However, they only identified general constraints and design rules of thumb. Interesting to notice here is that group discussions showed a shift in emphasis. While previously, students had spent their time classifying, supporting, and refuting ideas based on the evidence provided by the definitions of the classifications in question, here they seemed to be analyzing the content of the expert case in a more sophisticated way -- to understand the context of the ideas offered and using that context to support or refute how an idea should be described. We also saw group members beginning to consider that an audience other than the group might read their interpretations and articulating their responses with that consideration in mind.

5.8.1 Enactment

Two and a half weeks after using the Case Application Tool, groups used the Case Interpretation Tool for the third time. Before using the software, this episode began as Mr. J. told the class that they would be interpreting their last case from a set of cases: Simplon Tunnel, Seikan Tunnel, Chunnel Tunnel, and Hudson Tunnel. The Blue Ridge group was assigned the Chunnel Case. Student groups had 15-20 minutes to read the case before using the Case Interpretation Tool.

About 10 minutes after student groups began reading their assigned cases, Mr. J. interrupted the class. Unlike previous interpretation activities, Mr. J. gave instructions about what groups should be focusing on as they interpreted their last expert cases using the Case Interpretation Tool before they began using the software. He said he wanted each group to focus on five themes while they were reading the expert case. For each theme, he prompted the students to identify what they might look for in the expert case to address that theme:

1) Describing technical issues – this involved how the tunnel was constructed and the tools and technology used:

   `Mr. J: Technical issues…how was the tunnel constructed? What am I looking for?`

Student 1: What techniques they used to build the tunnel.

2) Identifying rocks and minerals – this involved associating the physical properties of rocks with the tunnel problems that the experts experienced.

Mr. J: Identify rocks and minerals. Associate their physical properties with the tunnel problems. What are we looking for based on the previous cases you've read?

Student 2: The types of rock—some of the rocks were permeable so they had to force grout through the rocks.

Mr. J: What would be the problem with a permeable rock?

Student 3: It would allow water in.

Student 1: If the rock wasn't very hard, it could cause problems.

3) Identifying geographic problems – this involved understanding the geography of the tunnel site.

> Mr. J: Identify geographic problems. Tunnel depth, faults, and folds.

Student 4: Our tunnel had 9 faults in it.

Mr. J: What's the problem with having faults?

Student 4: [inaudible].

Student 3: The tunnel was built under water so that could cause problems.

Mr. J: What would be a geographic problem associated with tunnel depth?

Student 4: If you take one certain area that's deeper and you go in that area, if you were there, there would be more weight on you, so it might be harder to dig through it.

4) Explaining how problems were resolved – this involved describing the solutions the experts used to address the problems they encountered.

   Mr. J: Explain how problems were resolved.

   Student 4: They ran grout into the faults.

5) Identifying any new questions and hypotheses – this involved identifying learning issues and making new connections between the problems the experts faced, why those problems arose, and what the experts did to address those problems.

Following this class discussion, groups went back to reading their assigned cases, and after reading their cases, each group grabbed a laptop, logged into the software and began working with no prompting from Mr. J. Student groups asked for very little help from Mr. J. as they worked, so he did not walk around providing as much coaching as in previous episodes.

5.8.2 Predictions

Our predictions for group capability using the Case Interpretation Tool were very similar to those described in the previous episode of Case Interpretation Tool use (Episode 5). Because students had grown used to working in their small groups interpreting expert cases using the Case Interpretation tool, and because they had grown used to justifying their ideas during class small group discussions, we predicted groups would describe more specific problems and solutions, including more causality, justification, and implementation details in those descriptions.

Because Mr. J. focused on discussing the difference between criteria and constraints in earlier class discussions, prompting them to justify why or how a criteria or constraint impacted the experts choosing a particular solution, we expected most groups to identify specific criteria and constraints in the expert cases, and include more justification of those criteria and constraints. Again, because the software did not explicitly support describing outcomes connected to constraints and because Mr. J. had not explicitly modeled or prompted the class to describe those outcomes, we did not expect an improvement in groups' ability to do this. However, because groups had previous experience using the Rule of Thumb template and because of their tendency to justify their ideas without being prompted to do so during small group work and whole class discussions, we thought groups would identify design rules of thumb that included correct causality and/or justification.

5.8.3 Student Work

As the Blue Ridge group used the Case Interpretation Tool for the third time, Margaret, Billy, and David used the expert case in their student books throughout this episode, looking back to it while they worked. Theresa referred to the expert case only occasionally during this episode. No one group member dominated the discussion. Although at times Theresa and Billy appeared to be disengaged from the conversation, they would always jump right into the discussion offering up ideas or asking questions related to the current discussion. Unlike their previous uses of the Case Interpretation Tool, this time the group spent most of their discussion time understanding the problems the experts faced and the solutions they used to address those problems.

As summarized in Table 5.18, the Blue Ridge group identified one expert problem, describing a specific aspect of a problem and including correct causality: *Construction stopped in 1971 due to money problems*, and one expert general expert problem that did not include causality, *Fissures were found*. The expert solutions the group identified included some detail about the benefit the solutions were supposed to have or the criteria or constraint the solutions were supposed to address as well as some detail about how the solutions were implemented. They typed *When fissures were found small holes were dug out and filled with sodium silicite grout* and *In 1986, a modernized tunnel plan was introduced and construction began although it was funded by a private corporation*. Using the Criteria and Constraints template, the group identified criteria, one specific, *The special train cars that helped passengers escape*, and the other also including justification for choosing the criterion, *The service tunnel that is used for ventilation and escape from disasters such as fires*. One constraint identified was specific, *Had to stay in the non-perforated chalk marl*, and the other one, *budget*, was general. As in previous uses of the Case Interpretation Tool (Episodes 4 and 5), this group identified a constraint that was actually a criterion when they typed *Couldn't allow water in*. The Blue Ridge group did not describe outcomes that might occur as a result of the experts addressing or failing to address constraints. However, they did use the Rule of Thumb template to articulate one general design rule of thumb, *When tunneling under the water, use rotating cutters to cut through the soft rock because round holes in soft rock*. Although the group did attempt to include justification in their design rule of thumb, it was not clear what was meant by "round holes in soft rock," so the rule of thumb was judged to be general

Table 5.18 – Blue Ridge Group's Two Best Answers From Case Interpretation Tool – Chunnel Tunnel Case

Blue Ridge Group		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Fissures were found.	2
	Construction stopped in 1971 due to money problems.	4
Identifies Solutions (II)	When fissures were found small holes were dug out and filled with sodium silicite grout.	4
	In 1986 a modernized tunnel plan was introduced and construction began although it was funded by a private corporation.	4
Specifies Implementation (III)		1
		2
Understands Criteria (V)	The service tunnel that is used for ventilation and escape from disasters such as fires	4
	The special train cars that helped passengers escape	3
Understands Constraints (VI)	Had to stay in the non-perforated chalk marl	2
	Budget	2
Connects Constraints To Outcomes (VII)		1
		1
Rules of Thumb (VIII)	When tunneling under the water, use rotating cutters to cut through soft rock because round holes in soft rock.	2

Table 5.19 shows the coding results for the group's ability to interpret the Chunnel Tunnel case using the Case Interpretation Tool. Reliability for this episode was 98%.

Table 5.19 – Blue Ridge Group Case Interpretation 3 Coding Results

	Blue Ridge Group's Coded Results Case Interpretation 3

	– Chunnel Tunnel		
Identifies Problems (I)	4	2	Total – 3
Identifies Solutions (II)	4	4	Total – 3
Specifies Solution Implementation (III)	1	2	Total – 3
Identifies Criteria (V)	4	3	Total – 2
Identifies Constraints (VI)	2	2	Total – 3
Connects Constraints To Outcomes (VII)	1	1	Total – 3
Rules of Thumb (VIII)	2		Total - 1

5.8.4 Group Discussions

To provide context for the written answers given by the Blue Ridge group for this episode, we turn to the transcribed group discussions as the group collaboratively interpreted the Chunnel Tunnel case. Similar to their previous use of the Case Interpretation Tool (Episode 5), the group's discussions about the expert's goal, solution chosen, time and location, solution implementation, science and technology, vocabulary and design rules of thumb was what we expected. As in previous interpretation episodes, a group member would present an idea and if the group agreed, there would be little discussion and the idea would be entered into the prompt, but if there were disagreement about an idea, the group would discuss the idea in an effort to reach intersubjectivity.

Again, this group spent most of their time discussing criteria and constraints. However, instead of using the definitions of criterion and constraint to classify, support, or refute the ideas generated, the group's discussion of criteria and constraints seemed to focus more on the content of the criteria and constraints. The group spent more time discussing the context surrounding the rise of a criterion or constraint, and they used the expert case more to support how the criterion or constraint should be described. For example, when using the Criteria and Constraints template to identify and understand two different criteria (lining in concrete and service tunnel), the group discussed the criteria and constraints by discussing the content of the expert case regarding those criteria. Notice that the group does not try to classify the ideas as criteria or constraints, but instead, they use of the content of the case to better understand and articulate the criteria and constraints:

(1) David: OK. Criteria. List each small goal. Can you
(2) please sit down? It's very annoying.
(3) Theresa: I have to pace.
(4) David: Mm-k.
(5) Theresa: Criteria!
(6) David: O…k…um…Criteria. Vent-no wait. No, that
(7) wasn't a criteria. That was something that couldn't
(8) be done.
(9) Theresa: Um…Criteria. Lining in concrete. Is that a
(10) criteria?
(11) David: Yeah, be-
(12) Billy: Well, except for where it was permeable, and
(13) then they were gonna line it in steel. Iron.
(14) Theresa: No, it wasn't permeable. Like, that's-
(15) Billy: No, the chalk. Near France-
(16) Theresa: The chalk was a mixture of chalk and clay.

Billy: Yeah, but the other chalk. The permeable chalk. Near France.

Theresa: I don’t remember anything about permeable chalk.

David: I do.

Billy: [Reading] They dug up through the permeable chalk with the fractures and so they lined that part with steel.

David: Right.

Billy: Yeah. [to Theresa] You see?

Theresa: I skipped a paragraph.

Billy: Well…Theresa: Um, also, the service tunnel was a criteria.

David: Tell me what they did. [inaudible] to pick out what they didn’t have to do. Ummm…

Theresa: Alright, so-

David: A service tunnel! That was a-

Theresa: That’s what I just said.

Billy: Whoa! That was, like, two minutes ago.

David: A service tun-they’re not gonna know what that is. So should we just give a short description?

Billy: Service tunnel.

Theresa: [at same time] There was a service tunnel connecting two tunnels. Service.

David: That’s not what it was used for. That was

Billy: A service tunnel is kind of, like, self

(43) explanatory. Yeah, just look at the name. Service
(44) tunnel-
(45) David: That was used for ventilation purposes.
(46) Theresa: No, it was used for, like, fires. It was
(47) also used for escaping.
(48) David: Let me see…Yeah.

Excerpt 5.8.1 – Discussion of Criteria

Here, the group was trying to identify criteria and constraints in the expert case. David, having read the criteria and constraints template, repeated what the hint for the criteria column said ("List each small goal") (line 1). After an exchange between Theresa and David regarding Theresa's pacing around the group (lines 2-4), Theresa brought the group back on task by announcing that they were looking for criteria (line 5). As David was reading the case to identify criteria, he came across a possible criterion, but ruled it out because the experts didn't actually implement it (lines 6-8). Theresa repeated the task to herself and thought of a criterion ("Lining [the tunnel] in concrete"), but immediately asked the group if they agreed (lines 9 and 10). Billy agreed that Theresa's idea was a criterion and attempted to justify why it should be a criterion (line 11). However, he remembered that the entire tunnel was not lined in concrete. Instead, places where the rock was permeable would be lined in either steel or iron (lines 12 and 13). Theresa disagreed with Billy stating that there was no permeable rock (line 14), but Billy stated that there was chalk near France (line 15). Theresa corrected Billy, telling him that the chalk was actually a mixture of chalk and clay (line 16), but Billy insisted that he was talking about permeable chalk near France, not the mixture of chalk and clay (lines 17 and 18).

Theresa said that she didn't remember anything about permeable chalk (line 19), but David did remember (line 20). When Billy located the passage in the expert case that talked about the permeable chalk and the steel that was used to line the tunnel in those places, and he read it out loud to support his claim that there was an exception to Theresa's original idea that the tunnel was only lined in concrete (lines 22-24). David supported what Billy read (line 25), and Billy asked Theresa if she found that passage in the expert case as well (line 26). Theresa replied that she didn't see it originally because she skipped that paragraph while reading the expert case (line 27).

Theresa generated another criterion, that the experts wanted a service tunnel (line 29). David asked Theresa to only mention things that the experts actually did as criteria and not things that they wanted to do but did not do (lines 30 and 31). Theresa suggested that she would honor David's request (line 32), but David immediately identified the same idea Theresa identified as a criterion ("A service tunnel!") (line 33). Theresa and Billy expressed surprise that David had just identified an idea that was not only already identified, but shot down by him (lines 34 and 35). David expressed concern that others reading their interpretation in the future may not understand what a service tunnel was and he asked the group if they should include a description of what a service tunnel is in their response (lines 36 and 37). Theresa mentioned where the service tunnel was located (lines 38 and 39), but David wanted to include what the service tunnel was used for in their description (line 41). Billy suggested that the name service tunnel suggested its use (lines 42-44), but David continued with his description, noting that the service tunnel was used for ventilation purposes (line 45). Theresa suggested that it was not used for ventilation purposes, but as a means of escape from fires (lines 46 and 47), and after checking the case to make sure, David agreed with Theresa (line 48).

5.8.5 Summary of Results

Overall, the Blue Ridge group's interpretation performance for the Chunnel Tunnel case was better for this episode than for Episode 5. The Blue Ridge Group identified specific problems that included correct causality, and they also identified solutions that included both the criteria/constraint the solutions were supposed to address and details about how the solutions were implemented. The group described specific objectives the experts wanted to address, sometimes including justification for identifying a criterion. While we expected groups to identify more specific constraints and to include justification in the design rules of thumb they articulated, the Blue Ridge group only identified general constraints and design rules of thumb.

In addition, we see two interesting phenomena. First, the group's discussion about criteria and constraints moves from classifying ideas based on the definitions of criterion and constraint to using the content of the expert case to understand the context of the criteria and constraints to support or refute how the criteria and/or constraints should be described. Second, a group member, David, begins to consider how an audience outside of the group might read and understand the group's interpretation, and the group articulates their response based on that consideration. In Chapter 8, we will look at how these phenomena may have impacted the Blue Ridge's development. But before we do that, we will turn our attention to describing how well members of the Blue Ridge group interpreted and applied expert cases in the absence of the Case Application Suite's system of scaffolds.

5.9 Summary

This chapter presented first of three case studies presenting the Blue Ridge group and designed to describe episodes of case use skill development during and following the *Digging In* Unit and during the *Tunneling Through Georgia* Unit. For each episode, we described Mr. J's emphasis on case use skills, our predictions for case use capability for that episode, coding results for group or individual performance of case use skills, and excerpts of group discussions that provide context for coding results.

While we predicted that the development of case use skills would increase over time for groups, coding results reveal there was variation across case use capability over time for the Blue Ridge group. There were four episodes of Case Application Suite Use: three episodes when the Blue Ridge group used the Case Interpretation Tool to interpret expert cases (Episodes 4, 5, and 7), and one episode when the group used the Case Application Tool to apply the Tecolote Tunnel case to their challenge (Episode 6). As a group, interpretation performance declined across their first and second episodes of Case Interpretation Tool use (Episodes 4 and 5). However, across their second and third episodes of Case Interpretation Tool use, interpretation performance improved.

In addition, there were two major changes in the group's discussions over time. First, the Blue Ridge group went from using the definitions of criterion and constraint to classify ideas as such or to support or refute the classification of an idea to using the content of the expert case to provide context for how the idea should be articulated. Second, this group began considering that an audience other than themselves might read or use their interpretation in the future, and they began to focus some of their discussion on what that audience might not understand and how their responses should be articulated to help that audience understand. In Chapter 8, we will look at how these changes in the group's discussions influenced group performance and interpretation capability; for now, we will look at Case Studies 2 and 3 for the Ridge and Valley and Coastal Plain groups, respectively.

CHAPTER 6

CASE STUDIES 2 AND 3: GROUP CASE USE SKILL ENACTMENT AND DEVELOPMENT FOR THE RIDGE AND VALLEY GROUP AND THE COASTAL PLAIN GROUP

6.1 Description of Target Group(s) /Target Students

6.1.1 Ridge and Valley Group – 6th Period

The Ridge and Valley group was made up of four students: Kenny, Sam, Michelle, and Daniel. This group worked together on the *Tunneling Through Georgia* Unit and was responsible for designing a tunnel that would run from Ringold to Dalton. They interpreted three (3) cases using the Case Interpretation Tool (Queens Midtown, Mono Craters, and Simplon Tunnel) and applied one case using the Case Application Tool (Mono Craters). Brief descriptions of these cases can be found in Chapter 3.

Kenny was judged by Mr. J. to be developing appropriately in the areas of science and society, history of science, and science content. He demonstrated excellence in the area of behavior and attitude, while unifying themes and technology were areas of concern. Kenny's homework and test grades were A and F, respectively.

Mr. J judged Daniel to be developing appropriately in the areas of unifying themes, and science content. He demonstrated excellence in all other areas. Daniel's homework and test grades were A and B, respectively.

Sam was a student who was judged by Mr. J. to be one who was developing appropriately in the areas of science inquiry, unifying themes, science and society, and science content. He demonstrated excellence in all other areas, and his homework and test grades were A and B, respectively.

Michelle was judged by Mr. J. to be one who was developing appropriately in the areas of science inquiry, unifying themes (i.e. critical thinking), and science content. She was judged as a student who demonstrated excellence all other areas. Her homework and test grades were A and B, respectively. Based on Mr. J.'s judgment of the members of the Ridge and Valley group based on performance in the areas described above, Sam, Kenny and Michelle would be considered typical students while Daniel would be considered an exemplary student. However, based on homework and test letter grades for each student, Kenny might be considered below average.

6.1.2 Coastal Plain Group – 6th Period

The Coastal Plain group was also made up of four students: Chris, Sandy, Melissa, and Chad. As this group worked together on the *Tunneling Through Georgia* Unit, they were responsible for designing a tunnel that would run from Baxley to Jessup. The Coastal Plain group also interpreted three (3) cases using the Case Interpretation Tool (Frejus/Mt. Cenis, Tecolote and Hudson) and applied one case using the Case Application Tool (Tecolote).

Sandy was judged by Mr. J. to be developing appropriately in all areas. Her homework and test grades were C and C, respectively.

Mr. J. judged Chris to be developing appropriately in the areas of behavior and attitude, science inquiry, unifying themes, technology, and science content. He demonstrated excellence in the areas of science and society, and history of science. His homework and test grades were B and B, respectively.

Mr. J judged Melissa to be developing appropriately in the areas of behavior and attitude, science inquiry, science and society, and science content. She demonstrated excellence in all other areas. Her homework and test grades were C and B, respectively.

Chad was judged by Mr. J. to be developing appropriately in the areas of behavior and attitude, science inquiry, unifying themes, history of science, and science content. He was judged as a student who demonstrated excellence in the area of technology, while science and society was judged as an area of concern for Chad. His homework and test grades were F and F, respectively. Based on Mr. J.'s judgment of the members of the Coastal Plain group based on performance in the areas described above, all of the members of this group would be considered typical students. However, based on homework and test letter grades for each student, Chad would be considered below average.

Like the Blue Ridge Group, the Ridge And Valley and Coastal Plain groups had their first encounters with expert cases while engaging in the Erosion Challenge but did not begin working together until they began the Tunneling unit.

6.2 Episode 1: Introduction To Case Application Skills – Landslide and Dust Bowl Cases

6.2.1 Enactment and Predictions

The emphasis and expectations for this episode were the same as those described in Episode 1 in Case Study 1. Mr. J. introduced interpretation and the beginning of application skills to the class, helping them began to think about how the expert case might be useful in guiding the modeling of erosion in stream tables. He also organized this introduction to interpretation skills around the prompts in the My Case Summary Design Diary page. Students answered his questions about the My Case Summary Design Diary page's prompts in the same ways that they did in Case Study 1.

Mr. J. also assigned two groups to read the Dust Bowl case and two groups to read the Landslide case, and he told them that each group would teach the class about the case that they read. As in Case Study 1, as groups began reading their cases and filling out their individual My Case Summary Design Diary pages, Mr. J told them to let him know if they had any questions or ran across words they didn't understand.

6.2.2 Student Work

Inter-rater reliability for this episode was the same as it was in Episode 1 for Case Study 1, 99%.

<u>6.2.2.1 Ridge And Valley Group</u>

Every member of the Ridge and Valley group completed My Case Summary Design Diary pages for the Dust Bowl and/or Landslide cases. Table 6.1 shows how we coded the two best answers each student gave for each dimension. As in Case Study 1, coding results for each episode will be presented using tables that show the two best answers given for each dimension and the ratings that those two best answers received as well as tables that summarize individual and/or group performance for student work per episode.

As summarized in Table 6.1, Kenny identified many problems, some including correct causality. For example, when identifying problems the experts faced in the Landslide case (Identifies Problems (I)), Kenny wrote: *Shaking causes landslides* and

Water caused landslides, spreads out soil on hills. He also identified expert solutions that described the benefits the solutions were supposed to have or the criteria/constraints the solutions were supposed to address. When identifying solutions the experts considered in the Landslide case (Identifies Solutions (II)), Kenny wrote: *Dewatering, but didn't always work because not all landslides are caused by rain* and *Not to build houses in bad places where landslides were most likely to happen*. Kenny did not identify any criteria (Understands Criteria (V)) or constraints (Understands Constraints (VI)) for this case, and he did not describe outcomes that occurred as a result of addressing or failing to address constraints (Connects Constraints to Outcomes (VII)). However, Kenny identified one design rule of thumb that included correct causality and/or justification, *Trees help anchor soil,* and one general design rule of thumb, *Bare hill would be bad.*

Table 6.1 – Kenny's Two Best Answers From My Case Summary Design Diary Page – Landslide Case

Kenny		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Shaking causes landslides.	4
	Water caused landslides, spreads out soil on hills.	4
Identifies Solutions (II)	Dewatering, but didn't always work because not all landslides are caused by rain.	3
	Not to build houses in bad places where landslides were most likely to happen.	3
Specifies Implementation (III)		N/A
		N/A

Table 6.1 – Kenny's Two Best Answers From My Case Summary Design Diary Page – Landslide Case (Continued)

Connects Problems and Solutions To Apply To Challenge (IV)		2
		1
Understands Criteria (V)		1
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	Trees help anchor soil.	3
	Bare hill would be bad.	2

Table 6.2 shows which parts of Daniel's page were analyzed as data. As summarized in the table, Daniel seemed to be able to read the Landslide case for understanding, identifying the important aspects of the case. He identified expert problems (Identifies Problems (I)), one that described a specific aspect of an expert problem, *How to make construction workers to not build houses on mountainsides or near the ocean waters because of landslides*, and another that included correct causality, *The law does not restrict house construction, so houses were built on hilly lands anyway*. Daniel also identified expert solutions. One expert solution he identified was general, *One other solution is an underground water drainage system,* while the other provided a description of a solution that included the benefit it was supposed to have or the criteria/constraint it was supposed to address (Identifies Solutions (II)), *Landslides can be prevented by building retaining walls, which divert the landslide from crushing a house. However, some landslides are too big and powerful to be prevented by walls*. Daniel did not explicitly connect the expert problems he identified with the expert solutions he identified (Connects Problems and Solutions To Apply To The Challenge (IV)). As a result, it was not clear which solutions addressed which problems. He identified one

general criterion for this case (Understands Criteria (V)), *Safety*, and one specific constraint that described what the constraint affected and included justification for choosing the constraint (Understands Constraints (VI)), *However, some landslides are too big and powerful to be prevented by walls.* Daniel also described outcomes that occurred as a result of addressing that constraint (Connects Constraints to Outcomes (VII)). He identified two design rules of thumb that included causality and/or justification as well as suggestions for ways the design rules of thumb could be applied to his challenge (Rule of Thumb (VIII)). Daniel wrote *On the basketball court, to make it safe, you have to prevent it from erosion. You could do this by planting trees on the hill so that it can slow down landslides or erosion* and *You could also build a wall around the court to prevent erosion.*

Table 6.2 – Daniel's Two Best Answers From My Case Summary Design Diary Page – Landslide Case

Daniel		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	How to make construction workers to not build houses on mountainsides or near the ocean waters because of landslides	3
	The law does not restrict house construction, so houses were built on hilly lands anyway.	4
Identifies Solutions (II)	Landslides can be prevented by building retaining walls, which divert the landslide from crushing a house. However, some landslides are too big and powerful to be prevented by walls.	3
	One other solution is an underground water drainage system.	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		1
		1
Understands Criteria (V)	Safety	2

Table 6.2 – Daniel's Two Best Answers From My Case Summary Design Diary Page – Landslide Case (Continued)

Understands Constraints (VI)	However, some landslides are too big and powerful to be prevented by walls.	4
		1
Connects Constraints To Outcomes (VII)		2
Rules of Thumb (VIII)	On the basketball court, to make it safe, you have to prevent it from erosion. You could do this by planting trees on the hill, so that it can slow down landslides or erosion.	4
	You could also build a wall around the court to prevent erosion.	4

As summarized in Table 6.3, Sam identified specific problems that the experts faced in the Landslide case: *When many people built houses on cliffs, they had no idea of landslides* and *There was also no restriction to building houses in these areas where landslides happen frequently.* Sam identified expert solutions (Identifies Solutions (II)), one that described the benefits the solution was supposed to have or the criteria/constraints the solution was supposed to address: *Landslides were managed by retaining walls which divert the landslide from crushing your house*. The other was a general solution: *Another solution is an underground water drainage system*. Sam identified one general criterion (Understands Criteria (V)), *Reliability*, and two constraints (Understands Constraints (VI)). One constraint, *Most slides are too big to be prevented by walls*, described a specific constraint and what the constraint affected. The other constraint, *Expensive*, was a general one. Sam also described an outcome that could occur as a result of addressing or not addressing the first constraint (Connects Constraints to Outcomes (VII)). He identified design rules of thumb that included correct causality and/or justification as well as suggestions for ways they could be applied. He wrote

Make sure that the hill next to the basketball court has trees because trees help prevent erosion and *If there aren't any trees, build a wall to protect the court from landslides*.

Table 6.3 – Sam's Two Best Answers From My Case Summary Design Diary Page – Landslide Case

Sam		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	When many people built houses on cliffs, they had no idea of landslides.	3
	There was also no restriction to building houses in these areas where landslides happen frequently.	3
Identifies Solutions (II)	Landslides were managed by retaining walls which divert the landslide from crushing your house.	3
	Another solution is an underground water drainage system.	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		1
		1
Understands Criteria (V)	Reliability	2
Understands Constraints (VI)	Most slides are too big to be prevented by walls.	3
	Expensive	2
Connects Constraints To Outcomes (VII)		2
		1
Rules of Thumb (VIII)	Make sure that the hill next to the basketball court has trees because trees help prevent erosion.	4
	If there aren't any trees, build a wall to protect the court from landslides.	4

Table 6.4 shows which parts of Michelle's page were analyzed as data. As summarized in the table, Michelle seemed to be able to read the Dust Bowl case for understanding, identifying the important aspects of the case. She identified expert problems (Identifies Problems (I)) that included causality and/or justification. She wrote

Farmers plowed in straight lines forming ditches for water to carry away soil and *When the soil we exposed to the sun, it dried up*. Michelle also identified a general expert solution (Identifies Solutions (II)), *New methods for farming and plowing*. She explicitly connected the expert problem she identified with the expert solution she identified (Connects Problems and Solutions To Apply To The Challenge (IV)). Michelle did not identify criteria (Understands Criteria (V)) or constraints (Understands Constraints (VI)) for the Dust Bowl case, and she did not describe outcomes that resulted by a constraint being addressed or not addressed (Connects Constraints to Outcomes (VII)). Michelle identified two general design rules of thumb, *Plant trees at base of hill, between hill and court* and *Place a ditch at base or other part of hill which would empty under the soil slowly.*

Table 6.4 – Michelle's Two Best Answers From My Case Summary Design Diary Page – Landslide Case

Michelle		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Farmers plowed in straight lines forming ditches for water to carry away soil.	4
	When the soil was exposed to the sun, it dried up.	4
Identifies Solutions (II)	New methods for farming and plowing.	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		2
Understands Criteria (V)		1
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1

Table 6.4 – Michelle's Two Best Answers From My Case Summary Design Diary Page – Landslide Case (Continued)

Rules of Thumb (VIII)	Plan trees at base of hill, between hill and court.	2
	Place a ditch at base or other part of hill which would empty under the soil slowly.	2

Table 6.5 summarizes performance for Kenny, Daniel, Sam, and Michelle for their first use of the My Case Summary Design Diary page for the Dust Bowl and Landslide cases.

Table 6.5 – Coding Results for My Case Summary Design Diary Pages – Dust Bowl and Landslide Cases

	Kenny's Coded Results			Daniel's Coded Results		
Identifies Problems (I)	4	4	Total - 6	4	3	Total – 3
Identifies Solutions (II)	3	3	Total – 5	3	2	Total – 2
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2	1	Total – 6	1	1	Total – 2
Identifies Criteria (V)	1		Total – 0	2		Total – 1
Identifies Constraints (VI)	1		Total – 0	1		Total – 0
Connects Constraints To Outcomes (VII)	1		Total – 1	1		Total – 1
Design rules of Thumb (VIII)	3	2	Total - 2	4	4	Total - 2
	Sam's Coded Results			**Michelle's Coded Results**		
Identifies Problems (I)	3	3	Total - 2	4	4	Total – 7
Identifies Solutions (II)	3	2	Total – 2	2		Total – 1
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	1	1	Total – 2	2	1	Total – 7
Identifies Criteria (V)	2		Total – 1	1		Total – 0
Identifies Constraints (VI)	3	2	Total – 2	1		Total – 0
Connects Constraints To Outcomes (VII)	2	1	Total – 2	1		Total – 1
Design rules of Thumb (VIII)	4	4	Total - 4	2	2	Total - 2

6.2.2.3 Plain Group

Only two members of the Coastal Plain group completed My Case Summary Design Diary Pages for the Dust Bowl and/or Landslide cases: Melissa and Chad. Table 6.8 shows how we coded the two best answers each student gave for each dimension.

As summarized in Table 6.6, Melissa identified many general expert problems in the Dust Bowl Case (Identifies Problems (I)), Melissa wrote: *Plants died* and *Rabbits at the only crops.* She also identified general expert solutions (Identifies Solutions (II)): *Different way to plow* and *Everyone captured the rabbits and killed them.* She connected expert problems to the solutions used to address those problems. However, Melissa did not identify any criteria (Understands Criteria (V)) or constraints (Understands Constraints (VI)) for this case, and she did not describe outcomes that occurred as a result of addressing or not addressing constraints (Connects Constraints to Outcomes (VII)). She also did not identify any design rules of thumb.

Table 6.6 – Melissa's Two Best Answers From My Case Summary Design Diary Page – Dust Bowl Case

Melissa		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Plants died.	2
	Rabbits ate the only crops.	2
Identifies Solutions (II)	Different way to plow	2
	Everyone captured the rabbits and killed them.	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		2
		2
Understands Criteria (V)		1
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1

Table 6.6 – Melissa's Two Best Answers From My Case Summary Design Diary Page – Dust Bowl Case (Continued)

Rules of Thumb (VIII)		1

Table 6.7 shows which parts of Chad's page were analyzed as data. As summarized in the table, Chad seemed to be able to read the Landslide case for understanding, identifying the important aspects of the case. He identified general expert problems (Identifies Problems (I)): *How to stop landslides that don't use water* and *How to make houses safe*. Chad was also able to identify expert solutions. One expert solution provided a description of a solution that included the benefit it was supposed to have or the criteria/constraint it was supposed to address as well as some detail about how the solution was implemented (Identifies Solutions (II)): *The way people stopped water from causing landslides was to put canals underground. to dewater loose ground.* The other expert solution identified was general: *Not to build houses around dangerous areas*. Chad explicitly connected one expert problem he identified with one expert solution (Connects Problems and Solutions To Apply To The Challenge (IV)). He identified criteria that described objectives the experts wanted to address (Understands Criteria (V)): *How to make houses safe* and *How to find out why the landslides happened and where they do*. Chad did not identify constraints for this case, nor did he describe outcomes that resulted by a constraint being addressed or not addressed (Connects Constraints to Outcomes (VII)). However, he identified two design rules of thumb, one that included causality and/or justification (Rule of Thumb (VIII)), *We should grow more trees to anchor the loose ground,* and one that was general, *We should also make the walls bigger, thicker, and longer.*

Table 6.7 – Chad's Two Best Answers From My Case Summary Design Diary Page – Landslide Case

Chad		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	How to stop landslides that don't use water	2
	How to make houses safe	2
Identifies Solutions (II)	The way people stopped water from causing landslides was to put canals underground to dewater the loose ground.	4
	Not to build houses around dangerous areas	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		4
		1
Understands Criteria (V)	How to make houses safe	3
	How to find out why the landslides happened and what they do	3
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	We should grow more trees to anchor the loose ground.	3
	We should also make the walls bigger, thicker, and longer.	2

Table 6.8 shows overall performance for Melissa and Chad for their first individual use of the My Case Summary Design Diary page.

Table 6.8 – Coding Results for My Case Summary Design Diary Pages – Dust Bowl and Landslide Cases

	Melissa's Coded Results			Chad's Coded Results		
Identifies Problems (I)	2	2	Total - 9	2	2	Total – 3
Identifies Solutions (II)	2	2	Total – 4	4	2	Total – 5
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2	2	Total – 9	4	1	Total – 5
Identifies Criteria (V)	1		Total – 0	3	3	Total – 3
Identifies Constraints (VI)	1		Total – 0	1		Total – 0
Connects Constraints To Outcomes (VII)	1		Total – 1	1		Total – 1

Table 6.8 – Coding Results for My Case Summary Design Diary Pages – Dust Bowl and Landslide Cases (Continued)

Design rules of Thumb (VIII)	1		Total – 0	2	2	Total - 2

6.2.3 Summary of Results

Table 6.8 shows that overall, most members of the Ridge and Valley and the Coastal Plain groups were able to interpret and begin to apply the Dust Bowl and Landslide cases, though they did so with varying degrees of sophistication. Michelle's ability to interpret and attempt to apply the Dust Bowl case was as we predicted. She identified general solutions as well as general design rules of thumb. Michelle also identified specific problems the experts faced that also included correct causality, which was better than we expected. Sam's interpretation and application performance for the Landslide case was also as we expected, as he identified specific problems the experts faced, solutions that included the criteria or constraint the solution was supposed to address, and general criteria and constraints. He also identified design rules of thumb that included justification and made suggestions for ways they could be applied to the Erosion Challenge, which was better than we expected for this episode.

Overall, Daniel's ability to interpret and attempt to apply the Landslide case was better than we expected, as he identified both specific expert problems as well as specific problems the experts faced that also included correct causality. He also identified a specific solution that included the criteria or constraint the solution was supposed to address as well as design rules of thumb that included justification and made suggestions about how they could be applied to the Erosion Challenge. Kenny's interpretation and application performance for the Landslide case was overall as we predicted for this episode. While Kenny identified problems the experts faced that also included correct causality, he identified specific solutions that included the criteria or constraint the solutions were supposed to address. He also identified design rules of thumb that included correct causality or justification.

Coding results reveal that Melissa's performance for the Dust Bowl case was as we expected. She identified general problems the experts faced as well as general solutions the experts used to address those problems. However, Melissa did not identify criteria, constraints, or design rules of thumb. Chad's ability to interpret and apply the Landslide case was overall as we expected for this episode. He identified general expert problems, specific criteria, and both general design rules of thumb as well as design rules of thumb that included correct causality. In addition, Chad identified an expert solution whose description not only included the criteria or constraint it was supposed to address, but that also included some detail about how the solution was implemented. This was better than we predicted for this episode. As we saw with the Blue Ridge group, this variation across individuals will continue as individuals continue to use case use skills.

6.3 Episode 2: Learning from the Dust Bowl and Landslide Cases

Episode 2's purpose was to review how to interpret expert cases and to go over the interpretations students had attempted of the Dust Bowl and Landslide cases to identify their important aspects and usefulness and make causal connections between their parts as a class. During this episode, Mr. J. and the class collaboratively discussed and wrote on the whiteboarded the facts, ideas, and learning issues gleaned from the expert cases.

6.3.1 Enactment, Predictions, and Student Work

The emphasis and expectations for this episode are the same as for Episode 2 in Case Study 1. The class finished their interpretations of the Dust Bowl and Landslide Cases, and they also participated in the whiteboarding activity. For this episode, Mr. J. facilitated the activity in the same way he did in 5th period. He prompted students in 6th period for the same information that he had in 5th, and students responded in similar ways. However, 6th period was able to complete more of the activity in class than 5th period was, as 6th period was able to identify and articulate Learning Issues in class. The final whiteboard for 6th period is shown in Table 6.9.

Table 6.9 - Period Class Whiteboard – 6th Period Class Discussion of Dust Bowl and Landslide Cases

Facts	Ideas	Learning Issues
Steep slopes form from erosion	Terracing a hill divides the hill	Retaining walls slightly off the hill
Vegetation acts as a wall to prevent erosion.	Deep contours on the hill could slow erosion	Vegetation (which types are best for managing erosion)
Plants anchor the soil (especially trees)	Retaining walls divert soil	Underground pipes (how do they work? How well do they work?)
Water flows more easily in certain soil types	Keep vegetation on hill (especially trees)	Terracing
Dry soil blows away easier by wind	Underground pipes to divert water	Soil Types
Too wet soil can cause landslides from the mud	Research the hill's history and soil type	
Clearcutting leads to landslides because roots are important	Fill with cement to reinforce	
Contour plowing helps slow down erosion		

6.4 Episode 3: Modeling Case Application Skills A Second Time – Lotschberg Case In the *Tunneling Through Georgia* Unit

In this episode, Mr. J. reinforces case interpretation skills and adds more to his presentation of application skills, again in the context of helping students use the scaffolding in My Case Summary Design Diary pages to guide their interpretation. We shall see that Michelle's ability to interpret and begin to apply the Lotschberg Tunnel case was relatively the same with the exception of her ability to identify expert solutions. Instead of identifying general solutions, she identified a specific solution that not only described the criteria or constraint the solution was supposed to address, but that also included some detail about how the solution was implemented. Overall, Daniel's performance was the same for this episode of My Case Summary Design Diary Page use as it was for its use in Episode 1. Daniel improved his ability to identify criteria, identifying a specific criterion instead of a general one. However, his ability to identify and articulate design rules of thumb declined as he identified general design rules of thumb during this episode. Compared to his first use of the My Case Summary Design Diary Page, Sam's ability to interpret and begin to apply the Lotschberg Tunnel case was the same with the exception of his ability to identify design rules of thumb, which declined. Instead of identifying design rules of thumb with correct causality that also made suggestions about how the design rules of thumb could be applied to the challenge as he did in Episode 1, Sam identified general design rules of thumb.

This is the first instance of My Case Summary Design Diary Page use for Chris and Sandy. Overall, Chris's ability to interpret and begin to apply the Lotschberg Tunnel case was as we expected for this episode, as he identified general problems the experts faced, general solutions, and general design rules of thumb. Chris identified criteria in a very sophisticated way in that he identified a specific criterion that also included justification for choosing that criterion. Sandy's overall performance was better than we predicted for this episode. She not only identified expert problems that included causality, but she also identified a specific criterion that included justification for choosing that criterion as well as design rules of thumb that included justification. Compared to her first use of the My Case Summary Design Diary Page for the Dust Bowl case, Melissa's interpretation and application performance shows improvement. However, while she is able to identify problems the experts faced and criteria as well as we predicted, she identifies general expert solutions, a general constraint, and general design rules of thumb which are below our expectations for this episode.

6.4.1 Enactment and Predictions

The emphasis and expectations were the same for this episode as they were for Episode 3 in Case Study 1. Mr. J had asked the class to read the case for homework the night before, and during class, he prompted them as they interpreted the case as a class, modeling the kinds of questions they should ask of themselves and their group members as they interpreted the Lotschberg case cases in the future. He explained the My Case Summary Design Diary Page the same way that he did for his 5th Period class. He also gave the 6th Period class 10 minutes to complete the My Case Summary Design Diary Page for the Lotschberg Case, and told them they could complete the assignment for homework that evening if they did not complete it in class.

Following their interpretation of the Lotschberg Case, the 6th Period class also engaged in The Magic Schoolbus activity, watching the video and completing a worksheet about the video. Following the Magic School Bus activity, each group continued creating their rock models by adding more sand and substrate, and they read about how they would test their rock models.

6.4.2 Student Work

Inter-rater reliability was 99% for this episode, as it was in Episode 3 for Case Study 1.

6.4.2.1 Ridge and Valley Group

Three students in the Ridge and Valley group completed My Case Summary Design Diary Pages for the Lotschberg Case: Daniel, Sam, and Michelle. As summarized in Table 6.10, Daniel identified specific problem/solution pairs during this enactment, but he still did not include correct causality (Identifies Problems (I)): *Found a hotspring in the tunnel when tunneling* and *How to get food , water, sleep, etc. near there instead of going back home at night and coming back in the morning*. This episode shows Daniel identifying one expert solution that included the benefit the solution was supposed to have or the criteria/constraint the solution was supposed to address when he wrote (Identifies Solutions (II)), *Set up a city near the construction site for the workers to drink, eat, and sleep*. The other expert solution Kenny identified was general, *By building the tunnel underwater (in the river)*. Kenny connected expert problems identified in the case with expert solutions that addressed those problems (Connects Problems and Solutions To Apply To Challenge (IV)).

Daniel identified one criterion that described a specific objective that the experts would like to address when he wrote (Understands Criteria (V)) *The tunnel was for a train to go to Simplon Tunnel, but it was going to try and go through the mountain*.

While he did not identify any constraints (Understands Constraints (VI)) for the Lotschberg Tunnel case , he did identify two design rule of thumb (Rules of Thumb (VIII)). The first, *Shows us what things could happen,* was not actually a design rule of thumb, but the other, *What to look for in the core that might affect the tunnel*, was a general one.

Table 6.10 – Daniel's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case

Daniel		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Found a hotspring in the tunnel when tunneling	3
	How to get food, water, sleep, etc. near there instead of going back home at night and coming back in the morning	3
Identifies Solutions (II)	By building the tunnel underwater (in the river)	2
	Set up a city near the construction site for the workers to drink, eat, and sleep.	3
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		2
		2
Understands Criteria (V)	The tunnel was for a train to go to Simplon tunnel, but it was going to try and go through the mountain.	3
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	Shows us what things could happen	1
	What to look for in the core that might affect the tunnel	2

Sam also seemed to be able to read a case for understanding, identifying the important aspects of the case as shown in Table 6.11. He identified specific problems in the case that included no causality or justification (Identifies Problems (I)): *The sand and the gravel below the river went farther than the engineers though it did* and *The engineers thought that there would be few different types of rock in the mountain, while drilling they found many more types*. Sam identified a general expert solution when he wrote (Identifies Solutions (II)) *Later the tunnel was closed within a wall*. Sam did not connect the expert problems he identified to the expert solution he identified (Connects Problems and Solutions To Apply To Challenge (IV)). He also did not identify and criteria or constraints (Understands Criteria (V), Understands Constraints (VI)). However, he identified two general design rules of thumb that did not include causality or justification (Rules of Thumb (VIII)). He wrote: *We can learn to test the soil before tunneling in case of the soil being different than what we expected* and *Watch out for water* as design rules of thumb.

Table 6.11 – Sam's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case

Sam		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	The sand and the gavel below the river went farther than the engineers though it did.	3
	The engineers thought that there would be few different types of rock in the mountain, while drilling they found many more types.	3
Identifies Solutions (II)	Later the tunnel was closed in with a wall.	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		1
Understands Criteria (V)		1
Understands Constraints (VI)		1

Connects Constraints To Outcomes (VII)		1

Table 6.11 – Sam's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case (Continued)

Rules of Thumb (VIII)	We can learn to test the soil before tunneling in case of the soil being different than we expected.	2
	Watch out for water.	2

As Table 6.12 shows, Michelle identified one general expert problem (Identifies Problems (I)), *River bottom fell into the tunnel,* and one specific aspect of an expert problem that included correct causality or justification, *Explosives caused an avalanche of boulders, silt, sand, and mud*. She identified an expert solution that not only included the benefit it was supposed to have or the criteria/constraint it was supposed to address, but that also included details about its implementation (Identifies Solutions (II)): *Tunnel was sealed off with a masonry wall and crossed under the river and curved back to meet south end of tunnel* as an expert solution. She connected an expert problem she identified an expert solution she identified that addressed that (Connects Problems and Solutions To Apply To Challenge (IV)), but Michelle did not identify any criteria or constraints (Understands Criteria (V), Understands Constraints (VI)). However, she identified a general design rule of thumb that did not include causality nor justification when she wrote (Rules of Thumb (VIII)) *Know placement of river, how thin layers are (if soil or rock or of the river)*.

Table 6.12 – Michelle's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case

Michelle		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	River bottom fell into the tunnel.	2
	Explosives caused an avalanche of boulders, silt, sand and mud.	4

Table 6.12 – Michelle's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case (Continued)

Identifies Solutions (II)	Tunnel was sealed off with a masonry wall and crossed under the river and curved back to meet south end of tunnel.	4
Specifies Implementation (III)		2
Connects Problems and Solutions To Apply To Challenge (IV)		2
Understands Criteria (V)		1
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	Know placement of river, how thin layers are (if soil or rock or of the river).	2

Table 6.13 summarizes the individual interpretation performance of Ridge and Valley group members for their second uses of the My Case Summary Design Diary page. They used the pages to interpret and begin to apply the Lotschberg Tunnel case.

Table 6.13 - Coding Results for My Case Summary Design Diary Pages – Lotschberg Case

	Daniel's Coded Results			Sam's Coded Results			Michelle's Coded Results		
Identifies Problems (I)	3	3	Total – 4	3	3	Total – 2	2	4	Total – 2
Identifies Solutions (II)	3	3	Total – 3	2		Total – 1	4		Total – 1
Specifies Solution Implementation (III)	N/A	N/A	Total – 0	N/A	N/A	Total –0	2		Total – 1
Connects Problems and Solutions (IV)	2	2	Total – 5	1		Total – 1	2		Total – 1
Identifies Criteria (V)	3		Total – 1	1		Total – 0	1		Total – 0

Table 6.13 - Coding Results for My Case Summary Design Diary Pages – Lotschberg Case (Continued)

Identifies Constraints (VI)	1		Total – 0	1		Total – 0	1		Total – 0
Connects Constraints To Outcomes (VII)	1		Total – 0	1		Total – 0	1		Total – 0
Rules of Thumb (VIII)	1	2	Total – 2	2	2	Total - 2	2		Total - 1

6.4.2.2 Coastal Plain Group

Three students in the Coastal Plain group completed My Case Summary Design Diary Pages for the Lotschberg Tunnel Case, and they were Sandy, Chris, and Melissa. As summarized in Table 6.14, Sandy identified specific problem/solution pairs that included causality and/or justification (Identifies Problems (I)): *In the tunnel hot water and crumbling rock had caused construction problems* and *They dynamite exploded, and only 2 men out of 25 were saved because they were on the rear*. Sandy identified two general expert solutions (Identifies Solutions (II)), *The geological commission rebuilt the train tunnels*, and *The geological commission confirmed that the new tunnel is working efficiently*. She did not connect expert problems she identified to expert solutions she identified in the expert case Connects Problems and Solutions To Apply To Challenge (IV)).

Sandy identified one criterion that described a specific objective that the experts would like to address and included justification for choosing that criterion when she wrote (Understands Criteria (V)) *Tunnelers are trying to find a way to build a tunnel through mountains, under water, and down by roads for a train to pass through, because they think that it would be easier for people to go from place to place without getting caught in traffic*. She did not identify any constraints (Understands Constraints (VI)).

However, Sandy identified two design rule of thumb for the Lotschberg Tunnel case (Rules of Thumb (VIII)). The first, *We can go under rivers and through it assuming there is good rock overhead so it wouldn't crumble down onto the train,* included causality and/or justification, while the other, *We can drill in mountains and make tunnels for trains to pass through*, was general.

Table 6.14 – Sandy's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case

Sandy		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	In the tunnel hot water and crumbling rock had caused construction problems.	4
	The dynamite exploded and only 2 men out of 25 were saved because they were on the rear.	4
Identifies Solutions (II)	The geological commission rebuilt the train tunnels.	2
	The geological commission confirmed that the new tunnel is working efficiently.	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		1
		1
Understands Criteria (V)	Tunnelers are trying to find a way to build a tunnel through mountains, under water, and down by roads for a train to pass through, because they think that it would be easier for people to go from place to place without getting caught in traffic.	4
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	We can go under rivers and through it assuming there is good rock overhead so it wouldn't crumble down onto the train.	3
	We can drill in mountains and make tunnels for trains to pass through.	2

Chris seemed to be able to read the Lotschberg Tunnel case for understanding, identifying the important aspects of the case as shown in Table 6.15. He identified general problem/solution pairs that included no causality or justification (Identifies Problems (I)): *Instead of just limestone, they found other minerals as well* and *People were hungry needed clothes and houses*. Chris identified two general expert solutions when he wrote (Identifies Solutions (II)) *It was only 575 feet long, so they passed it with no trouble* and *They built a whole new town*. Chris connected one expert problem he identified to an expert solution he identified that addressed that problem (Connects Problems and Solutions To Apply To Challenge (IV)).

He identified one criterion that described an objective that the experts wanted to address and also included justification for choosing that criterion when he wrote (Understands Criteria (V)) *They are tunneling so that access can be provided to the Simplon Tunnel*. Chris did not identify and constraints (Understands Constraints (VI)). However, he identified two general design rules of thumb that did not include causality or justification (Rules of Thumb (VIII)): *They should take core samples of the sediment* and *They should make sure they have at least 150 feet of good solid rock* as design rules of thumb.

Table 6.15 – Chris's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case

Chris		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Instead of just limestone, they found other minerals as well.	2
	People were hungry needed clothes and houses.	2

Table 6.15 – Chris's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case (Continued)

Identifies Solutions (II)	It was only 575 feet long, so they passed it with no trouble.	2
	They built a whole new town.	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		1
		2
Understands Criteria (V)	They are tunneling so that access can be provided to the Simplon Tunnel.	4
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	They should take core samples of the sediment.	2
	They should make sure they have at least 150 feet of good solid rock.	2

As Table 6.16 shows, Melissa identified one expert problem in the Lotschberg Tunnel case that included causality (Identifies Problems (I)), *While digging the tunnel there was a river valley, dynamite was set off and an avalanche of water etc. killed many,* and one general expert problem, *The tunnel would have to go under a river*. She identified two general expert solutions when she wrote (Identifies Solutions (II)) *The geological commission wrote a report and lied about what happened* and *Geologists were hired to see if there would be any problems* as expert solutions. She did not connect expert problems she identified to expert solutions she identified (Connects Problems and Solutions To Apply To Challenge (IV)).

Melissa identified one criterion (Understands Criteria (V)), *Miners needed to make a tunnel through mountains for trains,* that described an objective the experts wanted to address. She also identified one general constraint (Understands Constraints

(VI)), *The tunnel would have to go under a river*, but she did not describe outcomes that occurred as a result of the experts addressing or failing to address that constraint (Connects Constraints To Outcomes (VII)). Melissa identified two general design rules of thumb that did not include causality nor justification when she wrote (Rules of Thumb (VIII)) *Looking at the history of the land* and *Getting geologist to help see if there are any problems of the land*.

Table 6.16 – Melissa's Two Best Answers From My Case Summary Design Diary Page – Lotschberg Case

Melissa		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	While digging the tunnel there was a river valley, dynamite was set off and an avalanche of water etc. killed many.	4
	The tunnel would have to go under a river.	2
Identifies Solutions (II)	The geological commission wrote a report and lied about what happened.	3
	Geologists were hired to see if there would be any problems.	2
Specifies Implementation (III)		N/A
		N/A
Connects Problems and Solutions To Apply To Challenge (IV)		1
		1
Understands Criteria (V)	Miners needed to make a tunnel through mountain for trains.	3
Understands Constraints (VI)	The tunnel would have to go under a river.	2
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	Looking at the history of the land	2
	Getting geologist to help see if there are any problems of the land	2

Table 6.17 summarizes the individual interpretation performance of Coastal Plain group members as they interpreted the Lotschberg Tunnel case during their second uses of the My Case Summary Design Diary page.

Table 6.17 - Coding Results From My Case Summary Design Diary Pages – Lotschberg Case

	Sandy's Coded Results			Chris's Coded Results			Melissa's Coded Results		
Identifies Problems (I)	4	4	Total – 3	2	2	Total – 2	4	2	Total – 2
Identifies Solutions (II)	2	2	Total – 2	2	2	Total – 2	3	2	Total – 2
Specifies Solution Implementation (III)	N/A	N/A	Total – 0	N/A	N/A	Total –0	N/A	N/A	Total – 0
Connects Problems and Solutions (IV)	1	1	Total – 2	1	1	Total – 2	1	2	Total – 2
Identifies Criteria (V)	4		Total – 1	4		Total – 1	3		Total – 1
Identifies Constraints (VI)	1		Total – 0	1		Total – 0	2		Total – 1
Connects Constraints To Outcomes (VII)	1		Total – 0	1		Total – 0	1		Total – 1
Rules of Thumb (VIII)	3	2	Total – 2	2	2	Total - 2	2	2	Total - 2

6.4.3 Summary of Results

As summarized in Table 6.17, overall, Michelle's ability to interpret and begin to apply the Lotschberg Tunnel case matched the predictions we had for this episode. Her performance was almost the same as it was for her first use of the My Case Summary Design Diary Page, but the exception was her ability to identify expert solutions. Instead of identifying general solutions, she identified a specific solution that not only described the criteria or constraint the solution was supposed to address, but that also included some detail about how the solutions was implemented. Daniel's ability to identify criteria improved during this episode, and he identified a more specific criterion. However, his ability to identify and articulate design rules of thumb declined as he identified general design rules of thumb during this episode. Sam's ability interpretation and application performance remained the same except for his ability to identify design rules of thumb, which declined. Instead of identifying design rules of thumb with correct causality that also made suggestions about how the design rules of thumb could be applied to the challenge, in this episode Sam identified general design rules of thumb.

Chris's ability to identify expert problems, solutions, and design rules of thumb matched our predictions for this episode. He identified general problems the experts faced, general solutions, and general design rules of thumb. However, Chris's ability to identify criteria was better than we expected, as he identified a specific criterion that also included justification for choosing that criterion. Sandy's overall performance was better than we predicted for this episode. She not only identified expert problems that included causality, but she also identified a specific criterion that included justification for choosing that criterion as well as design rules of thumb that included justification. While Melissa's interpretation and application performance shows improvement from Episode 1 and her ability to identify expert problems and criteria matched our predictions, her ability to identify expert solutions, constraints, and design rules of thumb did not match our predictions. Instead of identifying more specific expert solutions, constraints, and design rules of thumb that include correct causality, she identified general ones.

6.5 Episode 4: Using the Case Interpretation Tool – First Software-Scaffolded Case Activity

Episode 4 presents the first time student groups used the Case Interpretation Tool to interpret an expert case. Overall, the Ridge and Valley group identified specific problems (one that also included correct causality), specific solutions, general and specific criteria and constraints, one of each that also included justification for choosing the criterion. The group also identified a design rule of thumb in the Queens Midtown Tunnel case that included both justification and suggestions for ways the design rule of thumb could be applied to the Tunneling Through Georgia challenge. However, the group's written work also reveals that there was some confusion about the difference between criteria and constraints because they identified one criterion as a constraint. Group discussions show that this group worked well together and tended to classify, support, and refute ideas using the definitions of the classifications in questions as justification or evidence. They also used the written case to inform their discussion, and they seemed to rely very heavily on Mr. J as a scaffold, turning to him after reading the prompt in many instances.

Overall, the Coastal Plain group had a difficult time interpreting the Frejus Tunnel case. While the group identified a general problem the experts faced, a solution that included the criterion or constraint the solutions was supposed to address, and specific criteria, because they were logged out of the software and suffered a laptop shutdown, they ran out of time before they could complete all of the prompts in the Case Interpretation Tool. As a result, Mr. J. asked them to skip down and complete the Lessons Learned prompt before they'd had an opportunity to reflect on the problems and solutions in such a way that the lessons they could learn from the expert case could be made visible. As a result, they identified a design rule of thumb that was unrelated to the expert case and deemed by one group member as being "horrible." Group discussions show that this group did not collaborate effectively, and at least half of the group was disengaged from the activity. Furthermore, the group did not seem to use the written expert case to inform their discussions, relying instead on their memories of the expert case.

6.5.1 Enactment and Predictions

One week following Mr. J's reinforcement interpretation skills during interpretation of the Lotschberg Tunnel case, groups interpreted expert cases for the first time using the Case Interpretation Tool. The emphasis and expectations for this episode were the same as they were for Episode 4 in Case Study 1. As in the 5th period class, this was the first time 6th period groups used the Case Interpretation Tool and its system of scaffolds to support them as they interpreted an expert case in their small groups. Each group interpreted a different case from the following set of cases: Hoosac, Frejus, Queens Midtown, and St. Gotthard. The Ridge And Valley Group interpreted the Queens Midtown case, and the Coastal Plain Group interpreted the Frejus case.
A week later, as in the 5th period classes, each group made comments on the other groups' case interpretations in their class period, and Mr. J. walked around to each group, helping them to generate comments and address comments made.

6.5.2 Student Work

As the Ridge and Valley group used the Case Interpretation Tool, every member had the written expert case in their student books in front of them. They looked back at what the cases said as needed while they worked. Michelle and Kenny dominated the discussion, while Daniel was less vocal. In general, they had an easy time with identifying expert problems, solutions, and using the rule of thumb template to generate design rules of thumb, but they required more discussion about criteria and constraints, spending most of their discussion time on this topic.

During the Coastal Plain group's use of the Case Interpretation Tool, every member had the written expert case in their student books in front of them. They looked back at what the cases said as needed while they worked. Only Melissa used and referred to the written expert case in the student book throughout the entire episode. Melissa and Chris dominated the discussion, while Sandy and Chad were much less vocal. This group spent quite a bit of their discussion time on the topic of criteria and constraints. During their episode, they were logged out of the software, and their laptop shut down, so by the time they logged back into the software, most of the class period had passed. In response, the group was instructed to skip down to identify design rules of thumb, and they struggled with this for the remainder of the class period. Inter-rater reliability for this episode was the same as it was for Episode 4 in Case Study 1, 98%.

6.5.2.1 Ridge and Valley Group

In this episode, summarized in Table 6.18, the Ridge And Valley group was able to identify problems the experts faced (Identifies Problems (I)). For one expert problem, they described a specific aspect of an expert problem, *People would suffocate* and for the other, they also included correct causality, *Because of the permeable rock, water was a problem*. This group identified solutions the experts used to address the problems they encountered (Identifies Solutions (II)), providing a description of a solution that included the benefit the solution was supposed to have or the criteria or constraint the solution was supposed to address, and including some detail about how the solution was implemented for one of the three expert solutions they identified. For example, they typed *People would suffocate if air pumps were not added to filter out exhaust* and *Compressed air was pumped in to force the water out* as solutions the experts used to address problems they encountered.

The Ridge And Valley group identified criteria (Understands Criteria (V)) and constraints (Understands Constraints (VI)). One criterion, *to break down traffic,* was general while the other, *They wanted to have the tunnel a certain width because they wanted to have two lanes* described an objective the experts wanted to address and also included justification for choosing that criterion. Of the constraints the group identified, one was general, *To go under the East River,* and the other, *To prevent damaging the tunnel, it had a minimum of 13 feet of cover,* described a specific constraint, what the constraint affected, and included justification for choosing that constraint. The Ridge and Valley group also described the outcomes that could occur as a result of addressing or failing to the last constraint described above (Connects Constraints To Outcomes (VII)). The Ridge And Valley group also used the Design rule of Thumb template to help them articulate a design rule of thumb (Rule of Thumb (VIII)). The group's design rule of thumb *If water somehow seeped through the permeable rock, you could use compressed air to pump it out of the tunnel and put a thick blanket of clay on the river bottom, because it would counter the air pressure and prevent the river from letting in*, included justification as well as suggestions for how it could be applied.

Table 6.18 – Ridge And Valley Group's Two Best Answers From Case Interpretation Tool – Queens Midtown Tunnel case

Ridge And Valley Group		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	People would suffocate	3
	Because of the permeable rock, water was a problem.	4
Identifies Solutions (II)	People would suffocate if air pumps were not added to filter out exhaust.	3
	Compressed air was pumped in to force the water out.	3
Specifies Implementation (III)		N/A
		N/A
Understands Criteria (V)	To break down traffic	2
	They wanted to have the tunnel a certain width because they wanted to have two lanes.	4
Understands Constraints (VI)	To prevent damaging the tunnel, it had a minimum of 13 feet of cover.	4
	To go under the East river	2
Connects Constraints To Outcomes (VII)		2
		1
Rules of Thumb (VIII)	If water somehow seeped through the permeable rock, you could use compressed air to pump it out of the tunnel and put a thick blanket of clay on the river bottom, because it would counter the air pressure and prevent the river from letting in.	4

Table 6.19 summarizes the coding results for this episode.

Table 6.19 – Ridge And Valley Group Case Interpretation 1 Coding Results

	Ridge and Valley Group's Coded Results Case Interpretation 1 – Queens Midtown Tunnel		
Identifies Problems (I)	3	4	Total – 2

Table 6.19 – Ridge And Valley Group Case Interpretation 1 Coding Results (Continued)

Identifies Solutions (II)	3	3	Total – 3
Specifies Solution Implementation (III)	N/A	N/A	Total – 0
Identifies Criteria (V)	2	4	Total – 2
Identifies Constraints (VI)	4	2	Total – 3
Connects Constraints To Outcomes (VII)	2	1	Total – 3
Rules of Thumb (VIII)	4		Total - 1

6.5.2.2 Group Discussions

The group began by discussing the goal the experts wanted to achieve, addressing criteria and constraints, the solution the experts chose, how they carried the solution out, science and technology used, vocabulary, and design rules of thumb. This group worked extremely well together sharing ideas with each other in the ways we expected in that a group member would propose an idea and, if the group agreed, they discussed how they would write it up in the software. If the group didn't agree, they talked about why there was disagreement figured out what they should do to move forward. However, the group's discussion about expert problems and solutions revealed that they used Mr. J. more as a scaffold than they did in their discussions about the other prompts in the Case Interpretation Tool, and their use of Mr. J. as a scaffold seemed to contribute to their sophisticated performance during this episode.

For this reason, and because in later episodes, when the group was not able to use Mr. J. as a scaffold nearly as much their ability to identify expert problems (Identifies

Problems (I)), identify expert solutions (Identify Solutions (II)) and identify and articulate design rules of thumb (Rules of Thumb (VI)) suffers, it seems appropriate to present excerpts for this group that focus on those discussions.

The Ridge and Valley group described expert problems and solutions across two different prompts: the *Solution Chosen* and *How The Solution Was Carried Out* prompts. Initially, when the group began identifying expert problems and solutions for the *Solution Chosen* prompt, they were having trouble figuring out what how they should respond and what they should type in the prompt, so they decided to ask Mr. J. for help. Notice that Mr. J. is the first scaffold they seek after reading the prompt, and they turn to him before turning to the hints or examples in the software:

(1) Michelle: OK, so...um…
(2) Daniel: What did they decide to do to meet the
(3) challenge?
(4) Michelle: Since the [inaudible]…hold on…Oh, I get it!
(5) OK, here’s a problem.
(6) Daniel: Well, what’s the challenge?
(7) Michelle: To build…tunnel...through…
(8) Daniel: water.
(9) Michelle: Yeah, well under-
(10) Daniel: Just like the Lotschberg Tunnel.
(11) Michelle: No, that was through a mountain.
(12) Kenny: [reading the screen] What did they do…
(13) Daniel: Yeah, but they had to go through rock
(14) and…water.
(15) Michelle: Yeah, water, but this one’s, like, right

(16) under a river.
(17) Kenny: [reading] What did they do to meet the
(18) challenge? They decided…What is this question
(19) actually asking?
(20) Daniel: It’s, it’s uh…
(21) Kenny: It’s a very broad question.
(22) Daniel: What did they decide to do to meet the
(23) challenge? Excuse me.
(24) [Daniel raises his hand]
(25) Michelle: Mr. J…
(26) Kenny: I hate school.
(27) Mr. J.: Yeah?
(28) Michelle: Um…we’re having trouble with Solution
(29) Chosen because there’s a lot of different parts of
(30) this challenge and we’re not sure which one they’re
(31) talking about.
(32) Mr. J.: OK, it says [reading the screen] What did they
(33) decide to do to meet the challenge? Give reasons why
(34) the experts chose this solutions. So, why don’t you
(35) break it down and do each one. So, what was the
(36) specific challenge you want to address and what was
(37) the solution for that specific part?
(38) Kenny: A-they wanted to break down the traffic, so
(39) they built these two tunnels. [to Mr. J.] Right?
(40) Mr. J.: What’s that?
(41) Kenny and Michelle: They wanted to break-

(42) Kenny: to break down the traffic so they built these
(43) two tunnels.
(44) Mr. J: Very good. That's one. Good one. There's
(45) probably quite a few, but that's a good start. That's
(46) a good first one.

Excerpt 6.5.1: Ridge and Valley's Teacher Scaffolded Group Discussion of Solution Chosen

What's going on in this discussion? After reading the Solution Chosen prompt (lines 2 and 3), Michelle thought she'd identified an expert problem (lines 4 and 5), but she was cut off by Daniel who seemed unsure of what the expert's challenge was (line 6). Michelle began to articulate that the expert's challenge was to build a tunnel (line 7), and Daniel piggybacked on Michelle's idea and added that the tunnel was constructed through water (line 8). Michelle began to clarify Daniel's addition (line 9), but was cut off as Daniel stated that this tunnel was like the Lotschberg Tunnel which they'd interpreted as a class with Mr. J during Episode 3 (line 10). Michelle pointed out that the Lotschberg Tunnel case involved going through a mountain (line 11), but Daniel pointed out that the parallel for him was that in both cases, there was construction through water (lines 13 and 14). Michelle agreed, but pointed out that the difference was that the Queens Midtown Tunnel was directly under a river (lines 15 and 16).

Meanwhile, Kenny mulled over the prompt reading it over and over to gain some understanding of it (lines 12 and 17), but finally asked the group what this prompt was really asking them for (lines 18 and 19). Daniel tried to formulate an answer, but Kenny stated that the prompt was a very broad question and seemed to be asking them for a lot (line 21). Daniel reread the prompt and raised his hand for help (lines 22-24). Michelle called Mr. J over to help them (line 25).

When Mr. J. arrived, Michelle explained the problem that the group was having answering the prompt (lines 27-31), and Mr. J. stepped them through the strategy of breaking the question down and answering each prompt (lines 32-37). He began by asking them about a specific challenge they wanted to write about and what the experts did to address that specific challenge (lines 36 and 37). Kenny stated that they wanted to break down traffic, so they built two tunnels (lines 38 and 39). When he asked Mr. J. if that was correct (line 39), Mr. J. asked him to repeat it (line 40). He did, and Mr. J. agreed that that was a good identification of a problem and solution (lines 44-46).

This approach of using Mr. J. as a primary scaffold following their reading of the prompt continued as they group identified another expert problem and solution during their discussion of the *How The Solution Was Carried Out* prompt:

(47) Kenny: What process did the experts use to design and
(48) build their solution? What steps did they take to
(49) carry the solution out ?
(50) Daniel: What process did the experts use to design
(51) and build their solution?
(52) Michelle: I don’t know! Why don’t we go check?
(53) Daniel: What steps did they take to carry out the
(54) solution?
(55) Kenny: This is a very broad question.
(56) [Daniel raises his hand]
(57) [Mr. J. stops by their table]
(58) Michelle: We’re having trouble understanding this
(59) question.
(60) Mr. J. [reading the screen] OK, What process did the

experts use to design and build their solution? To carry the solution out?
Kenny: What is it asking though?
Mr. J.: What was the solution?
Kenny: To build the tunnel.
Michelle: To build two tunnels.
Mr. J.: [inaudible] No, that was the challenge.
Michelle: Yeah…
Kenny: The solution was-
Michelle: What do you mean the solution?
Mr. J.: Oh, instead of one tunnel, they built two?
Daniel: Yeah,-
Michelle: No, it’s just a bridge.
Kenny: The solution was to build two tunnels cause there was too much traffic.
Mr. J.: Did they run into any material they were having problems with?
Michelle: Well, actually, once-
Kenny: The river-
Michelle: No, once-
Kenny: The river started touching the top of the tunnel.
Mr. J.: OK, so how did they solve that?
Kenny: And the tangible rocks-I mean permeable rocks.
Michelle: What was the problem?
Kenny: permeable rock-

(87) Michelle: Oh! Compressed air was pumped in to force
(88) the water out.
(89) Mr. J.: That’s the solution.

Excerpt 6.5.2: Ridge and Valley’s Teacher Scaffolded Group Discussion For the How The Solution Was Carried Out Prompt

This excerpt played out very much like the previous excerpt. Following the reading of the prompt (lines 47-49), Michelle stated she didn’t know the answer to the question and suggested that they ask Mr. J. (line 52). Daniel reread the prompt, and as in the previous excerpt, Kenny stated that the question was broad (line 55). Also similar to the previous excerpt, Daniel raised his hand and when Mr. J. came over, Michelle stated that the group was having trouble (lines 56-59). Again, Mr. J. gave them a strategy to answer the prompt which involved breaking the prompt down into smaller prompts and having the group respond to each one (lines 60-62, line 64, lines 76 and 77).

Initially, Kenny was not sure what the question was asking them (line 63), and Mr. J. asked Kenny to describe an expert solution (line 64). Kenny described building the tunnel as an expert solution, and Michelle added that the solution was that the experts built two tunnels (lines 65 and 66). Mr. J. stated that their answers described the expert’s challenge (line 67), and after several starts by Michelle and Kenny to describe the expert solution (lines 68 and 69), Michelle asked Mr. J. what he meant by the solution (line 70).

Mr. J., sensing that he didn’t fully understand the answers given by Michelle and Kenny restated their answer (line 71). Daniel agreed and Michelle began to offer a different explanation, but Kenny cut her off and stated that solution was to build two tunnels to handle the traffic (lines 72-75). Mr. J., trying to prompt them to describe a process that the experts may have used to implement the solution, asked the group if the experts ran into any material that resulted in problems (lines 76 and 77). After a few false starts by Michelle and Kenny (lines 78-80), Kenny stated that the river started to flood the tunnel because of the permeable rocks (lines 81 and 82, line 84). Mr. J asked how that problem was solved (line 83), and Michelle answered that compressed air was pumped into the tunnel to force the water out (lines 87 and 88).

Mr. J. also helped the Ridge and Valley group think about and describe the outcomes that might occur as a result of the experts addressing or failing to address constraints in the expert case. This is important because Mr. J.'s in-the-moment scaffolding was successful in helping the group articulate an outcome, something that the software did not scaffold for:

```
(90) Michelle: Uh…OK…I think they needed to pump fresh air
(91) in or else you'd be like,…
(92) Daniel:   Let's ask them.
(93) [Daniel raises his hand]
(94) Kenny:  Yeah they had to or else people would
(95) suffocate.
(96) Michelle: [to Mr. J.] Didn't they need to pump air in?
(97) Cause it says they pumped fresh air in, but I don't
(98) know if they needed-
(99) Mr. J:    Where is say?   What's is say? Read it to
(100)me.
(101)Daniel: [reading] The pumps were designed to
(102)completely change the air in the tunnel every 1.5
(103)minutes.
(104)Michelle:[reading] Fresh air would be pumped in
```

(105)through a passage under the road. Exhaust would
(106)be drawn out through another passage along the
(107)top of the tunnel.
(108)Mr. J: What would happen if they didn't change
(109)out the air, if they just left the exhaust in
(110)there?
(111)Michelle: [inaudible] OK.

Excerpt 8.2.3 – Mr. J. Discussing Outcomes with the Group

In this excerpt, Michelle suggested that pumping fresh air in was a constraint (lines 90 and 91), but Daniel, who was unsure, suggested that the group ask Mr. J (line 92). Kenny supported Michelle's position, but Daniel raised his hand anyway (lines 93-95). When Mr. J. arrived, Michelle asked if her idea was in fact a constraint (lines 96-98), and Mr. J. asked them to read the portion of the expert case that dealt with pumping fresh air into the tunnel (lines 99 and 100). After Daniel and Michelle read passages (lines 101-107), Mr. J. asked them what would happen if the air wasn't pumped out (lines 108-110). From that exchange, the group was able to classify Michelle's idea as a constraint and to describe the outcomes that may have occurred if the experts had not addressed that constraint.

<u>6.5.2.3 Coastal Plain Group</u>

In this episode, summarized in Table 6.20, the Coastal Plain group was unable to identify problems the experts faced (Identifies Problems (I)) or solutions used to address their problems (Identifies Solutions (II)). However, they identified criteria that described specific objectives the experts wanted to address (Understands Criteria (V)): *One criteria in the tunnel was that they wanted to be able to breathe* and *They wanted to build an air* *vent and chimneys for the dust to escape*. The Coastal Plain group did not identify any constraints (Understands Constraints (VI)). While the Coastal Plain group used the Rule of Thumb template to help them create a design rule of thumb (Rule of Thumb (VIII)), the group's design rule of thumb *The lessons that we When trying to find the answers we use highlighting and looking it up in the book because it gave the answers to all the questions*, was unrelated to the expert case.

Table 6.20 – Coastal Plain Group's Two Best Answers From Case Interpretation Tool – Frejus Tunnel case

Coastal Plain Group		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)		1
Identifies Solutions (II)		1
Specifies Implementation (III)		N/A
		N/A
Understands Criteria (V)	One criteria in the tunnel was that they wanted to be able to breathe.	3
	They wanted to build an air vent and chimneys for the dust to escape.	3
Understands Constraints (VI)		1
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	The lessons that we When trying to find the answers we use highlighting and looking it up in the book because it gave the answers to all the questions.	2

Table 6.21 summarizes the coding results for this episode.

Table 6.21 – Coastal Plain Group Case Interpretation I Coding Results

	Coastal Plain Group's Coded Results Case Interpretation 1

	– Frejus Tunnel		
Identifies Problems (I)	1		Total – 0
Identifies Solutions (II)	1		Total – 0
Specifies Solution Implementation (III)	N/A	N/A	Total – 0
Identifies Criteria (V)	3	3	Total – 3
Identifies Constraints (VI)	1		Total – 0
Connects Constraints To Outcomes (VII)	1		Total – 0
Rules of Thumb (VIII)	2		Total - 1

6.5.2.5 Group Discussions

The Coastal Plain group began by answering the *Goal* prompt, but after answering that prompt, the group was somehow logged off the software. It is not clear whether the log off was the result of a group member accidentally logging them off or the result of a malfunction with the laptop they were using. However, five minutes later, the group was logged back in and continued working.

They moved on to the Criteria and Constraints prompt. Notice several things in the following excerpt. First, they answered each question in the prompt separately and did not use the Criteria and Constraints template. Second, they do not seem to work well together and there appears to be an atmosphere of confusion as Melissa begged them to focus on the task at hand and as they struggle to talk about the expert case and answer the prompt. Third, every idea generated and discussed seemed to come from their memories of the expert case.

(1) Melissa: What criteria were used to select a solution?
(2) Chris: Well, they wanted to be able to breathe down
(3) there.
(4) Melissa: To select how the solution would be put into
(5) practice? What limitations did the experts have to
(6) address?
(7) Chris: First off, all they wanted to be able to
(8) breathe…[to Sandy] Why don't you just do criteria and
(9) then do 1, 2, 3.
(10) Sandy: Alright.
(11) Chad: I can't see the screen.
(12) Sandy: What criteria were used to select a solution?
(13) Chris: They didn't want it to cave in.
(14) Chad: [mocking Chris] They didn't want it to cave in.
(15) Melissa: To select how the solution would be put into
(16) practice.
(17) Chris: Make a huge fan.
(18) Sandy: The solution would be…[to Chris] Stop it!
(19) OK…The solution-
(20) Melissa: You guys! You have to pay attention.
(21) Chad: Wait! What are we doing?
(22) Sandy: When they tried to-
(23) Chris: build an air vent.
(24) Sandy: Wasn't it a well?
(25) Melissa: air vent.
(26) Sandy: and wasn't there a chimney?

Melissa: and a chimney.

Chris: I didn’t read the whole thing, so I shouldn’t know.

Chad: I thought that failed.

Chris: How does a chimney fail when we use them everyday?

Chad: I thought that failed.

Melissa [reading the screen] What limitations did the experts have to address?

Chad: Limitations?

Melissa: The experts had to…OK, guys?!?

Sandy: Wait! Hold on!

Melissa: What did the experts have to address?

Chad: How stupid they think we are.

Melissa: What did the experts have to address, you guys?…What did they have to address?

Chad: The fact that they had to wear dresses.

Melissa: You guys! I’m being serious-what did they have to address?

Chris: Let’s see…Well, first of all, there was the whole thing that the ground was hard.

Melissa: So they had to address how-

Chris: how to build the tunnel.

Sandy: how to build the tunnel.

Melissa: How they were going to tunnel through-

Sandy: how they were going to build the tunnel in the

(53) ground because it was [inaudible].

(54) Melissa: to drill through…Solution Chosen.

Excerpt 6.5.3.1 – Group Discussion of Criteria and Constraints

Here, Melissa began by reading the prompt (line 1). Chris cut Melissa off as she read and offered a criterion (lines 2 and 3). When Melissa finished reading the prompt (lines 4-6), Chris restated his idea (lines 7-9). After typing Chris's criterion in, Sandy reread the first portion of the Criteria and Constraints prompt (line12), and Chris offered another criterion (line 13). Sandy typed that idea in as well, and Melissa read to the second portion of the prompt (lines 15 and 16). Chris made a suggestion that they made a huge fan, and tried to type it in, but Sandy protested (lines 17-19). Melissa focused everyone's attention back to the task (line 20), and Sandy, Chris, and Melissa constructed pieces of an answer together which Melissa typed in (lines 21-27). Chad thought that Sandy's statement that the experts used chimneys failed (line 30), but Chris insisted it did not (line 31). Melissa, trying to move the discussion forward, read the third portion of the prompt, and had to repeat it four times before anyone in the group gave her a suitable response (lines 34-45). Chris stated that the ground was hard (lines 46 and 47), and together, he and Sandy told Melissa what to type into the prompt (lines 48-54).

They moved on to the Solution Chosen prompt. As they were discussing this prompt, Mr. J. walked by and looked at what they'd done so far. Noticing that they hadn't use the Criteria and Constraints template, he pointed to the template's link on the screen and told them to use the template. He said, "Catch back up by filling this out." The group began discussing criteria and constraints again using the template. However, instead of taking what they'd already discussed and reworking it to include in the template, they begin discussing their criteria from scratch.

Following their discussion of criteria and constraints, the group discussed the *Solution Chosen* and *Time and Location* prompts. In the middle of their discussion of the *Time and Location* prompt, Chad pulled the cord out of the laptop which caused it to shut down. In addition to it taking 10 minutes to bring the laptop back up and log the group back on, they also had not saved their work, so they lost their Criteria and Constraints template as well as their answers to the *Solution Chosen* and *Time and Location* prompt.

Once they were logged back in, they re-answered the Solution Chosen and Time and Location prompts. As they were beginning to work on the *How The Solution Was Carried Out* prompt, Mr. J. came over and told them to skip down to the Rule(s) of Thumb prompt and "work your way back" because there were only five minutes left in the class period. However, because they had not discussed and connected the problems the experts faced to the solutions they used to address those problems, they had a very difficult time generating and articulating a design rule of thumb:

```
(55) Melissa:  Oh! We might want to use the rule of thumb
(56) template…OK.
(57) Chris:    Basically, outside knowledge.
(58) Melissa:  OK…When…
(59) Chris:    [reading the template] describe the
(60) action…list your suggestions…When…
(61) Melissa:  If…
(62) Chris:    Just say when.  OK.  When the…um…
(63) Melissa:  Guys, what did we learn? Lessons we learned…
(64) Chris:    OK, we learned that…
(65) Sandy:    We learned that…um…
```

(66) Chris: Outside knowledge-just not of this thing.

(67) Sandy: We learned, then, that…

(68) Chris: It took 13 years to build the Swiss Alps

(69) Tunnel.

(70) Sandy: We learned that it…

(71) Chris: took 13 years to build-

(72) Melissa: No…No, we didn't learn that because we have to

(73) [pointing to the template] describe the action or

(74) choice we are working with. What WE are working with.

(75) We are working with…the book…and our minds and our

(76) knowledge…I give up.

Excerpt 6.5.3.3 – Coastal Plain Group Generating Design Rule of Thumb

In this excerpt, Melissa suggested that the group use the rule of thumb template to articulate their design rule of thumb (lines 55 and 56). The group attempted several times to read the template and begin articulating a design rule of thumb (lines 57-62), but they struggled to do so. Recognizing their struggle, Melissa again prompted the group for what they'd learned (line 63). The group still struggled (lines 64-67), and Chris stated a fact they learned from the case (lines 68 and 69). His fact was ignored (line 70), and he tried to introduce it as a possible lesson learned once again (line 71), but Melissa was able to use the scaffolding in the template to show Chris why the fact he identified did not qualify as a design rule of thumb (lines 72-74). Despite this, she and the rest of the group were unable to come up with a design rule of thumb from the expert case. Once they articulated a design rule of thumb, which was in no way connected to the content of the expert case, and Melissa read it back to the group, Chad exclaimed, "That's horrible!" As he exclaimed, the class period ended.

6.5.3 Summary of Results

This episode represents the first time student groups interpreted cases in their small groups using the Case Interpretation Tool. Overall, the Ridge and Valley group's performance for interpretation was as predicted for identifying problems and solutions. Their performance for identifying criteria, constraints, and design rules of thumb was better than we expected. They identified specific problems (one that also included correct causality), specific solutions, specific criteria and constraints that also included justification for choosing the criterion and constraint, and a design rule of thumb that included both justification and suggestions for ways the design rule of thumb could be applied to the Tunneling Through Georgia challenge. However, the group's written work also revealed that there was some confusion about the difference between criteria and constraints because they identified one criterion as a constraint. Group discussions show that this group worked well together and tended to classify, support, and refute ideas using the definitions of the classifications in questions as justification or evidence. They also used the written case to inform their discussion, and they seemed to rely very heavily on Mr. J as a scaffold, turning to him after reading the prompt in many instances.

Overall, the Coastal Plain group had a difficult time interpreting the Frejus Tunnel case. They were logged out of the software, and their laptop shut down after the cord was pulled out. As a result, they ran short on time to complete the prompts in the Case Interpretation Tool, and Mr. J. asked them to skip down and complete the Lessons Learned prompt before they'd had an opportunity to reflect on the problems and solutions in such a way that the lessons they could learn from the expert case could be made visible. As a result, they identified a design rule of thumb that was unrelated to the expert case and deemed by one group member as being "horrible." However, the group was able to identify a general problem the experts faced, a solution that included the criterion or constraint the solutions was supposed to address, and specific criteria. Group discussions revealed that this group did not collaborate effectively, and at least half of the group was disengaged from the activity. Furthermore, the group did not seem to use the written expert case to inform their discussions, relying instead on their memories of the expert case. We will show later how we think discussion of this topic impacted later capability for this group.

6.6 Episode 5: Using the Case Interpretation Tool: Second Software-Scaffolded Case Activity and Discussing the First Software-Scaffolded Case Activity

This episode presents the second time groups used the Case Interpretation Tool to interpret an expert case. Overall, the Ridge and Valley group identified specific expert problems and solutions that included the criteria/constraint the solution was supposed to address as well as some detail about how the solution was implemented. While the group's ability to identify expert solutions improved, their ability to identify criteria and design rules of thumb declined. Instead, they identified a specific criterion that did not include justification for choosing the criterion and a general design rule of thumb. The group's discussions were similar to those in Episode 4 in that the group continued to classify, support, and refute ideas using the definitions of the classifications in question as justification or evidence. However, they were different from those in Episode 4 because the group did not use the expert case to inform their discussions and written work, relying mostly on their memories of the Tecolote Tunnel case when generating, supporting, and refuting ideas. The Ridge and Valley group also did not have Mr. J's scaffolding available to them to push their reasoning.

Overall the Coastal Plain group performed much better during this, their second use of the Case Interpretation Tool than they did during their first use. They did not have all of the interruptions they had during Episode 4. As a result, the group's ability to identify problems the experts faced, solutions, criteria, and design rules of thumb matched our predictions for this episode. The Coastal Plain group identified specific problems and specific solutions that described the criteria or constraint the solutions was supposed to address and also included detail about how the solution was implemented. The group also identified specific criteria and design rules of thumb that included justification as well as suggestions about how the design rule of thumb could be applied to their Tunneling Through Georgia challenge. Group discussions revealed that the group collaborated much more effectively with three-fourths of the group members engaging in the group's discussions. The Coastal Plain group also used the written expert case to inform their discussions.

6.6.1 Enactment

The emphasis for this episode was the same as it was for Episode 5 in Case Study 1. As in his 5th period class, Mr. J. introduced topographic and relief maps, focusing on what each map was useful for and how each map should be read. He also led a class discussion to help students begin thinking more about what they should be focusing on as they interpret an expert case. Students responded to his questions in the same ways they had in 5th Period, summarizing the case in one or two sentences.

Then, groups began interpreting either the Tecolote Tunnel case or the Mono Craters Tunnel case in their small groups using the Case Interpretation Tool. The Ridge and Valley group interpreted the Mono Craters Tunnel case, while the Coastal Plain group interpreted the Tecolote Tunnel case. As the groups used the Case Interpretation Tool, Mr. J. went from group to group occasionally answering questions.

As in 5th period, students interpreted their second cases for about 30 minutes of class, and then went to the Library Tool in SMILE and commented on the interpretations of other groups in their period. After groups commented on the interpretations of other groups, Mr. J. facilitated a class discussion to pull together the lessons they had learned across the expert cases they had encountered up to that point by creating a table of important design rules of thumb for the cases that had been interpreted before that day as well as the sedimentary rock model lab that the class had been working on. They explored what those design rules of thumb might suggest for their challenge. Table 6.22 shows the table that resulted from that class discussion. Notice that this table is almost identical to Table 5.5 in Chapter 5 because Mr. J. prompted students for the same information in both class periods. As we described in Case Study 1, this table shows the lessons learned from each expert case or activity in the second column (Lessons) and how the lesson could be applied to the *Tunneling Through Georgia* challenge in the third (Applies to Our Tunnel). However, as we discussed in Case Study 1, some of the lessons that were articulated were not actually design rules of thumb. Instead, the entries in the Applies to Our Tunnel column seem to be general design rules of thumb, while entries in the Lessons column seem to be partial justifications for the design rules of thumb (i.e., Need to know what sedimentary rocks are at the tunnel site b/c different sedimentary rocks act differently).

Table 6.22 – Table of Expert Cases, Lessons Learned From Expert Cases, and Ideas for Applying to Tunnel Challenge

Source	Lessons	Applies to Our Tunnel
Lotschberg Case	Need to know the materials to be drilled through (rocks, etc.)	Take core samples
	Need food, water, shelter, supplies	Location of nearest city/town
	Explosive cased cave-ins	Need to take safety conscious

Table 6.22 – Table of Expert Cases, Lessons Learned From Expert Cases, and Ideas for Applying to Tunnel Challenge (Continued)

Sedimentary Rock Models	Sedimentary rock particles fell apart	Some sedimentary rocks make for poor tunneling
	Different sedimentary rocks act differently	Need to know what sedimentary rocks are at the tunnel site
	Rocks change over time	
St. Gotthard Tunnel	Water can flood and destroy the tunnel	Loose sediments cause cave-ins
Hoosac Tunnel	Sandy/silt materials cause cave-ins	Need to correctly locate core samples
Frejus/Mt. Cenis Tunnel	Hit a cold spring	Watch out for water
Queens Midtown Tunnel	Had to filter out air from machine exhaust	Ventilation system
	Concern of dredging destroy	Land elevation necessary to dig

6.6.2 Predictions

For the Coastal Plain group, expectations were the same as those for Episode 5 in Case Study 1. However, because the Ridge and Valley group was interpreting the Mono Craters Tunnel case, which was the shortest out of the expert cases interpreted by Mr. J's 5th and 6th period classes (only 3 pages in length including 3 large pictures), we predicted that the Ridge and Valley group would identify fewer expert problems, solutions, criteria, constraints, and design rules of thumb. This was because there were fewer of them to identify in this expert case when compared to the other expert cases. Looking at the description of solutions in the expert case, we see that they are not as descriptive in the Mono Craters Tunnel case as they are in other expert cases because they do not describe the process the experts used to implement the solution in as much detail as other expert cases do. Because this case does not include detailed descriptions about the implementation of the solutions the experts used to address their problems, we predicted that the Ridge and Valley group would either provide general descriptions of expert solutions in the case or to provide descriptions of expert solutions that included the benefit the solution was supposed to have or the criterion/constraint the solution was supposed to address.

6.6.3 Student Work

As the Ridge and Valley group used the Case Interpretation Tool, Every member either had their student book open to the written expert case. However, only Michelle, Sam, and Daniel referred to the written expert case throughout the entire episode; Kenny referred to his memories of the case. Kenny, Sam, and Michelle dominated the discussion, while Daniel was quiet. In general, the Ridge and Valley group had an easy time identifying problems and identifying criteria and constraints. However, they had a difficult time finding implementation details for the solutions in the short Mono Craters Tunnel case, and they struggled to articulate the justification for their design rule of thumb. They spent most of their discussion time talking about expert solutions and design rules of thumb.

In the Coastal Plain group, Melissa had the written expert case available during the entire episode, while Sandy and Chris looked onto Melissa's student book periodically throughout the episode when referring to the expert case. No one group member dominated the discussion. This group had an easy time identifying expert problems, solutions, and design rules of thumb. They had a more difficult time identifying criteria and constraints, spending most of their discussion time on this topic. Inter-rater reliability for this episode was 98%, as it was for Episode 5 in Case Study 1.

6.6.3.1 Ridge and Valley Group

As summarized in Table 6.23, the Ridge and Valley group was able to identify one specific aspect of a problem the experts faced in the Tecolote Tunnel case that did not include causality (Identifies Problems (I)) *High water pressure on the tunnel* as an expert problem. The group identified a solution the experts used to address the problem they encountered, *Due to high water pressure on the tunnel, holes were drilled into the tunnel walls that led to pipes to carry the water away,* that provided a description of a solution that included the benefit the solution was supposed to have or the criteria or constraint the solution was supposed to address and also included some detail about how the solution was implemented (Identifies Solutions (II)).

The Ridge and Valley group identified one criterion that described a specific objective the experts wanted to address(Understands Criteria (V)), *The experts wanted* *the tunnel to be 9 feet and 7.5 inches in diameter*. They also identified two constraints (Understands Constraints (VI)). The first constraint, *The tunnel had to go hundreds of miles to get the fresh water they needed*, described a specific constraint, what the constraint affected, and included justification for choosing the constraint. The second constraint, *Had to go through 9000 feet of soft earth while tunneling* was a general constraint. The Ridge and Valley group also described an outcome that could occur as a result of the experts addressing the first constraint (Connects Constraints To Outcomes (VII)). The group identified one general design rule of thumb (Rule of Thumb (VIII)), *When water is a problem, use holes drilled in the tunnel to extract water because water will flow out because of the law of gravity.* Although this group included justification for this design rule of thumb, the justification was incorrect, so the design rule of thumb was rated as being a general one.

Table 6.23 – Ridge And Valley Group's Two Best Answers From Case Interpretation Tool – Mono Craters Tunnel case

Ridge and Valley Group		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	High water pressure on the tunnel.	3
Identifies Solutions (II)	Due to high water pressure on the tunnel, holes were drilled into the tunnel walls that led to pipes to carry the water away.	4
Specifies Implementation (III)		3
Understands Criteria (V)	The experts wanted the tunnel to be 9 feet and 7.5 inches in diameter.	3
Understands Constraints (VI)	The tunnel had to go hundreds of miles to get the fresh water they needed.	4
	Had to go through 9000 feet of soft earth while tunneling.	2
Connects Constraints To Outcomes (VII)		2
		1
Rules of Thumb (VIII)	When water is a problem use holes drilled in the tunnel to extract water because water will flow out because of the law of gravity.	2

Table 6.24 shows the coding results for this episode.

Table 6.24 – Ridge And Valley Group Case Interpretation 2 Coding Results

	Ridge and Valley Group's Coded Results Case Interpretation 2 – Mono Craters Tunnel		
Identifies Problems (I)	3		Total – 1
Identifies Solutions (II)	4		Total – 1
Specifies Solution Implementation (III)	3		Total – 1

Table 6.24 – Ridge And Valley Group Case Interpretation 2 Coding Results (Continued)

Identifies Criteria (V)	3		Total – 1
Identifies Constraints (VI)	4	2	Total – 2
Connects Constraints To Outcomes (VII)	2	1	Total – 2
Rules of Thumb (VIII)	2		Total – 1

6.6.2.2 Group Discussions

The Ridge and Valley group began by talking about the goal the experts faced and the criteria and constraints the experts had to address in the problem. As in Episode 4, this group used the expert case to inform the criteria and constraints they identified. However, about midway through their discussion of criteria and constraints, Mr. J. began calling members of the group up to his desk one at a time to give them and discuss their mid-term progress reports:

(1) Sam: Uh, a constraint would be that they had to go
(2) through 9000 feet of soft earth.
(3) Daniel: 8000-oh no. Sorry.
(4) Michelle: To get [inaudible].
(5) Sam: To get the water.
(6) [Sam walks over and points in Michelle's book]
(7) Michelle: But they wanted-
(8) Daniel: No, 9000 was in soft earth. They said it.
(9) Mr. J.: Michelle…Come on up.
(10) [Michelle walks away]
(11) Sam: I think that's it. We're done.

Excerpt 6.6.3.1 – Mr. J. Interrupts Ridge And Valley Group

In this excerpt, Sam identified a constraint the experts had to address, namely, that they had to go through 9000 feet of soft earth (lines 1 and 2). Daniel began to correct Sam's constraint, but as he looked at the constraint in the expert case, he saw that Sam was correct and withdrew his correction (line 3). Michelle seemed to express confusion about some aspect of Sam's constraint (line 4), and Sam not only attempted to relieve Michelle's confusion verbally (line 5), but he also showed her in the expert case where his idea came from (line 6). Still not satisfied, Michelle seemed to suggest that some aspect of Sam's idea was a criterion (line 7), but she was cut off by Daniel who supported Sam's classification by saying that the expert case said there was 9000 feet of soft earth (line 8). However, before Michelle can argue her point, Mr. J. called her up to his desk and she walked away (lines 9 and 10).

During most of the group's discussion of the *Solution Chosen* prompt, Michelle was at Mr. J.'s desk talking with him about her progress report. This discussion presented the first time the group included an idea that was not supported by the written expert case as a response to a prompt in the Case Interpretation Tool, and it also included the first instance of Kenny bullying the group to include an unsupported idea in their response:

(12) Daniel: Alright…What did they decide to do to meet
(13) the challenge?
(14) Sam: Uh…They…
(15) Kenny: The experts…the experts decided…
(16) Sam: Decided to…uh…
(17) Kenny: They went through the craters 'cause it
(18) would save the most time.

(19) Sam: Did they?

(20) Kenny: Wouldn't it? Like, they couldn't gone

(21) around the craters, couldn't they? But it saved time

(22) to go through the craters.

(23) Daniel: I don't know.

(24) [Kenny types it in—Michelle returns]

Excerpt 6.6.3.2 – Inclusion of Unsupported Idea in Group Answer and An Instance of Bullying

This excerpt began as Daniel read the *Solution Chosen* prompt (lines 12 and 13). Sam and Kenny both tried to generate a response for the prompt (lines 14-16), and Kenny finally suggested that the experts went through the craters instead of around them because it would save time (lines 17 and 18). Sam asked Kenny if he was sure the experts did this (line 19), and Kenny provided a justification that used his own logic (lines 20-22). Daniel was not convinced (line 23), but Kenny typed in his idea as the group's response anyway (line 24).

At this point, Michelle returned to the group, but she was not asked her opinion about Kenny's idea nor did she ask the group what they'd talked about while she was gone. Instead, the discussion continued with Sam identifying an expert solution and using persistence to insure that the idea was articulated in such a way that people outside of the group would be able to understand it. This presented the first time a member of the group verbally acknowledged and considered an audience outside of the group and articulated a response based on that consideration:

(25) Sam: OK…Kenny, due to high water pressure, they had

(26) to, uh…due to high water pressure…uh…oh! Holes were

(27) drilled in the tunnel walls in certain locations to

(28) bleed the water into closed pipe drains to keep the
(29) gases from escaping into the air.
(30) Daniel: Where's it say about the holes?
(31) Kenny: walls…
(32) Sam: that lead to pipes…to carry the water away…Due
(33) to high water pressure-Hey, Kenny! Due to high water
(34) pressure on the tunnel…No! Due to high water pressure
(35) ON the…KENNY! Due to high water pressure ON the
(36) tunnel, 'cause they might think it was in the tunnel.

Excerpt 6.6.3.3 – Sam's Persistence And Consideration of Audience Outside Of The Group

Here, Sam began by identifying an expert solution. Although it took him a while to describe the entire expert solution, he was able to include a small amount of detail about how the solution was implemented (lines 25-29). While Kenny began typing Sam's idea into the *Solution Chosen* prompt, Daniel asked Sam where the detail about the solution's implementation could be found in the expert case (line 30). Noticing that Kenny typed "Due to high pressure in the tunnel," Sam corrected Kenny's error, but Kenny did not seem to be paying attention to him. Remaining persistent, Sam used his persistence to get Kenny to change the wording to "Due to high pressure *on* the tunnel," and he stated that others might think that the high pressure was in the tunnel as opposed to on the tunnel if they left the wording as it was (line 32-36).

The group moved on to the *Time and Location* prompt, and as he was in mid-sentence, Sam was called away by Mr. J. to receive his progress report:

(37) Sam: Time and Location.
(38) Michelle: This challenge took place-
(39) Kenny: The experts took the challenge-

(40) Sam: In California.

(41) Michelle: [Inaudible]

(42) Sam: No, it was in California. Talking ‘bout the Mono

(43) Craters.

(44) Daniel: This wasn’t Leevining?

(45) Sam: California. I don’t think it says-

(46) Mr. J.: Sam?

(47) Sam: Yes? [He walks away]

Excerpt 6.6.3.3 – Interruption of Group Discussion By Mr. J.

Following Sam’s departure from the group, they tried to complete the *Time and Location* prompt, but they could find any additional information in the expert case so they moved on to the *How The Solution Was Carried Out* prompt. The group struggled to answer this prompt because there was almost no detail about expert solutions outside of the short description of holes being drilled in the tunnel to relieve the pressure on the tunnel described by Sam in the previous prompt. This inability to answer the prompt due to a lack of information began to frustrate the group and they seemed to begin losing focus. In addition, Mr. J. called another member away from the group to discuss mid-term progress reports:

(48) Michelle: What process did the experts use to design

(49) and build their solution? What steps did they take to

(50) carry the solution out?…The experts used the process

(51) of…

(52) Daniel: The experts used the process of…

(53) Michelle: It was designed to have circular shape.

(54) Kenny: The experts used the process of…

(55) [Sam returns from seeing Mr. J.]

(56) Sam: You guys, c'mon. What process did the experts

(57) use to design and build their solution? What steps

(58) did they take to carry the solution out?

(59) Daniel: The experts used the process of…The experts

(60) used the process of…

(61) Kenny: Elimination!

(62) Daniel: The experts used the process of…[to

(63) Michelle] What were you gonna say?

(64) [Michelle tries to give her student book to Sam]

(65) Sam: [pointing to his own student book] I'm looking at

(66) it.

(67) [Michelle gives her student book to Kenny]

(68) Kenny: You just gotta tell me what to type, and

(69) I'll type it.

(70) Sam: Guys…Kids…

(71) [Sam walks away and comes back with a chair to sit

(72) down]

(73) Daniel: What were you guys saying about the process?

(74) Michelle: Well, it was just saying that…

(75) Sam: It doesn't really give that much.

(76) Mr. J: Kenny!

(77) Kenny: Yes?

(78) Mr. J: Come on up!

(79) [Kenny walks away]

(80) Sam: Uh, we need a-There's nothing in there!

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(81) Michelle:  Maybe we should just skip that one for now.
     Cause he said-
(82) Sam:  OK!  What's Science & Technology?…
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Excerpt 6.6.3.4 – Group Struggles To Describe Implementation And Mr. J. Calls Another Student Away

Here, Michelle began by reading the *How The Solution Was Carried Out* prompt and attempted to formulate a response (lines 48-51). Daniel also attempted to formulate a response (line 52), and Michelle suggested an answer which no one acknowledged (line 53). As Kenny attempted to articulate a response (line 54), Sam returned from talking with Mr. J (line 55). Seeing their pondering as them not working, he encouraged them to get back on task and read the prompt (lines 56-58). Daniel unsuccessfully tried again to generate a response (lines 59-62), and he finally acknowledged Michelle's suggestion (line 63). Michelle attempted to give her student book to Sam and Kenny, but they both refused (lines 64-69), and again, Sam tried to refocus the group (line 70). Daniel asked Michelle again what her suggestion was (line 73), and as she began to describe her suggestion (line 74), she was cut off by Sam who stated that the case really didn't provide much information (line 75). Mr. J. called Kenny up to discuss his mid-term report, and he walked away from the group (lines 76-79). Frustrated, Sam tried to formulate a response to the prompt, but exclaimed, "There's nothing in there!" (line 80). Michelle suggested they skip that prompt, and before she could complete her suggestion, Sam moved on to the next prompt.

Kenny returned at the beginning of the group's discussion of the *Science and Technology* prompt. This marked the first time that all four members of the group were together during group discussion since the *Criteria and Constraints* prompt. The group's discussion about Science and Technology, Vocabulary, and Learning Issues prompts were what we expected. During the Rule(s) of Thumb prompt, the group even collaboratively explained the design rule of thumb template to Sam, who was absent from school during Episode 4 and had never seen the template. However, toward the end of the group's discussion about the Rule(s) of Thumb prompt, the group struggled to identify and articulate justification for the design rule of thumb they'd identified. Kenny suggested an idea for justification that was neither grounded in the expert case nor seemed correct to the rest of the group, but he was able to force his idea into the group's response, presenting the second instance of bullying by Kenny:

(83) Kenny: When—take away the you. When water is a
(84) problem…use
(85) Michelle: Holes.
(86) Kenny: Yeah, use holes drilled into the tunnel-
(87) Daniel: Use holes to extract water-
(88) Kenny: In the tunnel to…take out the water.
(89) Daniel: To extract.
(90) Kenny: Because…
(91) Sam: Because…
(92) Kenny: Because it works.
(93) Sam: It's a proven method…
(94) Mr. J.: How many of you are on lessons learned?
(95) Sam: [to Kenny] 'Cause it's a…Because it is a
(96) what?…Because it is proven…
(97) Daniel: Well, it says [reading the template] please
(98) supply the science concept or principle that backs up

(99) your suggestion.

(100)Kenny: Because water will go through the holes

(101)because of the law of gravity.

(102)[The group stares at him in silence]

(103)Kenny: They drilled the holes more at the

(104)bottom, right? So the water will just flow right

(105)out.

(106)Daniel: But they…uh…

(107)Sam: Will flow?

(108)Kenny: Will flow out because of the law of

(109)gravity.

(110)Michelle: Will flow.

(111)Sam: Because of basic science principles…

(112)Kenny: Alright. Insert sentence.

(113)Sam: Because of the law of gravity?

(114)Kenny: Because of the law of gravity.

Excerpt 6.6.3.5 – Group Discussion About Design Rule Of Thumb

Here, Kenny began formulating a design rule of thumb using the scaffolding provided in the design rule of thumb template (lines 83 and 84). Michelle, Kenny, and Daniel articulated the first portion of the design rule of thumb together (lines 85-89). When the group reached the justification portion of the design rule of thumb, they got stuck (lines 90-96). Daniel tried to use the scaffolding of the template to help them formulate a justification that was connected to a science concept or principle (lines 97-99). Kenny suggested that water would go through the holes because of the law of gravity (lines 100 and 101). The group seemed to stare at him in disbelief, but Kenny provided his thoughts on why his justification was correct (lines 103-105). Daniel attempted to interject (line 106), but was cut off by Sam who was typing (line 107). Kenny restated his idea for justifying the group's design rule of thumb (lines 108 and 109), and Michelle repeated part of Kenny's suggestion (line 110). Sam suggested a more general justification (line 111), but Kenny ignored it and told Sam to insert the design rule of thumb into the group's Case Interpretation Tool artifact (line 112). Sam asked again if the justification was what the group wanted (line 113), and Kenny repeated his justification (line 114). Because the group could not come up with an alternative justification and because of Kenny's persistence that they use his suggestion, the group used the law of gravity as justification for their design rule of thumb.

6.6.2.3 Coastal Plain Group

In this episode, summarized in Table 6.25, the Coastal Plain group identified one specific aspect of a problem the experts faced that did not include causality (Identifies Problems (I)): *The filling of the water inside the tunnel* as an expert problem. The Coastal Plain group identified a solution the experts used to address a problem they encountered that not only provided a description of the solution that included the benefit the solution was supposed to have or the criteria or constraint the solution was supposed to address, but also that included some detail about how the solution was implemented (Identifies Solutions (II)). They typed *The solution they came to for filling of the water inside the tunnel was that they used two drainage tunnels that carried the water that was filling the tunnel up. They dug smaller tunnels off the sides to drain the water out*.

The group identified criteria that described specific objectives the experts wanted to address(Understands Criteria (V)), namely *They wanted it to be horseshoe shaped* and

The tunnel was proposed to be 6.4 miles long. They also identified general constraints (Understands Constraints (VI)): *They needed the design to be a diameter of 7 feet* and *The experts needed to find a new water source*. The group did not describe the outcomes that could occur as a result of the experts addressing or failing to address constraints (Connects Constraints To Outcomes (VII)). However, they identified one design rule of thumb that included causality and/or justification as well as suggestions for ways it might be implemented when they typed (Rule of Thumb (VIII)), *When tunneling across Georgia, we need to use dams to block water, concrete to line the walls, and reservoirs to keep the water in one place so the water doesn't get in the tunnel.*

Table 6.25 – Coastal Plain Group's Two Best Answers From Case Interpretation Tool – Tecolote Tunnel case

Coastal Plain Group		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	The filling of the water inside the tunnel	3
Identifies Solutions (II)	The solution they came to for filling of the water inside the tunnel was that they used two drainage tunnels that carried the water that was filling the tunnel up. They dug smaller tunnels off the sides to drain the water out.	4
Specifies Implementation (III)		2
Understands Criteria (V)	They wanted it to be horseshoe shaped.	3
	The tunnel was proposed to be 6.4 miles long.	3
Understands Constraints (VI)	They needed the design to be diameter of 7 feet.	2
	The experts needed to find a new water source.	2
Connects Constraints To Outcomes (VII)		1
		1
Rules of Thumb (VIII)	When Tunneling across Georgia, we need to use dams to block water, concrete to line the walls, and reservoirs to keep the water in one place so the water doesn't get into the tunnel.	4

Table 6.26 summarized the coding results for the Coastal Plain group for this episode.

Table 6.26 – Coastal Plain Group Case Interpretation 2 Coding Results

	Coastal Plain Group's Coded Results Case Interpretation 2 – Tecolote Tunnel		
Identifies Problems (I)	3		Total – 1
Identifies Solutions (II)	4		Total – 1

Table 6.26 – Coastal Plain Group Case Interpretation 2 Coding Results (Continued)

Specifies Solution Implementation (III)	2		Total – 1
Identifies Criteria (V)	3	3	Total – 3
Identifies Constraints (VI)	2	2	Total – 3
Connects Constraints To Outcomes (VII)	1	1	Total – 3
Rules of Thumb (VIII)	4		Total – 1

6.6.2.4 Group Discussions

Group discussions during this episode were more like what we expected. The group was able to work together much better during this episode than they were during Episode 4, and they did not experience the technical issues they experienced in Episode 4. They began by discussing the expert's goal. Then, they discussed criteria and constraints the experts had to address. Unlike their discussions during Episode 4, there was more participation by more of the group during this episode. Despite Chris's decline in participation from Episode 4 to this episode, Sandy and Chad seem more focused and contributed more to the group's discussion and the articulation of the group's responses. Also unlike their discussions during Episode 4, where they answered each question in the Criteria and Constraints prompt separately, in this episode, they used the Criteria and Constraints template from the beginning to guide their discussion. Although the criteria and constraints they generated were all based on the group's memories of the expert case instead of being grounded in the written facts of the expert case, the group's discussion began to focus on classifying ideas generated using the definitions of criterion and constraint as evidence to support or refute the classification of those ideas:

(1) Melissa: OK, criteria.
(2) [Group talks about camera]
(3) Melissa: OK, you guys, criteria.
(4) Sandy: They needed a new water supply.
(5) Melissa: OK, is that a criteria though?
(6) Sandy: Yeah.
(7) Melissa: OK…criteria…they needed…
(8) Chad: Criteria…Isn’t that wants?
(9) Melissa: Yeah.
(10) Chad: They didn’t need the water? Didn’t they need
(11) the water?
(12) Melissa: They needed the design to be a diameter of 7
(13) feet?
(14) Chris: [pointing to the water entry in the table and
(15) sliding his finger over to the constraints column]
(16) They needed that.
(17) Melissa: I know. I’m just putting this one…OK, they
(18) wanted it to be horseshoe shaped…OK.
(19) Chad: They wanted the water to go down it so they
(20) tilted it a wee bit.
(21) Melissa: They wanted water to go…[to Chad] what did
(22) they want? They wanted water to go down what?
(23) Chad: They wanted it to go, like, downward, so it

(24) would end at the place.

(25) Melissa: So it would…

(26) Chad: Yeah, when it’s flowing downstream.

(27) Melissa: so it would go…

(28) Chad: Go faster or something.

(29) Melissa: So it would go to…

(30) Sandy: Reach the other side.

(31) Chad: It would get there faster…’Cause if you slant

(32) it, it would go [makes a noise].

(33) Melissa: So, [reading the screen] they wanted water

(34) to go down the tunnel so it would reach the other

(35) side?

(36) Chad: Yeah.

(37) Sandy: Yeah.

Excerpt 6.6.4.1 – Group’s Discussion of Criteria And Constraints Focusing On Classification

In this excerpt, Melissa prompted the group for criteria (line 1). The group started to look at and talk about the camera being used to videotape their discussion, but Melissa prompted the group for criteria to get their focus back on the task (line 3). Sandy suggested an idea for a criterion, that the experts needed a new water supply (line 4). Noticing Sandy’s use of the word “needed,” Melissa asked if Sandy was sure it was a criterion (line 5), and Sandy answered that she was (line 6). Not convinced, but seeming to not want to debate with Sandy, Melissa began typing Sandy’s idea in as a criterion (line 7). However, Chad, remembering the definition of criterion, asked the group if criteria are wants (line 8). Hearing that they were, he felt that Sandy’s idea was a constraint and asked if the experts needed the water as opposed to wanting the water (lines 10 and 11). Melissa interjected with another constraint, but Chris pointed to Sandy's idea in the criteria column of the template and suggested that Melissa move it to the constraints column because "they needed that" (lines 14-16). Melissa affirmed that she would do that after entering her idea into the criteria column (which she never did), and then suggested yet another criterion (lines 17 and 18). Chad also suggested a criterion (lines 19 and 20), and Chad and Sandy helped Melissa articulate Chad's criterion (lines 21-35).

The classification-focused discussion continued throughout the group's discussion of criteria and constraints. Melissa suggested that the tunnel being proposed to be 6.4 miles long was a criterion, and asked the group if they agreed. Sandy used the definition of criterion and the facts of the expert case to support Melissa's classification:

```
(38) Melissa:  Where would this go? [reading the expert
(39) case] A tunnel was…guys…where would this go?  [reading
(40) the expert case] A tunnel was proposed 6.4 miles to
(41) carry the water.  That would be a…would that be a
(42) criteria?  Would be a tunnel was proposed 6.4 miles
(43) long?
(44) Sandy:  Yeah, that would be a criteria, 'cause it was
(45) proposed.
```

Excerpt 6.6.4.2 – Classification-Focused Discussion About Criterion

The Coastal Plain group continued to move through the remainder of the prompts in their intended order and did not skip around as they had in Episode 4. Although Melissa was the only group member who consistently used the written expert case to generate ideas, she periodically passed the expert case to Sandy and Chad to use to support or refute generated ideas or they looked over her shoulder.

6.6.3 Summary of Results

This episode represents the second time student groups interpreted cases in their small groups using the Case Interpretation Tool. Overall, while the Ridge and Valley group's performance for interpretation matched our predictions for this episode, the group's ability to identify expert problems, criteria, and design rules of thumb declined from their first use of the Case Interpretation Tool. In this episode, they identified a specific problem, a specific criterion that did not include justification for choosing the criterion, and a general design rule of thumb. Although the group's discussion about criteria and constraints continued to focus on using the definitions of criterion and constraint to classify, support or refute ideas generated by the group, fewer group members used the expert case in the student book to generate, support, and refute ideas. Also, the group did not have Mr. J's in-the-moment scaffolding available to them as they worked. Because their case was one of the shortest cases, it did not provide as much detail as some of the other expert cases, and the group became frustrated when they could not find all of the detail they were being prompted for. As a result, the group became less and less engaged with the task over the course of Case Interpretation Tool use. However, during this episode, Sam considers an audience outside of the group and pushes for a criterion to be articulated in such a way that the outside audience is taken into consideration.

Overall, the Coastal Plain group's performance for interpretation matched our predictions for this episode. The group's was able to identify specific problems and specific solutions that described the criteria or constraint the solutions was supposed to address and that also included detail about how the solution was implemented. The Coastal Plain group identified specific criteria and design rules of thumb that included justification as well as suggestions about how the design rule of thumb could be applied to their Tunneling Through Georgia challenge. Group discussions revealed that the group collaborated much more effectively with three-fourths of the group members engaging in the group's discussions. The group also used the written expert case to inform their discussions, which focused on classifying the ideas generated.

6.7 Episode 6: Using the Case Application Tool

This presents the first time groups used the Case Application Tool to analyze and apply design rules of thumb gleaned from a previously interpreted expert case. Overall, both the Ridge and Valley and Coastal Plain groups' abilities to apply the Mono Crater Tunnel case matched our predictions. While the Ridge and Valley group was able to apply a relevant design rule of thumb, the Coastal Plain group attempted to apply a design rule of thumb that did not seem to be derived directly from the expert case. As a result, the predictions they made about the design rule of thumb were incorrect. However, neither group applied design rules of thumb identified and articulated during their interpretation of the expert cases. Instead, both groups attempted to apply new design rules of thumb.

6.7.1 Enactment and Predictions

A week following their second use of the Case Interpretation Tool, groups applied a case they had previously interpreted. The emphasis and expectations for this episode were the same as for Episode 6 in Case Study 1. Groups engaged in the rock lab and built and tested a core sample model, after which they re-read their previous case interpretations to decide which of those cases they wanted to apply using the Case Application Tool. As groups worked, this was the first time Mr. J. went from group to group reminding them to read the hints and examples for each prompt. He also helped them figure and describe out what the goals, criteria, and constraints of their challenge were.

As in 5th period, groups had 10-15 minutes to respond to the first two prompts of the Case Application Tool (Table 4.1), and used the remainder of the 50 minute class period to complete the Applying Our Rules of Thumb template (Figure 6.2). Mr. J. directed each group's attention to the example accompanying the Rule(s) of Thumb prompt (Figure 6.3) and told them to be sure to look at the example to understand how to use the template and to understand what information the template was reminding and hinting them for.

6.7.2 Student Work

As the Ridge and Valley group used the Case Interpretation Tool for the third time, Margaret, Billy, and David used the expert case in their student books throughout this episode, looking back to it while they worked. Theresa referred to the expert case only occasionally during this episode. No one group member dominated the discussion. Although at times Theresa and Billy appeared to be disengaged from the conversation, they would always jump right into the discussion offering up ideas or asking questions related to the current discussion. Unlike their previous uses of the Case Interpretation Tool, this time the group spent most of their discussion time understanding the problems the experts faced and the solutions they used to address those problems.

As the Blue Ridge group used the Case Interpretation Tool for the third time, Margaret, Billy, and David used the expert case in their student books throughout this episode, looking back to it while they worked. Theresa referred to the expert case only occasionally during this episode. No one group member dominated the discussion. Although at times Theresa and Billy appeared to be disengaged from the conversation, they would always jump right into the discussion offering up ideas or asking questions related to the current discussion. Unlike their previous uses of the Case Interpretation Tool, this time the group spent most of their discussion time understanding the problems the experts faced and the solutions they used to address those problems. Inter-rater reliability for this episode was the same as for Episode 6 in Case Study 1, 97%.

6.7.2.1 Ridge And Valley Group

As summarized in Table 6.27, the Ridge And Valley group seemed to understand their challenge. They provided a general but correct description of their challenge: *Our design goal is to build a successful tunnel for a high speed train to transport people across Georgia. Another goal is to make the tunnel safe for the passengers to travel through*. The Ridge and Valley group identified specific objectives they wanted to address: *We would like to have a safe trip for the passengers that are traveling on the train* and *We would like to have a fast trip to their destination within a short period of time*. They identified general constraints: *We have to go through a mountainous region* and *Time constraint: by the same time the other tunnels are finished*.

The Ridge and Valley group identified general design rules of thumb, neither of which was carried over from the group's interpretation of the Mono Craters Tunnel. As with the Blue Ridge group, despite having read their case interpretation for the Mono

Craters Tunnel case immediately before using the Case Application Tool and despite the Case Interpretation Tool artifact for the Mono Craters tunnel case being available in Browse mode in the left frame, the Ridge and Valley group did not seem to recognize that they should use the design rules of thumb they created during their interpretation of the Mono Craters Tunnel from Episode 5. Instead, they typed *Water can seep through permeable rock* and *Drilling around mountains could mean an encounter with a spring*.

When analyzing their design rules of thumb to not only determine whether they were applicable, but to also explore how they might be incorporated into their design solution, the resulting Applying Our Rules of Thumb template was generated:

Applying our Rules of Thumb

Rule of Thumb	Criteria addressed by rule of thumb	Predictions the rule of thumb makes	Is the rule of thumb applicable (yes or no)	Ways the rule of thumb applies
Water can seep through permeable rock.	We do not want this to happen.	That we will run into water problems because of this rock.	YES!	If we drill through permeable rock, water will leak through the tunnel and may cause destruction.
Softer materials are more difficult to drill through.	This addresses our desire to avoid soft materials while drilling.	With softer material, there might be cave-ins in the tunnel.	YES!	If we hit softer material, destruction will be likely to happen.
Drilling around mountains could mean an encounter with a spring.	This addresses our concern of striking water.	We predict more springs in mountainous regions than lowlands.	YES!	This applies to our case because we are going through mountainous areas.

Figure 6.1 Ridge And Valley Group's Applying Our Rules of Thumb Template

As shown in Figure 6.1 and summarized in Table 6.27, the Ridge and Valley group was able to judge whether their design rules of thumb were applicable. Looking at the first entry in the template, we see that although the criterion the group identified as being addressed by the design rule of thumb was incomplete (i.e., We do not want this to happen), the group was still able to identify a correct prediction or suggestion that this design rule of thumb could make for their challenge (i.e., That we will run into water problems because of this rock). Looking at the third entry in the template, we see another design rule of thumb that the group judged as being applicable to their challenge. This design rule of thumb addressed a criterion not previously mentioned (i.e., This addresses our concern of striking water), but the group nonetheless identified a correct prediction or suggestion that the design rule of thumb could make for their challenge (i.e., We predict more springs in mountainous regions than lowlands).

Looking at the quality of application of the design rules of thumb, we see that while the Ridge and Valley group was able to apply the design rules of thumb as predictions or justifications for application, they did not incorporate the suggestions or justifications made by the design rules of thumb into solutions or suggestions for a solutions. For example they typed, *If we drill through permeable rock, water will leak through the tunnel and may cause destruction* and *This applies to our case because we are going through mountainous areas*. The first of these answers is a prediction that the design rule of thumb makes, while the second is a justification for applying the design rule of thumb to their solution. However, neither of these answers is a solution or a suggestion for a solution. Given the group's ability to judge their design rules of thumb as applicable and given the quality of the application of those design rules of thumb, it follows that the Ridge and Valley group was able to find a match between some criterion in their challenge and a problem that each of these design rules of thumb addressed, and they were able to identify correct predictions or suggestions these design rules of thumb could made for their design solution.

Table 6.27 – Ridge And Valley Group's Two Best Answers From Case Application Tool – Mono Craters Tunnel case

Ridge And Valley Group		
Dimension	Answer(s) Given	Rating(s) Given
Understands Criteria (V)	We would like to have a safe trip for the passengers that are traveling on the train.	3
	We would like to have a fast trip to their destination within a short period of time.	3
Understands Constraints (VI)	We have to go through a mountainous region.	2
	Time constraint: by the same time the other tunnels are finished.	2
Connects Constraints To Outcomes (VII)		1
		1
Rule of Thumb (VIII)	Water can seep through permeable rock.	2
	Drilling around mountains could mean an encounter with a spring.	2
Judges Applicability of Rule of Thumb (IX)		2
		3
Quality of Application of Rule of Thumb (X)		2
		2
Understands the Challenge (XI)		3
Finds a Match Between Criteria and Problem Rule of Thumb Addresses (XII)		4
		4

Table 6.28 summarizes the coding results for group capability using Case Application Tool to apply the Tecolote Tunnel case.

Table 6.28 – Ridge And Valley Group Case Application I Coding Results

	Ridge And Valley Group's Coded Results Case Application I – Mono Craters Tunnel		
Understands Criteria (V)	3	3	Total – 3
Understand Constraints (VI)	2	2	Total – 4

Table 6.28 – Ridge And Valley Group Case Application I Coding Results (Continued)

Connects Constraints to Outcomes (VII)	1	1	Total – 4
Rule of Thumb (VIII)	2	2	Total – 3
Judges Applicability of Rule of Thumb (IX)	2	3	Total – 3
Quality of Application of Rule of Thumb (X)	2	2	Total – 3
Understands the Challenge (XI)	3		N/A
Finds a Match Between Criteria and Problem Rule of Thumb Addresses (XII)	4	4	Total – 3

6.7.2.2 Coastal Plain Group

As summarized in Table 6.29, the Coastal Plain group did not seem to understand their challenge. They provided an incorrect description of their challenge when they typed *Our design was to build a tunnel from Chattanooga to Jekyll Island.* In fact, the Coastal Plain group's goal was to design a tunnel that would run from Baxley to Jessup. However, the Coastal Plain group was able to identify criteria and constraints. They identified one general criterion (Understands Criteria (V)), *We want the shortest route,* and one specific objective they wanted to address, *We want to follow interstate 75.* The Coastal Plain group identified general constraints when they typed *There is a cost constraint* and *We have to go underground.*

The Coastal Plain group identified one general design rule of thumb that was not carried over from the group's interpretation of the Tecolote Tunnel. Like the other two target groups, this group did not recognize that they should use the design rules of thumb they created during their interpretation of the Tecolote Tunnel from Episode 5. Instead, they typed *We have to get the information that the tunnelers need to apply to the challenge.*

When analyzing their design rules of thumb to not only determine whether they were applicable but to also explore how they might be incorporated into their design solution, the resulting Applying Our Rules of Thumb template was generated:

Rules(s) of Thumb
Use the "Applying Rules of Thumb" chart to figure out which rules of thumb apply to your challenge.

Applying our Rules of Thumb

Rule of Thumb	Criteria addressed by rule of thumb	Predictions the rule of thumb makes	Is the rule of thumb applicable (yes or no)	Ways the rule of thumb applies
We have to get the information that the tunnelers need to apply to the challenge.	We want the tu nneler's information to be accurate and precise.	A prediction that our rule of thumb makes is that the information that we got from the tunellers will be right.	Yes	

Figure 6.2 – Coastal Plain Group's Applying Our Rules of Thumb Template

As shown in Figure 6.2 and summarized in Table 6.29, the Coastal Plain group seemed unable to judge whether their design rule of thumb was applicable. Looking at the template, we see that the criterion the group identified as being addressed by the design rule of thumb was incorrect (i.e., We want the tunneler's information to be accurate and precise) and the prediction the group thought this design rule of thumb made for their challenge was also incorrect (i.e., A prediction that our rule of thumb makes is that the information that we got from the tunnelers will be right). Yet, the group still judged this design rule of thumb as being applicable to their challenge.

Looking at the quality of application of the design rules of thumb, we see that the Coastal Plain group did not explore the ways that the design rule of thumb they identified could be incorporated into a solution. Given the group's inability to judge their design rule of thumb as applicable and given the poor quality of the application of that design rule of thumb, it follows that the Coastal Plain group's prediction does not follow directly from the design rule of thumb. Instead, a match between a criterion and a problem addressed by the design rule of thumb was made, but the prediction made about the design rule of thumb was incorrect.

Table 6.29 – Coastal Plain Group's Two Best Answers From Case Application Tool – Tecolote Tunnel Case

Coastal Plain Group		
Dimension	Answer(s) Given	Rating(s) Given
Understands Criteria (V)	We want the shortest route.	2
	We want to follow interstate 75.	3
Understands Constraints (VI)	There is a cost constraint.	2
	Has to run beside a highway.	2
Connects Constraints To Outcomes (VII)		1
		1
Rule of Thumb (VIII)	We have to get the information that the tunnelers need to apply to the challenge.	2
Judges Applicability of Rule of Thumb (IX)		1
Quality of Application of Rule of Thumb (X)		1
Understands the Challenge (XI)		2
Finds a Match Between Criteria and Problem Rule of Thumb Addresses (XII)		3

Table 6.30 summarizes the coding results for group capability using Case Application Tool to apply the Tecolote Tunnel case.

Table 6.30 – Coastal Plain Group Case Application I Coding Results

	Coastal Plain Group's Coded Results Case Application I – Tecolote Tunnel		
Understands Criteria (V)	2	3	Total – 2
Understand Constraints (VI)	2	2	Total – 5
Connects Constraints to Outcomes (VII)	1	1	Total – 4
Rule of Thumb (VIII)	2		Total – 1

Table 6.30 – Coastal Plain Group Case Application I Coding Results (Continued)

Judges Applicability of Rule of Thumb (IX)	1		Total – 0
Quality of Application of Rule of Thumb (X)	1		Total – 0
Understands the Challenge (XI)	3		N/A
Finds a Match Between Criteria and Problem Rule of Thumb Addresses (XII)	1		Total – 0

6.7.3 Summary of Results

This episode presents student group's first time applying expert cases to their *Tunneling Through Georgia* challenge using the Case Application Tool. Overall, the both the Ridge and Valley and Coastal Plain groups understood the criteria and constraints that informed their challenge, and they identified and articulated both a general design rules of thumb. While the Ridge and Valley group was able to judge design rules of thumb as being applicable to their challenge, suggesting ways these design rules of thumb could be incorporated into their solution, the Coastal Plain group was unable to judge their design rule of thumb or incorporate it into a solution. This was because the design rule of thumb was not directly linked to the expert case, so the predictions the group made about the design rule of thumb were incorrect. However, the Ridge and Valley group was able to make connections between the criteria in their challenge and the problems the design rules of thumb made, and they were able to figure out how they could actually integrate and apply the design rules of thumb into their design solution, justifying their connections, integrations, and applications along the way.

6.8 Episode 7: Using the Case Interpretation Tool: Third Software-Scaffolded Case Interpretation Activity

Episode 7 presents the third and final time student groups used the Case Interpretation Tool to interpret an expert case. Overall, the Ridge and Valley group identified general problems as well as specific solutions, one that also included both the criteria/constraint the solutions were supposed to address and details about how the solutions were implemented in the Simplon Tunnel case. The group described a general criterion and constraint, and they identified a design rule of thumb that included correct causality. The Coastal Plain group's ability to interpret the Hudson Tunnel case was exactly the same as their ability to interpret the Mono Craters Tunnel case during Episode 5. They identified a specific expert problem and a solution that includes the criteria or constraint the solution was supposed to address as well as some detail about how the solution was implemented. The group also identified specific criteria, general constraints, and a design rule of thumb that includes justification and suggests how it could be applied to the group's challenge. Due to technical difficulties with our video observations, group discussions during this episode of Case Interpretation Tool use were not available.

6.8.1 Enactment and Predictions

The emphasis and expectations for this episode were the same as for Episode 7 in Case Study 1. Mr. J. told the class that they would be interpreting their last case from a set of cases: Simplon Tunnel, Seikan Tunnel, Chunnel Tunnel, and Hudson Tunnel. The Ridge And Valley group was assigned the Simplon Tunnel case, and the Coastal Plain group was assigned the Hudson Tunnel. Groups had 15-20 minutes to read the case before used the Case Interpretation Tool. Mr. J. also asked 6th period to focus on the same five themes he'd described during 5th period while they were reading and interpreting the expert case: describing technical issues, identifying rocks and minerals, identifying geographic problems, explaining how problems were resolved, and identifying any new questions and hypotheses. As in 5th period, following the class discussion, groups went back to reading their assigned cases, and after reading their cases, each group grabbed a laptop, logged into the software and began working with no prompting from Mr. J. Groups asked for very little help from Mr. J. as they worked, so he did not walk around providing as much coaching as in previous episodes.

6.8.2 Student Work

Inter-rater reliability for this episode was 98% as it was for Episode 7 in Case Study 1.

6.8.2.1 Ridge And Valley Group

In this episode, as shown in Table 6.31, the Ridge and Valley group was able to identify general problems the experts faced, but they did not include causality (Identifies Problems (I)): *Hot springs* and *Hot air and hot rock* as expert problems. The group also identified solutions the experts used to address the problems they encountered (Identifies Solutions (II)). One expert solution identified, *The builders made drainage tunnels to carry the water away because of the hot springs*, provided a description of a solution that included the benefit the solution was supposed to have or the criteria or constraint the solution was supposed to address. The other expert solution identified, *There was a ventilation system to condition the hot air, and hot rock. They sprayed cool water to do this,* also included some detail about how the solution was implemented.

The Ridge and Valley group identified one general criterion (Understands Criteria (V)) and one general constraint (Understands Constraints (VI)). They typed *Wanted a quick route* as a criterion and *Money constraint* as a constraint. This group did not identify outcomes that resulted because a constraint was addressed or not addressed (Connects Constraints To Outcomes (VII)), but they did identify one general design rule of thumb (Rule of Thumb (VIII)), *When water is unexpected and you encounter it, use drainage systems because it saves lives.*

Table 6.31– Ridge And Valley Group's Two Best Answers From Case Interpretation Tool – Simplon Tunnel case

Ridge and Valley Group		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	Hot springs	2
	Hot air and hot rock	2
Identifies Solutions (II)	The builders made drainage tunnels to carry the water away because of the hot springs.	3
	There was a ventilation system to condition the hot air and hot rock. They sprayed cool water to do this.	4
Specifies Implementation (III)		1
Understands Criteria (V)	Wanted a quick route	2
Understands Constraints (VI)	Money constraint	2
Connects Constraints To Outcomes (VII)		1
Rules of Thumb (VIII)	When water is unexpected and you encounter it use drainage systems because it saves lives.	3

Table 6.32 summarizes the coding results for the Ridge and Valley group's capability to interpret the Simplon Tunnel case using the Case Interpretation Tool.

Table 6.32 – Ridge And Valley Group Case Interpretation 3 Coding Results

	Ridge and Valley Group's Coded Results Case Interpretation 3 – Simplon Tunnel		
Identifies Problems (I)	2	2	Total – 2
Identifies Solutions (II)	3	4	Total – 2
Specifies Solution Implementation (III)	1		Total – 1
Identifies Criteria (V)	2		Total – 1
Identifies Constraints (VI)	2		Total – 1
Connects Constraints To Outcomes (VII)	1		Total – 1
Rules of Thumb (VIII)	3		Total – 1

6.8.2.2 Coastal Plain Group

As shown in Table 6.33, the Coastal Plain group was able to identify a specific aspect of a problem the experts faced, but they did not include causality (Identifies Problems (I)): *They needed to stop the mud from flowing into the tunnel*. The group identified a solution the experts used to address the problem they encountered (Identifies Solutions (II)). The expert solution identified, *A combination of the iron shield and compressed air held back the mud*, provided a description of a solution that included the benefit the solution was supposed to have or the criteria or constraint the solution was supposed to address and included some detail about how the solution was implemented for one of the three expert solutions they identified.

The Coastal Plain group identified two general criteria (Understands Criteria (V)). The first, *They wanted to build the tunnel that goes from NJ to NY,* described a specific objective that the experts wanted to address, while the other, *They wanted to use the least amount of money possible,* was a general criterion. They also identified what they believed were constraints (Understands Constraints (VI)). The first, *They needed the fastest route between the two cities*, was not mentioned in the expert case, and therefore, was not a constraint the experts faced. The other, *They needed money because they ran out of money*, was a general constraint. In identifying this constraint, the Coastal Plain group also described an outcome that occurred as a result of the experts not addressing the money constraint (Connects Constraints To Outcomes (VII)). They also identified one design rule of thumb (Rule of Thumb (VIII)) that not only included causality and/or justification, but also included details about how it might be applied: *When tunneling through Georgia use shields to keep back mud because it won't overflow the tunnel.*

Table 6.33 – Coastal Plain Group's Two Best Answers From Case Interpretation – Hudson Tunnel Case

Coastal Plain Group		
Dimension	Answer(s) Given	Rating(s) Given
Identifies Problems (I)	They needed to stop the mud from flowing into the tunnel.	3
Identifies Solutions (II)	A combination of the iron shield and compressed air held back the mud, the technology that was used in choosing the solution was the Greathead shield to keep back the mud from overflowing the tunnel.	4
Specifies Implementation (III)		2

Table 6.33 – Coastal Plain Group's Two Best Answers From Case Interpretation – Hudson Tunnel Case (Continued)

Understands Criteria (V)	They wanted to build the tunnel that goes from NJ to NY.	3
	They wanted to use the least amount of money possible.	2
Understands Constraints (VI)	They need the fastest route between the two cities.	1
	They needed money because they ran out of money.	2
Connects Constraints To Outcomes (VII)		
		2
Rules of Thumb (VIII)	When tunneling through Georgia use shields to keep back mud because it won't overflow the tunnel.	4

Table 6.34 summarizes the coding results for the Coastal Plain group's ability to interpret the Hudson Tunnel case using the Case Interpretation Tool.

Table 6.34 – Coastal Plain Group Case Interpretation 3 Coding Results – Hudson Tunnel

	Coastal Plain Group's Coded Results Case Interpretation 3 – Hudson Tunnel		
Identifies Problems (I)	3		Total – 1
Identifies Solutions (II)	4		Total – 1
Specifies Solution Implementation (III)	2		Total – 1
Identifies Criteria (V)	3	2	Total – 2
Identifies Constraints (VI)	1	2	Total – 2
Connects Constraints To Outcomes (VII)	1	2	Total – 2
Rules of Thumb (VIII)	4		Total – 1

6.8.3 Group Discussions

Unfortunately, technical difficulties prevented us from having a useable video-recorded account of the discussions that took place as the Ridge and Valley and Coastal Plain groups used the Case Interpretation Tool for the third time. As a result, we can only look at the student work that came out of this interpretation activity to help us answer our research questions.

6.8.4 – Summary of Results

Overall, the Ridge and Valley group's interpretation performance for the Simplon Tunnel case was better for some interpretation skills and not as good for others than for Episode 5. While the group identified more specific expert problems, solutions, and constraints than identified during their second use of the Case Interpretation Tool, the Ridge and Valley group's only identified a specific criterion that did not include justification for choosing the criterion and a general design rule of thumb. Overall, the Coastal Plain group's interpretation performance for the Hudson Tunnel case was the same as it was during their second use of the Case Interpretation Tool. They identified a specific expert problem and a solution that includes the criteria or constraint the solution was supposed to address as well as some detail about how the solution was implemented. The group also identified specific criteria, general constraints, and a design rule of thumb that includes justification and suggests how it could be applied to the group's challenge. Due to technical difficulties with our video observations, group discussions during this episode of Case Interpretation Tool use were not available.

6.9 Summary

This chapter presents the second and third case studies presenting the Ridge and Valley and Coastal Plain groups. It was designed to describe episodes of case use skill development during and following the *Digging In* and during the *Tunneling Through Georgia* Unit. As we did in Case Study 1, for each episode, we described Mr. J's emphasis on case use skills, our predictions for case use capability for that episode, coding results for group or individual performance of case use skills, and when available, excerpts of group discussions that provide context for coding results.

While we predicted that the development of case use skills would increase over time for groups, coding results reveal there was variation across case use capability over time for the Ridge and Valley group. There were four episodes of Case Application Suite Use: three episodes when the Ridge and Valley and Coastal Plain groups used the Case Interpretation Tool to interpret expert cases (Episodes 4, 5, and 7), and one episode when these groups used the Case Application Tool to apply the expert cases to their challenge (Episode 6). The Ridge and Valley group applied the Mono Craters Tunnel case, was the Coastal Plain group applied the Tecolote Tunnel case.

As a group, interpretation performance for the Ridge and Valley group declined across their first and second episodes of Case Interpretation Tool use (Episodes 4 and 5) and continued to decline across their second and third uses of the software (Episodes 5 and 7). Possible explanations for this decline will be explored in the next chapter.

There were changes in the Ridge and Valley group's discussions across their first and second uses of the Case Interpretation Tool. The group's discussion from their third use of the software was not available. The video observations we do have reveal that the

Ridge and Valley group began to consider that an audience other than themselves might read or use their interpretation in the future, and they began to focus some of their discussion on what that audience might not understand and how their responses should be articulated to help that audience understand. However, their group discussions also changed in some negative ways. Over time, they did not seem to use the written expert case to generate, support, and/or refute ideas during Case Interpretation Tool use, and their discussions were less informed. Group members also seemed to disengage from group discussions over time.

As a group, the Coastal Plain group's interpretation performance improved across their first and second episodes of Case Interpretation Tool use (Episodes 4 and 5) and remained the same across their second and third uses of the software (Episodes 5 and 7).

For the Coastal Plain group, there were changes in the group's discussions across their first and second uses of the Case Interpretation Tool. While the group's discussion from their third use of the software was not available, video observations from their first and second use of the software reveal that the Coastal Plain group became more informed. The group used the written expert case more to generate, support, and/or refute ideas. Their discussion also moved from being unfocused and full of chaos to using the definitions of criterion and constraint to classify ideas as such or to support or refute the classification of an idea.

CHAPTER 7

EFFECTS OF THE CASE APPLICATION SUITE ON CASE USE PERFORMANCE AND CAPABILITIES

This chapter is the first of three chapters that present analysis of our findings. Up to this point, we have examined the effects with the Case Application Suite or how well groups were able to interpret and apply case use skills supported by the Case Application Suite's system of scaffolds. In this chapter, we will examine the effects of the Case Application Suite on individuals' abilities to apply case use skills in new situations. We begin by looking at individual interpretation, application, and assessment performance and capabilities for the Bald Head Island performance assessment (Performance Assessment 1). Then, we look at individual interpretation, application, and assessment performance for the Snowshoe Hare/Lynx performance assessment (Performance Assessment 2). Administered five months after Performance Assessment 1, we wanted to see how well individuals retained case use skills. During that five month period, individuals and groups did not use the Case Application Suite. Instead, they engaged in a problem-based, inquiry unit, the Immune and Reproductive Systems Unit (IRSU). Designed by Mr. J., students learned about STDs by working in groups of two (dyads) and reading small excerpts about a mock patient (e.g. symptoms the patient displayed, test results/procedures run by doctor, etc.) and making predictions about the diagnosis of a mock patient. Their final predictions were then compared to the doctor's diagnosis of the patient.

Originally, we did not think the IRSU would further inform or impact the effects of the Case Application Suite on individuals' abilities to apply case use skills in new situations. However, Performance Assessment 2 coding results revealed that most individuals' interpretation, application, and assessment performance improved across performance assessments. This suggested that something may have occurred during the IRSU that resulted in an increase in case use performance from Performance Assessment 1 to Performance Assessment 2. We describe the capabilities dyads displayed and examining how those capabilities are reflected in the improvement in case use performance, especially interpretation performance, across Performance Assessments 1 and 2.

7.1 First Application of Case Use Skills In the Absence of Software-Realized Scaffolding: Performance Assessment 1

At the completion of the *Tunneling Through Georgia* Unit, we wanted to see how much students had learned about interpreting and applying cases. We knew what they could do with the software available to them, but we wanted to find out how much they could do in the absence of the Case Application Suite's system of scaffolds. We had students work in groups and then individually write up their interpretations of and suggestions about application of the Bald Head Island case to a problem involving an island off the coast of Georgia. The Bald Head Island case described how the shoreline was eroding away, ways the experts had tried to manage that erosion (i.e. dredging the channel, building groins, passing legislation), and the varying degrees of success of those management methods. In the first part of the performance assessment, which assessed interpretation performance, students were asked to find and describe the risks involved in the challenge, describe ways to manage those risks, design a plan to test those management methods, and identify design rules of thumb for managing the risks involved in their challenge. In the second part of the performance assessment, which assessed application and assessment performance, students were asked to design a plan for addressing the Bald Head Island challenge and make recommendations to the construction company.

This performance assessment involved students giving recommendations to a construction company about a project to build two subdivisions on an island off the coast of Georgia. Students worked in their *Tunneling Through Georgia* groups for this performance assessment, and each team was given two copies of the Bald Head Island case, and a packet for each team member.

We administered Performance Assessment 1 a week and a half following groups' last use of the Case Interpretation Tool (Episode 7), and the performance assessment took the entire class period to administer.   For both 5th and 6th period classes, I read the Bald Head Island Challenge description and explained the chart that they should use for the first part of the performance assessment. I encouraged students to discuss their ideas as a group, but to write up their own answers in their individual packets, and told them that they had 15 minutes to complete the first part. About 10 minutes into Part 1, I interrupted the class and told them that they could continue completing Part 1, but to make sure that they started identifying design rules of thumb. Five minutes later, I read the description for Part 2, and told them to use the space provided in Part 2 to describe their plan and recommendations. I also told the class that if they wanted to draw sketches of where the subdivisions should be, what they should look like, etc., they had space to do that. I told them that they had 10 minutes to complete Part 2.

7.1.1 Predictions

Although this activity did not involve using the Case Application Suite's software-realized scaffolding, students had already had multiple opportunities to deliberately practice interpreting cases while supported by the Case Application Suite. As such, we predicted that individuals' interpretation performance would be quite sophisticated, describing specific problems and solutions, including causality, justification, and implementation details. We thought most individuals would identify specific criteria and constraints in the expert cases, including more justification for choosing those criteria and constraints. We did not think individuals would describe outcomes that occurred as the result of the expert addressing or failing to address constraints because they had not had prior experience describing these kinds of outcomes. However, because of students' previous experiences using the Rule of Thumb template to articulate design rules of thumb while working in small groups, we predicted students would identify design rules of thumb and include correct causality and/or justification.

While groups used the Case Application Tool to support them as they analyzed the design rules of thumb they created and integrated into a solution, they only had one opportunity to use the scaffolding provided by the Case Application Tool. Therefore, we predicted that student application capability would not be as developed and as sophisticated as interpretation capability. Prior to this performance assessment, had no prior experience making predictions about criteria or constraints that were addressed or overlooked. Because of this, we predicted that individual assessment capability would show the most variation and be the least sophisticated.

7.1.3 Coding Results

Overall, every member of the Blue Ridge, Ridge and Valley, and Coastal Plain groups seemed able to apply case use skills in the absence of the Case Application Suite's system of scaffolds. Individuals interpreted and applied expert cases with varying degrees of sophistication and many experienced the same kinds of difficulties, which will be described in Chapter 8. Reliability for Parts 1 and 2 of this performance assessment was 98%.

Table 7.1 summarizes interpretation performance for members of the Blue Ridge group. Theresa identified a general problem and a solution that included the benefit or criteria/constraint it was supposed to address. Margaret, Billy, and David all identified a specific problem and included causality and a general solution. However, performance for understanding criteria and constraints and articulating design rules of thumb was not as good as we predicted, as none of the members of the Blue Ridge group identified any criteria, constraints, or design rules of thumb because no individual identified design rules of thumb for the expert case. Table 7.2 summarizes application and assessment performance for members of the Blue Ridge group. As the table reveals, no individual in this group made recommendations to the construction company, so we could not assess how well they judged their plan to be applicable or how well they used their plan to inform their recommendations. Remember that a rating of 1 represents an absence of that dimension present in the data for that episode. For example, if an individual receives a rating of 1 for Dimension XIII – Rule(s) of Thumb, the rating indicates that the individual did not identify any design rules of thumb in that episode. It does not suggest that the individual is not capable of identifying design rules of thumb or does not know how to identify design rules of thumb. In many instances (especially in Performance Assessment

1), individuals ran out of time during both parts of the performance assessment and were unable to finish those parts. As a result, many individuals did not included responses that could be coded for every dimension.

Table 7.1 – Members of the Blue Ridge Group's Coded Results for Individual Interpretation Performance:
Performance Assessment 1 Part 1- Bald Head Island Challenge

	Theresa's Coded Results			Margaret's Coded Results		
Identifies Problems (I)	2		Total - 1	4		Total – 1
Identifies Solutions (II)	3		Total – 1	2		Total – 1
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	1		Total – 1	1		Total – 1
Identifies Criteria (V)	1		Total – 0	1		Total – 0
Identifies Constraints (VI)	1		Total – 0	3		Total – 1
Connects Constraints To Outcomes (VII)	1		Total – 1	1		Total – 1
Design rules of Thumb (VIII)	1		Total – 0	1		Total – 1
	Billy's Coded Results			David's Coded Results		
Identifies Problems (I)	4		Total - 1	4		Total – 1
Identifies Solutions (II)	2		Total – 1	2		Total – 1
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	1		Total – 1	1		Total – 1
Understands Criteria (V)	1		Total – 0	1		Total – 0
Understands Constraints (VI)	1		Total – 0	1		Total – 0
Connects Constraints To Outcomes (VII)	1		Total – 1	1		Total – 1
Rule of Thumb (VIII)	1		Total – 0	1		Total – 1

Table 7.2 – Members of the Blue Ridge Group's Coded Results for Individual Application and Assessment Performance:
Performance Assessment 1 Part 2- Bald Head Island Challenge

	Theresa's Coded Results			Margaret's Coded Results		
Understands Criteria (V)	4	4	Total - 3	4	3	Total – 4
Understands Constraints (VI)	1		Total – 0	1		Total – 0
Judges Applicability of Plan (IX)	1		Total – 0	1		Total – 0

Table 7.2 – Members of the Blue Ridge Group's Coded Results for Individual Application and Assessment Performance:
Performance Assessment 1 Part 2- Bald Head Island Challenge (Continued)

Predicts Which Criteria Are Addressed (XIII)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0
	Billy's Coded Results			David's Coded Results		
Understands Criteria (V)	4	3	Total - 3	4	4	Total – 2
Understands Constraints (VI)	1		Total – 0	1		Total – 0
Judges Applicability of Plan (IX)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Addressed (XIII)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0

For interpretation skill for members of the Ridge and Valley group summarized in Table 7.3, Michelle, Sam, and Daniel identified a specific problem that included correct causality, a general solution, a specific criterion, and a general constraint and design rule of thumb. While Kenny also identified a specific problem that included correct causality, a general solution, and a general design rule of thumb, he identified a general criterion and no constraints. For application and assessment performance summarized in Table 7.4, all members of the Ridge and Valley group were able to consider proposed solutions. However, the usefulness of those proposed solutions were not considered because the proposed solutions were not pulled from the plans articulated by individuals. None of the individuals in the Ridge and Valley group made predictions about criteria or constraints that were met or overlooked.

Table 7.3 – Members of the Ridge and Valley Group's Coded Results for Individual Interpretation Performance:
Performance Assessment 1 Part 1- Bald Head Island Challenge

	Kenny			Daniel		
Identifies Problems (I)	4		Total - 1	4		Total – 1
Identifies Solutions (II)	2		Total – 1	2		Total – 1
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2		Total – 1	2		Total – 1
Understands Criteria (V)	3		Total – 1	3		Total – 1
Understands Constraints (VI)	2		Total – 1	2		Total – 1
Connects Constraints To Outcomes (VII)	1		Total – 1	1		Total – 1
Design rules of Thumb (VIII)	2		Total – 1	2		Total – 1
	Sam			Michelle		
Identifies Problems (I)	4		Total - 1	4		Total – 1
Identifies Solutions (II)	2		Total – 1	2		Total – 1
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2		Total – 1	2		Total – 1
Understands Criteria (V)	3		Total – 1	3		Total – 1
Understands Constraints (VI)	2		Total – 1	2		Total – 1
Connects Constraints To Outcomes (VII)	1		Total – 1	1		Total – 1
Rule of Thumb (VIII)	2		Total – 0	2		Total – 1

Table 7.4 – Members of the Ridge and Valley Group's Coded Results for Individual Application and Assessment Performance:
Performance Assessment 1 Part 2- Bald Head Island Challenge

	Kenny's Coded Results			Daniel's Coded Results		
Understands Criteria (V)	3	4	Total - 2	3	4	Total – 2
Understands Constraints (VI)	4	4	Total – 2	4	4	Total – 2
Judges Applicability of Plan (IX)	2		Total – 1	2		Total – 1

Table 7.4 – Members of the Ridge and Valley Group's Coded Results for Individual Application and Assessment Performance:
Performance Assessment 1 Part 2- Bald Head Island Challenge (Continued)

Predicts Which Criteria Are Addressed (XIII)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0
	Sam's Coded Results			Michelle's Coded Results		
Understands Criteria (V)	3	4	Total - 2	3	4	Total – 2
Understands Constraints (VI)	4	4	Total – 2	4	4	Total – 2
Judges Applicability of Plan (IX)	2		Total – 1	2		Total – 1
Predicts Which Criteria Are Addressed (XIII)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0

Coding results for interpretation performance for the Coastal Plain group summarized in Table 7.5 revealed that while Melissa identified a specific expert problem that included correct causality, Chad and Sandy identified specific expert problems that did not include causality, and Chris identified general problems. Every individual in the Coastal Plain group identified general solutions. Sandy and Chris identified general criteria and constraints, while Melissa and Chad identify general constraints but no criteria. No individual identified or articulated design rules of thumb. Like the Blue Ridge group, we could not determine how well individuals in the Coastal Plain group could apply the lessons learned from the Bald Head Island case as a part of their recommendations to the construction company because no individual identified design rules of thumb for the expert case. Table 7.6 summarizes application and assessment performance for members of the Coastal Plain group. The table reveals that no one described recommendations to the construction company. As a result, we were unable to assess how well they judged their plan to be applicable or how well they used their plan to inform their recommendations

Table 7.5 – Members of the Coastal Plain Group's Coded Results for Individual Interpretation Performance:
Performance Assessment 1 Part 1- Bald Head Island Challenge

	Sandy's Coded Results			Chris's Coded Results		
Identifies Problems (I)	2	2	Total - 3	2	2	Total – 3
Identifies Solutions (II)	2	2	Total – 3	2	2	Total – 3
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2	1	Total – 3	2	1	Total – 1
Understands Criteria (V)	2		Total – 1	2		Total – 1
Understands Constraints (VI)	1		Total – 0	1		Total – 0
Connects Constraints To Outcomes (VII)	1		Total – 0	1		Total – 0
Design rules of Thumb (VIII)	1		Total – 0	1		Total – 0
	Melissa's Coded Results			Chad's Coded Results		
Identifies Problems (I)	3	4	Total - 2	3	3	Total – 3
Identifies Solutions (II)	2	2	Total – 2	2	2	Total – 2
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2	1	Total – 2	2	1	Total – 1
Understands Criteria (V)	1		Total – 0	1		Total – 0
Understands Constraints (VI)	2		Total – 1	2		Total – 1
Connects Constraints To Outcomes (VII)	1		Total – 0	1		Total – 0
Rule of Thumb (VIII)	1		Total – 0	1		Total – 0

Table 7.6 – Members of the Coastal Plain Group's Coded Results for Individual Application and Assessment Performance:
Performance Assessment 1 Part 1- Bald Head Island Challenge

	Sandy's Coded Results			Chris's Coded Results		
Understands Criteria (V)	3	4	Total - 3	3	4	Total – 3
Understands Constraints (VI)	1		Total – 0	1		Total – 0
Judges Applicability of Plan (IX)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Addressed (XIII)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0
	Melissa's Coded Results			Chad's Coded Results		
Understands Criteria (V)	3	4	Total - 3	3	4	Total – 3
Understands Constraints (VI)	1		Total – 0	1		Total – 0
Judges Applicability of Plan (IX)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Addressed (XIII)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0

7.1.4 Summary of Results

This section presents the first time students interpreted and applied expert cases following their use of the Case Application Suite as they worked in small groups. Students did not have the Case Application Suite's system of scaffolds available to them, but they were encouraged to discuss their ideas as a group and write up their own answers. The slight variation across student answers suggests that this was done.

Overall, individuals did not perform as well as we predicted they would. For interpretation, while most individuals identified specific expert problems that included causality, instead of identifying detailed solutions with implementation details, they identified general solutions. We expected individuals to identify specific criteria, constraints, and design rules of thumb that included causality or justification, but coding results revealed that most individuals either did not identify any criteria or constraints, or they identified general criteria and constraints.

This finding seems to have occurred for two reasons. First, most groups spent most of their time discussing the specific types of erosion that they should describe out of the several types of erosion that the experts faced as well as the solutions that the experts used to address the challenge and did not have a lot of time to discuss the pros and cons. The pros and cons columns were where most students described criteria and constraints. The second reason for this finding is that many individuals did not choose to write down the ideas that came out of the group's discussion about criteria and constraints in the form of pros and cons. For example, despite of the Blue Ridge group's discussion about the pros and cons of certain management methods like groins, which managed erosion but caused flooding during storms, only Margaret included what came out of the group's discussion about the pros and cons on her chart in the form of a criterion or constraint. Only members of the Ridge and Valley group identified design rules of thumb, and they were general without causality or justification.

For application performance, while individuals were able to understand the criteria and constraints of their challenge with a high level of sophistication, only members of the Ridge and Valley group applied were able to consider proposed solutions. However, the usefulness of those proposed solutions were not considered because the proposed solutions were not pulled from the plans they articulated during Part 2 of the performance assessment. No individual made predictions about criteria or constraints that were met or overlooked.

7.2 Second Application of Case Use Skills In the Absence of Software Realized Scaffolding: Performance Assessment 2

This section presents students' second application of case use skills, which occurred five months after Performance Assessment 1. We wanted to find out what they retained and what they became more capable of doing with respect to interpreting and applying cases and assessing solutions they had come up with. We had them do another performance assessment exercise, again without the aid of the Case Application Suite. We weren't sure to what extent individuals would retain their skills or what effect the activities they engaged in since *Tunneling Through Georgia* would effect their ability to reason with cases.

In the Snowshoe Hare/Lynx Challenge, students worked in groups of two (dyads), and their challenge was to make recommendations to a wildlife federation about changes in land use policies that should be made to save the cheetah from endangerment. To aid them in making their recommendations, they had as a resource a case describing the plight of the Canada Lynx, an endangered species that faces threats similar to the cheetah (i.e., dwindling habitat, declining numbers of prey, limited to one main prey, etc.). Figure 7.1 shows the instructions for Part 1 of the Snowshoe Hare/Lynx Performance Assessment. In Part 1, they were asked to interpret the case and extract rules of thumb from it, to apply later to the new situation.

Four years ago, the cheetah was listed as a threatened species on federal lands in Africa, protected by the Endangered Species Act. The cheetah's main prey is the Grant gazelle, a herbivore, and also an endangered species. Now, the International Wildlife Preservation Summit has agreed to consider changes to land management activities that further endanger the cheetah. Research has shown that threats to the cheetah are similar to threats facing the Canada lynx, while threats to the gazelles are similar to threats facing the Snowshoe hare. Your team has been selected to uncover the issues or threats that may have contributed to the cheetah's endangerment and to make recommendations to the Summit to help save the cheetah.

For Part I, your team has been asked to do the following:

- Find and describe the issues that contribute to the cheetah's endangerment,
- Identify and describe the possible ways to address the issues mentioned in the previous bullet. Describe the pros and cons of each.
- Identify rules of thumb for identifying and addressing the issues described.

Use the chart to help you complete the tasks described above.

Figure 7.1 – Instructions for Part 1 of Snowshoe Hare/Lynx Performance Assessment

Two members who worked together in the Ridge and Valley group were also part of the same dyad for Performance Assessment 2: Michelle and Sam. Other than those two students, no other members who worked together in the Blue Ridge, Ridge and Valley or Coastal Plain groups worked with other members of their group this performance assessment. Each team was given one copy of the Snowshoe Hare/Lynx case, and a packet for each team member. Figure 7.2 shows the instructions for Part 2 of the performance assessment:

For Part II, your team's task is to:

- Develop a plan for saving the cheetahs from endangerment. Include materials, tools, supplies, amount of time, money, and any other criteria/constraints you would like to address.
- Write a formal letter to the International Wildlife Preservation Summit giving your team's recommendations for addressing the threats facing the cheetah.
    - Be sure to explain why your team is making the recommendations and how they can help to save the cheetah from endangerment.

Use the attached sheets to help you complete the tasks described above.

Figure 7.2 –Write-Up for Part 2 of Snowshoe Hare/Lynx Performance Assessment

I read the Snowshoe Hare/Lynx Challenge description given above and described the chart used for Part 1 of the performance assessment. As I did during Performance Assessment 1, I encouraged students to discuss their ideas as a dyad, but to write up their own answers in their individual packets and told them that they had 15 minutes to complete the first part. About 10 minutes into Part 1, I told the class they had 5 minutes left for this part of the PA and asked them to make sure that they started identifying design rules of thumb. Five minutes later, I read the instructions for Part 2 given above, told them where to write their answers on the pages provided, and told them that they had 10 minutes to complete Part 2.

7.2.1 Predictions

Because students had not interpreted and applied expert cases in this way since Performance Assessment 1 five months before, we expected individuals to be able interpret and apply expert cases, but not as well as they had for Performance Assessment 1. We expected individuals to identify general or specific problems, general solutions, general criteria and constraints, and either no design rules of thumb or general ones. Based on individual performance on the Performance Assessment 1 and the amount of time that had passed since their last engagement in a performance assessment, we also expected few individuals to apply design rules to their plan or make recommendations to the International Wildlife Preservation Summit.

7.2.2 Coding Results

As Tables 7.7-7.12 summarize, surprisingly every individual's interpretation performance was as good as or better on Performance Assessment 2 than for Performance Assessment 1, with the exception of Sam and Melissa whose interpretation performance declined and Daniel whose performance remained the same. Every individual's application performance was as good as or better for Performance Assessment 2 than for Performance Assessment 1. In addition, results for this episode reveal that individual performance for application was comparable to individual performance for interpretation, even though students had more opportunities to develop interpretation skills than application skills both during *Tunneling Through Georgia* and between the two performance assessments. As a result, most individuals were able to retain interpretation and application skills across Performance Assessments 1 and 2, and the disparity between interpretation and application performance that we saw in Parts 1 and 2 of Performance Assessment 1 was not as great for Parts 1 and 2 of this performance assessment. Reliability for both Parts 1 and 2 of this performance assessment was 98%.

Table 7.7 – Coding Members of the Blue Ridge Group's Coded Results for Individual Interpretation Performance:
Performance Assessment 2 Part 1- Snowshoe Hare/Lynx Challenge

	Theresa's Coded Results			Margaret's Coded Results		
Identifies Problems (I)	4		Total - 1	4	2	Total – 3
Identifies Solutions (II)	3	2	Total – 2	2	3	Total – 2
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	3	1	Total – 2	2	3	Total – 2
Identifies Criteria (V)	2	2	Total – 4	2		Total – 1
Identifies Constraints (VI)	1		Total – 0	1		Total – 0
Connects Constraints To Outcomes (VII)	1		Total – 1	1		Total – 1
Design rules of Thumb (VIII)	1		Total – 0	1		Total – 0
	Billy's Coded Results			David's Coded Results		
Identifies Problems (I)	4		Total - 1	4	4	Total – 2
Identifies Solutions (II)	3		Total – 1	2	2	Total – 5
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2		Total – 1	2	2	Total – 5
Understands Criteria (V)	2		Total – 1	3	2	Total – 3

Table 7.7 – Coding Members of the Blue Ridge Group's Coded Results for Individual Interpretation Performance:
Performance Assessment 2 Part 1- Snowshoe Hare/Lynx Challenge (Continued)

Understands Constraints (VI)	1		Total – 0	2		Total – 1
Connects Constraints To Outcomes (VII)	1		Total – 1	1		Total – 1
Rule of Thumb (VIII)	2		Total – 1	2	2	Total – 2

Table 7.8 – Coding Members of the Blue Ridge Group's Coded Results for Individual Application and Assessment Performance:
Performance Assessment 2 Part 2- Snowshoe Hare/Lynx Challenge

	Theresa's Coded Results			Margaret's Coded Results		
Understands Criteria (V)	4	4	Total - 6	3	3	Total – 4
Understands Constraints (VI)	2		Total – 1	3	3	Total – 2
Judges Applicability of Plan (IX)	3	4	Total – 2	1		Total – 0
Predicts Which Criteria Are Addressed (XIII)	3		Total – 1	2		Total – 1
Predicts Which Constraints Are Met (XIV)	1		Total – 0	2	2	Total – 2
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0
	Billy's Coded Results			David's Coded Results		
Understands Criteria (V)	4	4	Total - 5	4	4	Total – 3
Understands Constraints (VI)	3		Total – 1	3		Total – 1
Judges Applicability of Plan (IX)	3		Total – 1	4	3	Total – 3
Predicts Which Criteria Are Addressed (XIII)	2		Total – 1	1		Total – 0
Predicts Which Constraints Are Met (XIV)	1		Total – 0	2		Total – 1
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0

Table 7.9 – Coding Members of the Ridge and Valley Group's Coded Results for Individual Interpretation Performance:
Performance Assessment 2 Part 1- Snowshoe Hare/Lynx Challenge

	Kenny's Coded Results	Daniel's Coded Results

Identifies Problems (I)	4		Total - 1	4	4	Total – 3
Identifies Solutions (II)	2	2	Total – 3	3	2	Total – 2
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	1	1	Total – 3	2	1	Total – 2
Identifies Criteria (V)	2		Total – 1	4		Total – 1
Identifies Constraints (VI)	1		Total – 0	1		Total – 0
Connects Constraints To Outcomes (VII)	1		Total – 0	1		Total – 0
Design rules of Thumb (VIII)	2		Total – 1	2	2	Total – 2
	Sam's Coded Results			Michelle's Coded Results		
Identifies Problems (I)	3	2	Total - 2	3	2	Total – 2
Identifies Solutions (II)	2	2	Total – 2	2	2	Total – 2
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2	1	Total – 2	2	2	Total – 2
Understands Criteria (V)	3	2	Total – 3	2	2	Total – 2
Understands Constraints (VI)	1		Total – 0	2		Total – 1
Connects Constraints To Outcomes (VII)	1		Total – 0	1		Total – 0
Rule of Thumb (VIII)	2		Total – 1	2		Total – 1

Table 7.10 – Coding Members of the Ridge and Valley Group's Coded Results for Individual Application and Assessment Performance:
Performance Assessment 2 Part 2- Snowshoe Hare/Lynx Challenge

	Kenny's Coded Results			Daniel's Coded Results		
Understands Criteria (V)	2	4	Total - 2	4	4	Total – 2
Understands Constraints (VI)	1		Total – 0	1		Total – 0
Judges Applicability of Plan (IX)	3	3	Total – 2	4		Total – 1
Predicts Which Criteria Are Addressed (XIII)	1		Total – 0	2		Total – 1
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0

Table 7.10 – Coding Members of the Ridge and Valley Group's Coded Results for Individual Application and Assessment Performance:
Performance Assessment 2 Part 2- Snowshoe Hare/Lynx Challenge (Continued)

Predicts Which Constraints	1		Total – 0	1		Total – 0

Are Not Met (XVI)						
	Sam's Coded Results			Michelle's Coded Results		
Understands Criteria (V)	4		Total - 1	4		Total – 1
Understands Constraints (VI)	2		Total – 1	2		Total – 1
Judges Applicability of Plan (IX)	4		Total – 1	4		Total – 1
Predicts Which Criteria Are Addressed (XIII)	3		Total – 1	2		Total – 1
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0

Table 7.11 – Coding Members of the Coastal Plain Group's Coded Results for Individual Interpretation Performance:
Performance Assessment 2 Part 1- Snowshoe Hare/Lynx Challenge

	Sandy's Coded Results			Chris's Coded Results		
Identifies Problems (I)	4	4	Total - 3	4	4	Total – 4
Identifies Solutions (II)	2	2	Total – 3	3	2	Total – 2
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2	2	Total – 3	3	2	Total – 4
Identifies Criteria (V)	3	2	Total – 3	1		Total – 0
Identifies Constraints (VI)	1		Total – 0	3		Total – 1
Connects Constraints To Outcomes (VII)	1		Total – 0	2		Total – 1
Design rules of Thumb (VIII)	1		Total – 0	2		Total – 1
	Chad's Coded Results			Melissa's Coded Results		
Identifies Problems (I)	4	4	Total - 3	4	4	Total – 2
Identifies Solutions (II)	2	2	Total – 3	3	2	Total – 5
Specifies Solution Implementation (III)	N/A	N/A		N/A	N/A	
Connects Problems and Solutions (IV)	2	2	Total – 3	2	2	Total – 5
Understands Criteria (V)	3	3	Total – 2	2	2	Total – 4

Table 7.11 – Coding Members of the Coastal Plain Group's Coded Results for Individual Interpretation Performance:
Performance Assessment 2 Part 1- Snowshoe Hare/Lynx Challenge (Continued)

Understands Constraints	2	2	Total – 2	1		Total – 0

(VI)						
Connects Constraints To Outcomes (VII)	1	1	Total – 2	1		Total – 0
Rule of Thumb (VIII)	1		Total – 0	2		Total – 1

Table 7.12 – Coding Members of the Coastal Plain Group's Coded Results for Individual Application and Assessment Performance:
Performance Assessment 2 Part 2- Snowshoe Hare/Lynx Challenge

	Sandy's Coded Results			Chris's Coded Results		
Understands Criteria (V)	3		Total - 1	4	4	Total – 2
Understands Constraints (VI)	3	2	Total – 2	1		Total – 0
Judges Applicability of Plan (IX)	4	2	Total – 2	4	3	Total – 2
Predicts Which Criteria Are Addressed (XIII)	2	2	Total – 2	3		Total – 1
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	1		Total – 0
	Chad's Coded Results			Melissa's Coded Results		
Understands Criteria (V)	3	3	Total - 2	3	3	Total – 4
Understands Constraints (VI)	1		Total – 0	2		Total – 1
Judges Applicability of Plan (IX)	4		Total – 1	4		Total – 1
Predicts Which Criteria Are Addressed (XIII)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Met (XIV)	1		Total – 0	1		Total – 0
Predicts Which Criteria Are Overlooked (XV)	1		Total – 0	1		Total – 0
Predicts Which Constraints Are Not Met (XVI)	1		Total – 0	3		Total – 1

7.2.3 Summary of Results

This section represents the second time we assessed students' case use skills without the scaffolding in the Case Application Suite. Students did not have the Case Application Suite's system of scaffolds available to them, but they were encouraged to discuss their ideas as a group and write up their own answers. None of the members of the Blue Ridge group worked together during this episode.

Overall, every member of the Blue Ridge, Ridge and Valley, and Coastal Plain groups was able to interpret the Snowshoe Hare/Lynx case without the Case Application Suite's system of scaffolds. Surprisingly, not only did individuals seem to have retained some case use skills across Performance Assessments 1 and 2, but coding results also reveal that performance of interpretation and application skills for most individuals was better for this performance assessment than it was for Performance Assessment 1. In addition, the disparity between interpretation capability and application capability that we saw in Part 1 and Part 2 of Performance Assessment 1 was not as great for Parts 1 and 2 of this performance assessment.

7.3 What Happened Between Performance Assessments 1 and 2 That May Account For This Improvement In Performance: The Immune and Reproductive Systems Unit (IRSU)

Given our surprising results that five months after Case Application Suite use and Performance Assessment 1, individuals' interpretation, application, and assessment performance was better, we wondered why individuals did better when they had no LBD in between performance assessments. In order to find out why, we looked back at the IRSU to understand what 5^{th} and 6^{th} period classes did during the IRSU that may have impacted individual interpretation, application, and assessment performance in Performance Assessment 2. We also hoped to understand the capabilities individuals displayed that were not explicitly emphasized in Mr. J's enactment of the IRSU. The Immune and Reproductive Systems Unit (IRSU) was a problem-based learning unit designed by Mr. J. As described earlier, individuals worked in group of two (dyads) and learned about STDs by making predictions about the diagnosis of a mock patient. At the end of the challenge, dyads' final predictions were compared to the doctor's diagnosis of the patient. To support dyads as they interpreted different kinds of information that was presented to inform their predictions, Mr. J. designed 5 tools to help dyads (i.e., symptoms the patient displayed, test results/procedures run by the doctor, treatment prescribed by the doctor, etc.).

7.3.1 During Class Discussions, Mr. J. Modeled Describing Outcomes That Occurred As A Result of Doing Or Failing To Do Something, And He Indirectly Modeled Articulating Lessons Learned

Before engaging in the main IRSU challenge or using the IRSU Tools, students spent two weeks learning about the immune and reproductive systems. Mr. J used "Immunity and Preventing Disease" by Cyber Ed Plate Science, interactive software that presented multi-media content about the immune and reproductive systems separately and interspersed interactive quizzes throughout that content to assess students' understanding of the concepts presented. Instead of lecturing, Mr. J. presented small portions of the software on a projector screen, pausing it along the way to help students make connections between the content being presented and their experiences dealing with common diseases (e.g., chickenpox, cold virus, flu virus) as well as to help them understand new vocabulary (i.e., virus, pasteurization, pathogen, etc.).

Most notably, Mr. J. also helped students understand how certain diseases, treatments, or activities resulted in certain outcomes in one or both of the systems being studied. For example, as the class discussed communicable diseases, namely Pasteur's

Germ Theory which posits that disease is spread by microorganisms, Mr. J. helped the class understand how the introduction of hand-washing practices by doctors resulted in a decrease in the number of deaths in hospitals due to infection:

(1) Mr. J: OK, so Pasteur came up with what theory?
(2) Class: Germ Theory.
(3) Mr. J: So, he gets the word out–we've got these micro-
(4) organisms called germs that spread disease, so he got
(5) the word out. So if you clean, wash your hands, clean
(6) your operating room, we can get rid of these germs and
(7) keep them from getting people sick, right? And what
(8) happened? The doctors went ahead and did this to see
(9) what would happen and what happened?
(10) Various class members: People didn't die.
(11) Mr. J: Less people died from infections....
(12) Mr. J: What kind of correlation did they notice?
(13) Student 1: Positive correlation.
(14) Mr. J: A positive correlation. And what's a positive
(15) correlation? Describe the correlation between
(16) cleanliness and fatalities from infection.
(17) Student 1: OK. Well, when the doctors in the 1800's
(18) weren't washing their hands, people died of infections
(19) because [muffled] and then Louis Pasteur found out the
(20) germ theory of disease and when doctors started washing
(21) their hands, then people didn't die.
(22) Mr. J: What do we know as fact? You need to separate

(23) the theory from the fact? What's the fact?

(24) Student 2: Germs cause disease?

(25) Mr. J: No, that's the theory. What's the fact?

(26) Student 3: Less people died?

(27) Mr. J: Less people died when doctors washed their

(28) hands—that's the fact. That's the relationship.

(29) Washing—when doctors started washing their hands, less

(30) people died. That's the fact.

Excerpt 7.3.1.1 – Mr. J helping the class understand outcomes that occurred as a result of doing or failing to do something

In this excerpt, Mr. J. began by describing an outcome that came out of Pasteur's Germ Theory, i.e., that hand-washing and cleaning operating rooms can prevent germs from getting people sick in hospitals (lines 1-7). He termed this outcome a positive correlation, and he prompted the class to describe the correlation between cleanliness and fatalities from infection; he wanted them to restate the outcome he'd just described (lines 8-16). One student attempted to describe the outcome that occurred as a result of the doctors washing their hands, but he mixed the outcome and the theory (lines 17-21). Mr. J. prompted the class again to describe only the outcome ("What are the facts?") because he wanted the class to understand the outcome separate from the theory (lines 22 and 23). Another student stated the Germ Theory as the outcome, but Mr. J. told him that his idea was actually the theory (lines 24 and 25). Yet another student described the outcome (line 26), and Mr. J. put the outcome together with what the doctors, restating the outcome once again (lines 27-30).

Another interesting outcome of this discussion was Mr. J.'s presentation of the outcome. He stated, "When doctors started washing their hands, less people died."

While this is most certainly an outcome that occurred as a result of doing or not doing something, it is also phrased like a lesson learned or a design rule of thumb without the justification piece. As such, Mr. J. also seems to indirectly model how to extract and articulate design rules of thumb.

The class studied the reproductive system first, focusing on the parts of the male and female reproductive systems, how they work, and how they interact with other systems in the body. Then, the class studied the immune system focusing on how it works, the differences between viruses, bacteria, and fungi, how each of these affect the immune system differently (and as a result, must be treated differently), how the body uses the immune system to protect itself from disease, how disease is spread, and how vaccinations are created, formulated, and used to prevent certain diseases like smallpox.

Following their use of the "Immunity and Preventing Disease" software as a class, each dyad began learning about all of the sexually transmitted diseases (STDs) that they might encounter as they worked to achieve the main IRSU challenge. Mr. J. began by giving a brief overview of STDs focusing on what they are and how they are spread. Following this overview, each dyad received a chart to complete as they researched the following diseases using resources from the school library: Human Immune-deficiency Virus (HIV), gonorrhea, syphilis, trichonomisis (crabs), pelvic inflammatory disease (PID), Chlamydia, genital warts, Herpes, and Hepatitis C. The chart's column headings were *Disease, Pathogen, Symptoms, and Treatment*. After collecting information about each of the STDs, Mr. J. facilitated a class discussion where dyads presented their findings, focusing on the STD itself, the symptoms displayed by humans (if any) when infected with the STD, and any means used by doctors to diagnose and treat it. The class discussion helped dyads find out what other dyads learned. Students were encouraged to add any additional information presented that was not already listed on their charts, insuring that each dyad had the same information about all of the STDs before beginning the main challenge. Every dyad having the same information was important because during their use of the Story and Screening and Analysis Tools, dyads referred to these charts to inform their predictions about the diagnosis of their mock patient.

7.3.2 What Did We Expect IRSU Tools Artifacts To Reveal?

We did not expect IRSU Tools artifacts to reveal much about why individuals showed improvement across performance assessments even after five months had passed since they used the Case Application Suite or engaged in Performance Assessment 1. Because the IRSU Tools employed prompting as a scaffold similar to the Case Application Suite and because individuals were used to the placement of SMILE's prompts and hints on the screen based on their previous uses of the Case Application Suite, we expected dyads to be able to correctly identify the information they were being prompted for. Because the IRSU Tools prompted dyads to justify their ideas, reflect on their predictions in light of previous and new information presented, and because students had a great deal of experience justifying their ideas during the *Digging In* and *Tunneling Through Georgia* units, we thought they would make informed predictions and include justifications in their responses during IRSU Tool use. However, we did not expect students to use interpretation or application skills as they had when using the Case Application Suite because the IRSU Tools were neither designed to support those skills nor did they explicitly prompt dyads to use those skills.

7.3.3 We Found That Dyads Used Some Interpretation Sub-Skills During IRSU Tools Use

When we informally analyzed IRSU Tools artifacts generated by dyads that contained former members of the Blue Ridge, Ridge and Valley, and Coastal Plain groups, we found several trends. Surprisingly, most dyads identified lessons learned when using the Diagnosis, Prevention and Treatment Tool, and about one-fourth of those lessons learned followed the format of the Rule of Thumb template employed in the Case Interpretation Tool. Also surprising was the finding that eight out of ten of the dyads identified outcomes that occurred or could occur as a result of doing or failing to do something. Most of these outcomes were identified within the lessons learned. Furthermore, most dyads included justification in their responses even when they were not prompted to do so. Let's look at each of these trends in more detail.

7.3.3.1 Most Dyads Identified Some Form of Lessons Learned

Eight out of ten dyads identified lessons learned in the Diagnosis, Prevention and Treatment Tool. Examples of lessons learned include *Abstinence is the only method of prevention that works 100%, If women use douche, it decreases the number of bacteria in the vagina, so it could increase the risk of infection, If you don't take antibiotics the disease can travel throughout the rest of the body including the heart and bloodstream—it can kill you,* and *Always have safe sex, using condoms, sponges, diaphragms, etc*. About one-quarter of the dyads' lessons learned had the same format used in the Rule of Thumb template in the Case Interpretation Tool. This suggests that some students may have internalized the Rule of Thumb template as a way to articulate lessons learned from an experience or information, even in the absence of the template. This trend was surprising not only because many of the lessons learned had the format suggested for design rules of thumb, but also because dyads were not explicitly prompted to articulate lessons learned. While we have no data that may explain why so many dyads described lessons learned in the Diagnosis, Prevention and Treatment Tool, in particular, for the Consequences prompt, perhaps something about the way that prompt was worded seemed to elicit lessons learned from most dyads.

7.3.3.2 Most Dyads Described Outcomes That Occurred (Or Could Occur) As A Result of Doing Or Failing To Do Something

In the Case Use Skills Tree, we see that describing outcomes that occur as a result of addressing or failing to address constraints is a part of the interpretation phase of the case use process. However, the Case Interpretation Tool did not provide any scaffolding to help groups describe these kinds of outcomes. Surprisingly, the IRSU artifacts reveal that eight out of ten dyads were able to do something very similar: describe outcomes that occurred or could occur as a result of doing or failing to do something. Examples include *If you don't take antibiotics the disease can travel throughout the rest of the body including the heart and bloodstream—it can kill you, If women use douche, it decreases the number of bacteria in the vagina, so it could increase the risk of infection, Having multiple partners makes someone have a higher chance of getting Chlamydia,.* Most of these outcomes were described within the lessons learned discussed earlier. What's surprising about this trend is while Mr. J. did help students understand how doing (or failing to do) something (e.g., doctors washing their hands) resulted in a particular outcome (e.g., decrease in the number of infections in hospitals), dyads had not had opportunities to carry these skills out for themselves prior to IRSU software use.

These examples also reveal that in instances where dyads described outcomes that *could* occur as a result of doing or failing to do something, they were actually making predictions. While this was a skill that is a part of the case use process and one supported by the Solution Assessment Tool, dyads do not show any prior ability to make these kinds of predictions prior to the IRSU Unit. They were unable to use the Solution Assessment Tool in their *Tunneling Through Georgia* groups due to time constraints, and Performance Assessment 1 coding results reveal that Blue Ridge and Coastal Plain group members did not articulate recommendations to the construction company; hence, they did not make predictions about the criteria or constraints that were met or overlooked.

7.3.3.3 Dyads Included Justification In Their Responses

Eight out of ten dyads also included justifications in their responses, even when they were not explicitly prompted to explain or justify them. *We weren't able to eliminate any of the two STD's because the pathogen of Trichomonaisis isn't known to us, Gonerrhea, Chlamydia and Yeast infection and Trichomonaisis are all possible illnesses because they all have painful urination as a symptom, The patient could have either genital herpes or HIV/AIDS. Both of the diseases have symptoms of sore throat, swollen glands, and fever*, *HIV/AIDS should be eliminated because the age group is different from her age and she doesn't have most of the symptoms,* and *He should seek medical advice quickly or he will enter the third stage and his death may occur* are examples of the kinds of justifications included by dyads. This suggests that justifying ideas had become second-nature to most students and a part of the way they thought about and "talked" science.

7.3.4 Summary of Results

This section described the IRSU and the capabilities dyads displayed that were not explicitly emphasized in Mr. J's enactment of the unit. An analysis of IRSU Tools artifacts revealed that there was a connection between some interpretation sub-skills in the case use process and skills performed and captured in the artifacts dyads produced when they used IRSU Tools. In particular, described outcomes that occurred as a result of doing or failing to do something, which Mr. J. modeled during class discussion prior to IRSU Tools use. This skill was very similar to the interpretation sub-skill of describing outcomes that occurred or could occur as a result of addressing or failing to address constraints, which the Case Interpretation Tool did not scaffold. Dyads also made predictions about which outcomes that could occur if something was or was not done, despite having no prior experience doing so. They also articulated lessons learned, with about one-quarter having the same format as suggested by the rule of thumb template. This was a sub-skill Mr. J. indirectly modeled during class discussion when he modeled describing outcomes.

7.4 Summary

The chapter presents the effects of the Case Application Suite by focusing on individual interpretation, application, and assessment performance for Performance Assessments 1 and 2 as well as how IRSU activities may have informed the interpretation, application, and assessment improvement we saw for most individuals across performance assessments.

The individual members of the Blue Ridge group displayed varied performance. Theresa's performance improved from her interpretation of the Landslide Case to her interpretation of the Lotschberg Tunnel case using the My Case Summary Design Diary pages, but declined from her interpretation of the Landslide Case to Performance Assessment 1. Margaret's performance from her interpretation of the Landslide case to carrying out case use skills during Performance Assessment 1 was inconsistent. While her ability to identify expert problems and understand criteria remained the same, her ability to understand constraints improved, but her ability to identify expert solutions, connect expert problems and solutions to apply to the challenge, and identify and articulating design rules of thumb declined. Billy's performance declined from his interpretation of the Lotschberg Tunnel case using the My Case Summary Design Diary Page to his enactment of case use skills during Performance Assessment 1. David's performance was also inconsistent across those same episodes. His ability to identify expert solutions and understand criteria was the same, but his ability to identify expert problems declined while his ability to identify and articulate design rules of thumb improved. This seems odd, as between Lotschberg and Performance Assessment 1, students had at least two experiences using scaffolding in the Case Application Suite as they interpreted tunneling cases. On the other hand, the performance of every member of the Blue Ridge Group improved between Performance Assessments 1 and 2 for both interpretation and application skills, even though application was not emphasized between the two PA's.

All of the members of the Blue Ridge group struggled with the same interpretation skills during Performance Assessments 1 and 2. While they seemed fluent at identifying expert problems (I) and connecting those problems to solutions (IV), all group members had difficulty identifying expert solutions (II), identifying and understanding criteria and constraints (V and VI), and identifying and articulating design rules of thumb (VIII).

The individual members of the Ridge and Valley group also displayed varied performance. Kenny's performance improved in some areas and declined in others from his interpretation of the Landslide Case to Performance Assessment 1. In particular, his ability to identify expert problems, criteria, and constraints improved, while his ability to identify solutions and design rules of thumb went from more specific to general. Daniel's performance from his interpretation of the Landslide case to carrying out case use skills during Performance Assessment 1 was inconsistent. While his ability to identify expert solutions, connect expert problems and solutions to apply to the challenge, and understand criteria improved, his ability to identify expert problems and identify and articulating design rules of thumb declined.

Michelle's performance improved from her interpretation of the Dust Bowl case to her interpretation of the Lotschberg Tunnel case using the My Case Summary Design Diary Page. Her performance also increased from My Case Summary Design Diary Page use to her application of case use skills during Performance Assessment 1. However, Michelle's interpretation performance declined from Performance Assessment 1 to Performance Assessment 2 for every sub-skill except identifying design rules of thumb. Sam's performance decreased from his interpretation of the Landslide case to his interpretation of the Lotschberg Tunnel case using the My Case Summary Design Diary Page. In particular, his ability to identify criteria and constraints went from identifying general or specific criteria and constraints to not identifying either at all. Sam's ability to identify design rules of thumb went from identifying design rules of thumb that included correct causality and made suggestions for applying them to his challenge to identifying general design rules of thumb. While his interpretation performance improved from My

Case Summary Design Diary Page use to Performance Assessment 1, his interpretation performance declined across performance assessments. His ability to identify expert problems, connect problems to solutions, and understand constraints declined, while his ability to identify expert solutions and design rules of thumb did not change. Although students had at least two experiences using scaffolding in the Case Application Suite as they interpreted tunneling cases, there is still a lot of variation in individual interpretation and application performance over time. This variation continues across performance assessments, though results are not as varied. Every individual showed improved interpretation and application performance across Performance Assessments 1 and 2 expect Michelle and Sam, who displayed declined interpretation performance but improved application performance, and Daniel who showed no change across performance assessments.

All of the members of the Ridge and Valley and Costal Plain groups struggled with the same interpretation skills during Performance Assessments 1 and 2. While they seemed fluent at identifying expert problems (I) and connecting those problems to solutions (IV), most individuals had difficulty identifying expert solutions (II), identifying and understanding criteria and constraints (V and VI), and identifying and articulating design rules of thumb (VIII).

Like the other groups, the individual members of the Coastal Plain group displayed varied performance. Sandy's performance declined from her interpretation of the Lotschberg Tunnel case to Performance Assessment 1. In particular, her ability to identify expert problems, criteria, and design rules of thumb went from more specific and including causality and/or justification to general. However, her interpretation and application performance improved across performance assessments. Chris's performance from his interpretation of the Lotschberg Tunnel case to carrying out case use skills during Performance Assessment 1 was inconsistent. While his ability to connect expert problems and solutions to apply to the challenge, and understand constraints improved and his ability to identify expert problems and solutions remained the same, his ability to understand criteria and identify and articulate design rules of thumb declined.

Chad's performance declined from his interpretation of the Landslide case to his application of case use skills during Performance Assessment 1. In particular, his ability to identify expert solutions, connect problems and solutions to apply to the challenge, understand criteria, and identify and articulate design rules of thumb went from more specific and including justification to identifying more general solutions and not identifying criteria or design rules of thumb at all. Nonetheless, Chad's performance improved across performance assessments. Melissa's interpretation performance improved across her interpretation of the Dust Bowl case and her interpretation of the Lotschberg Tunnel Case using the My Case Summary Design Diary Page. However, her performance declined from My Case Summary Design Diary Page use to Performance Assessment 1. Her ability to identify expert solutions, understand criteria, and identify design rules of thumb went from more specific to general. Her interpretation and application performance improved across performance assessments.

All of the members of the Costal Plain group struggled with the same interpretation skills during Performance Assessments 1 and 2. While they seemed fluent at identifying expert problems (I) and connecting those problems to solutions (IV), most individuals had difficulty identifying expert solutions (II), identifying and understanding criteria and constraints (V and VI), and identifying and articulating design rules of thumb (VIII). In the following chapter, we'll look more closely at the factors that may have influenced group and individual performance and discussion as well as what these factors suggest about group and individual case use capability.

In Chapter 8, we'll present tables that summarize the way group performance and capabilities and individual performance changed over time. We'll also look more closely at the factors that may have influenced group and individual performance and discussion as well as what these factors suggest about group and individual case use capability.

CHAPTER 8

ANSWERING OUR RESEARCH QUESTIONS

This chapter presents answers to our research questions based on our analysis and interpretation of results. The first research question is an effects with question, seeking to help us understand the effects with the Case Application Suite by analyzing how groups case use capabilities developed over time. Analysis of Case Interpretation Tool artifacts and video observations revealed that the development of case use skills looks different for every group, and group performance improves or worsens from one episode to the next. Group performance and capability do not improve uniformly, as expected; instead, they fluctuate. What seems to influence this fluctuation are a group's discussions and how fully the group is able to reason about the expert case. These are also indicators of group capability and performance. The completeness of a group's reasoning and a group's interpretation capability are revealed through their discussions, and the characterizations that seem to have the biggest influence on group discussions is how informed, non-chaotic and engaged they are. Factors that seem to influence how informed, non-chaotic and engaged group discussions are include how willing a group is to seek help when help is needed, how fully a group reasons about the expert case, the amount of detail in the expert case, the skills that are focused on early by the teacher and reinforced by the teacher, classroom activities, and software's scaffolding over time, and the personalities of group members.

The second research question focuses on the effects of the Case Application Suite by examining how well individual students were able use interpretation skills and how well individual students were able to interpret and apply expert cases in the absence of the Case Application Suite's system of scaffolds. The analysis revealed that individual performance was also varied, with individuals starting and ending in different places and their capabilities and performance. While most individuals did not perform as well as was predicted for Performance Assessment 1, surprisingly, individuals were able to perform and retain case use skills over time, and most individuals performed better for Performance Assessment 2 than for Performance Assessment 1. This was true even though they had not used interpretation, application, and assessment skills in that way in five months. Given this improvement with no LBD in between, we looked back at the IRSU to understand more about what may have occurred during that unit to explain the results. When we did, we saw that Mr. J. modeled describing outcomes that occur as a result of doing or not doing something, and he indirectly modeled how to articulate lessons learned based on those outcomes. This was done in during whole class discussions. When we analyzed IRSU Tools artifacts, we saw that dyads did these same things, and they made predictions, many of which were found within the lessons learned that they identified. These findings were surprising because they occurred without explicit prompting from the IRSU Tools.

We also examined the relationship between individual and group performance, especially in the context of Performance Assessments 1 and 2, and we identified four factors that seem to impact group and individual performance and capability most. They are the character of group discussions, how fully a group is able to reason about the expert case, how fully an individual is able to reason about the expert case in light of group reasoning, and what an individual chooses to write down based on the reasoning that has been done.

The final research question examines the difficulties groups and individuals faced when developing and applying case use skills. The analysis revealed that the same factors that most affect group and individual performance and capabilities are also the difficulties that groups and individuals faced. From this, four trends that describe the relationship between group performance and capability, group capability and individual capability, and individual capability and individual performance were described. These trends not only helped us understand the connections between group and individual performance and capability, but they also allowed us to make predictions about what impact addressing a particular difficulty should have.

We looked at how the Case Application Suite could better support case use skill development, and examined ways we might accomplish this better support. We found that we could better support case use skill development by helping groups have more informed, non-chaotic, engaged discussions and pushing their reasoning by drawing their attention to more of the full set of scaffolds. Ways we might accomplish this include adding more explicit including hints that encourage groups to engage in practices that are more likely to promote informed, non-chaotic, engaged discussions and including hints that explicitly remind groups about the help available to them.

Finally, we made suggestions for designing and integrating software into a learning environment where software and teacher share scaffolding responsibilities. Software in support of complex cognitive skill development should encourage students to employ the teacher's in-the-moment-scaffolding as well as the software's system of scaffolds to take advantage of the strengths of each. The fact that we were able to design software that serve as a coach in a cognitive apprenticeship environment was important because it suggests that software in support of complex cognitive skill development is able to take on a particular role within a learning environment. Finally, software should be designed to support complex cognitive skills in such a way that it can do so even if the teacher is uncomfortable with modeling or coaching those skills or if the teacher is not at skilled at carrying out the skill so the help students have available to them is not limited by how well or how completely the teacher models those skills.

8.1 Development of Group Interpretation Skills Over Time

In this section, I address the first of my three research questions, which focuses on development of case use skills:

How do small-group case use capabilities develop over time?

This question is a question that analyzes the effects with the Case Application Suite. In particular, this question focuses on how well groups can interpret an expert case and how their capability develops when scaffolding is available. To address this question, our intention was to examine development of as many of the three case use component skills as possible. In the original plan, designed in conjunction with the teacher, students were to have multiple opportunities with each of the component skills (interpretation, application, assessment). However, in the end, the teacher gave less attention to each component than we wanted, and only case interpretation was done more than once in small groups while using the software. We had hoped also that the teacher would have set up each use of cases similarly and given students enough time for their work each time so that students would feel that they were expected to interpret the cases in depth and carefully apply their lessons. But this did not always happen either; as discussed in Chapters 6 and 7, there was often insufficient time for students to fully interpret and apply the cases they were reading. Making matters worse, when the teacher knew he was not giving students enough time for in-depth work, he sometimes suggested to them that they skip some component tasks.

In the end, our answer to this question is based on analysis of three (3) case interpretation experiences each group engaged in. We tracked positive and negative changes in groups' performance across the three case interpretation activities described in Episodes 4, 5, and 7 of the previous two chapters, and then we looked across groups for trends. In addition to their performance on written work, we used groups' discussions to provide context for that work and to understand how group members participated in group discussions. In the end, this was more indicative of group case use capability than performance on written work.

We expected to be able to report specific trends with respect to skill development, i.e., to find consistent patterns in cognitive capabilities across groups. However, as Table 8.1 summarizes, results were far more varied. The Blue Ridge group's interpretations decreased and then increased over time. The Ridge and Valley group's interpretations were best in the first episode and decreased from there. The Coastal Plain group's interpretations increased from the first to the second episode and then remained the same.

Table 8.1 – Summary Of Changes In Case Interpretation Performance among Groups Over Time (repeated from Chapter 6)

Name of Group	Cases Interpreted (in order of interpretation)	Shifts in Capability For Case Interpretation Across Case Interpretation Activities 1 and 2 (Episodes 4 and 5)	Shifts in Capability For Case Interpretation Across Case Interpretation Activities 2 and 3 (Episodes 5 and 7)
Blue Ridge	St. Gotthard (Episode 4) Tecolote (Episode 5) Chunnel (Episode 7)	Decrease	Increase

Table 8.1 – Summary Of Changes In Case Interpretation Performance among Groups Over Time (repeated from Chapter 6) (Continued)

Ridge and Valley	Queens Midtown (Episode 4) Mono Craters (Episode 5) Simplon (Episode 7)	Decrease	Decrease
Coastal Plain	Frejus (Episode 4) Tecolote (Episode 5) Hudson (Episode 7)	Increase	No Change

Instead of trying to track trends in capabilities, therefore, we decided that it made more sense to address this question by identifying factors that might be responsible for these variations and to consider to what extent each seemed to influence groups' performance. We did this by examining the video data that showed the discussions students had with each other as they were working together at case interpretation, their ways of participating in those discussions, and their interactions with each other and with artifacts in the environment, identifying group capabilities during discussions, and using those capabilities to further inform group performance.

As groups responded to the prompts while interpreting an expert case using the Case Interpretation Tool, many would discuss their ideas before entering a final response into the software. Looking at group work in concert with those transcribed group discussions helped us understand how those discussions changed over time and how changes in discussion affected group interpretation capability and group work. From our analysis of the data, we identified and named five pairs of characterizations for group discussions: more-informed vs. less-informed, chaotic vs. classification-focused vs. content-focused, engaged vs. disengaged, between-group (inter-group) centered vs. within-group (intra-group) centered, and system-scaffolded vs. single scaffolded. We found that analyzing the character of discussions not only seemed to show more than written work alone, but it also ultimately affected what was written. We found several factors that seemed to impact groups' performance. A group might be far more capable than their performance shows at a surface level; performance and capability are not synonymous. Table 8.2 shows each pair of characterizations along with their definitions.

Table 8.2 – Characteristics of Group Discussion

Pair (or triplet) of Discussion Characterizations	Discussion Characterization	Description
More informed vs. less informed	Informed	Discussion that uses and refers to the written artifact representing the expert case to generate, explain, justify, support, or refute ideas.
	Less-Informed	Discussion that uses memories of the expert case and independent logic to explain, justify, or refute ideas.
Chaotic vs. Classification-focused vs. Content-focused	Chaotic	Discussion that has no particular focus and lacks direction.
	Classification-focused	Discussion that focuses on giving an idea a particular label based on the definitions of the labels in question.
	Content-focused	Discussion that uses the content surrounding an idea to understand how an idea should be articulated.
Engaged vs. Disengaged	Engaged	Discussions characterized by participation of more than half of the group in discussions and more than half the group focusing on the task at hand.
	Disengaged	Discussions characterized by a lack of participation and focus by half or more than half of the group.
Inter-group vs. Intra-group	Inter-group	Discussion that focuses on an audience outside of the group.
	Intra-group	Discussion that focuses on only on what the group understands.

Table 8.2 – Characteristics of Group Discussion (Continued)

System-scaffolded vs. single-scaffolded	System-scaffolded	Discussions that employ two or more of the software's scaffolds simultaneously.
	Single-Scaffolded	Discussions that employ only one of the software's system of scaffolds.

In addition to the factors described in Table 8.2, other factors that seem to make a difference are how willing a group is to seek out help, the completeness of the group's reasoning, the level of detail in the expert case, the skills the teacher focuses on and reinforces early on, and the personality of the group members. Taking this whole set of factors into account has allowed us to describe eleven trends revealed in this study regarding group performance and engaged participation in collaborative reasoning. The remainder of the chapter discusses the factors that seem to influence the character of group discussions and presents the predictions we extracted.

8.1.2 Trends In The Impact of Discussion on Case Interpretation Performance and Capability

8.1.2.1 Trend 1: The more informed the discussion, the better the interpretation of a case.

In an informed discussion, students are referring to the case itself and its facts, looking at the text of the case itself as they are collaborating. Comparing group discussions over time, we see that when the Blue Ridge group used the text of the expert case to inform their discussions (as they did during their first and third uses of the Case Interpretation Tool (Chapter 6, Episodes 4 and 7)), their interpretations were far better than when they relied on their memories of what they had read (as they did during their second use of the software). For example, in their third use (Chunnel Tunnel case), they identified *Construction stopped in 1971 due to money problems* as a problem the experts faced. This problem was much more descriptive and detailed than the more general *A lot of water flooded the tunnel* that was identified from memory during their second use (Tecolote Tunnel).

Similarly, when the Ridge and Valley group relied on their own memories of a case, as they did during their second use of the Case Interpretation Tool (Mono Craters Tunnel case – Chapter 7, Episode 5), their ability to interpret the expert case suffered. However, when they looked at the expert case to inform their discussions as they did during their first software use (Queens/Midtown Tunnel Case – Chapter 7, Episode 4), their ability to interpret the expert case was very sophisticated. For example, when using the Queens/Midtown Tunnel case to inform their discussions, they identified a design rule of thumb that included correct causality or justification (e.g., *If water somehow seeped through the permeable rock, you could use compressed air to pump it out of the tunnel and put a thick blanket of clay on the river bottom, because it would counter the air pressure and prevent the river from letting in.*), but when relying on their memories of the Mono Craters Tunnel case, their design rule of thumb was much more general and their justification was incorrect (e.g., *When water is a problem use holes drilled in the tunnel to extract water because water will flow out because of the law of gravity*.)

<u>8.1.2.2 Trend 2: As groups develop their ability to interpret cases, they seem to move from chaotic discussion to more classification-focused discussion and then to more content-focused discussion.</u>

As student groups develop interpretation capability, they seem to move from a lack of focus to having discussions that focus on classifying ideas, and finally moving to discussions that use the content of the expert case to understand the context of an idea and inform how that idea should be expressed. Of our three target groups, the Blue Ridge group showed the most definitive movement from classification-focused to content-focused discussion, having classification-focused discussions while identifying criteria and constraints in their first and second uses of the software (St. Gotthard and Tecolote Tunnel cases – Chapter 6, Episodes 4 and 5)), and moving to content-focused discussion while identifying criteria and constraints in their third use (Chunnel Tunnel case - Chapter 6, Episode 7)). During Episodes 4 and 5, the Blue Ridge group used the definitions of criterion and constraint to classify an idea as a criterion or constraint or to support or refute a classification. They used phrases like "they didn't have to do it", "what limitations did they have to face", and "they wanted concrete lining" to do those things. In Episode 7, their discussions did not focus on whether an idea generated should be a criterion or a constraint, but focused rather on the context that caused the criterion or constraint to arise and how the criterion or constraint should be articulated in the Case Interpretation Tool. When Theresa offered "lining in concrete" as a criterion, Billy engaged her in a discussion about whether a material other than concrete was used in areas where the rock was permeable. The concern wasn't whether Theresa's idea was classified appropriately. Instead, the concern was whether her idea was articulated accurately. The Ridge and Valley group's discussions remained classification-focused across all case interpretation activities.

However, the Coastal Plain group shows the most definitive movement from chaotic to classification focused. They started out trying to have classification-focused discussions while interpreting the Frejus Tunnel case (Chapter 7, Episode 4), but ended up having chaotic discussions that did not focus on the content, but focused rather on the chaos happening in the group. The time lost due to getting logged out of the software, the laptop shutting down, the instructions of the teacher to skip down and work backward, and the group's inability to collaborate effectively all contributed to the sense of chaos that dominated the group's discussions. However, during their interpretation of the Tecolote Tunnel case (Chapter 7, Episode 5), those difficulties did not exist, and the Coastal Plain group was able to move from chaotic to classification-focused discussion.

<u>8.1.2.3 Trend 3: The more engaged group members are in the discussion, the better the interpretation performance of the group.</u>

Engaged discussions involve the input of more than half of the group who are sharing multiple perspectives and experiences. The Coastal Plain group showed much better interpretation performance for their second use of the Case Interpretation Tool (Tecolote Tunnel) than for their first use (Frejus Tunnel). This was due, in part, to three-fourths of the group members being focused on the task of the interpreting the Tecolote Tunnel case as opposed to only half the group being engaged during the Frejus Tunnel case. Also, the Ridge and Valley group showed that discussion where group members are disengaged resulted in poorer case interpretation performance, as they lost more and more interest in interpreting the Mono Craters Tunnel case over the course of the activity (Chapter 6, Episode 5).

Unlike the Ridge and Valley or Coastal Plain groups, the Blue Ridge group is interesting because engagement seemed to decrease over time, but group performance improved over time. In their interpretations of the St. Gotthard and Tecolote Tunnel cases (Chapter 6, Episodes 4 and 5), all of the group members engaged, but group performance worsened across those episodes. However, during the group's third use of the Case Interpretation Tool (Chunnel Tunnel – Chapter 6, Episode 7), Theresa and Billy seemed to engage and disengage from the discussion repeatedly, carrying a non-related conversation throughout the episode, but jumping in quickly to offer important details or opinions about what was being typed by David or discussed by Margaret and David. Their constant engagement and disengagement with the group's discussion did not seem to hinder the group's ability to interpret the expert case effectively. Perhaps their ability to interpret expert cases as a group had developed to the point that full engagement wasn't required by all group members throughout the entire task, or perhaps Billy and Theresa weren't as disengaged as they appeared.

8.1.2.4 Trend 4: Discussions that consider an audience outside of the group (Inter-group centered discussions) seem to result more often in more specific and detailed descriptions in group artifacts, while discussions that focus only on what the group understands (intra-group discussions) seem to result more often in only a summary or general description of ideas in group artifacts.

Typically, all of our target groups focused solely on what the group itself did or did not understand. Groups only considered an audience outside of the group twice across all case interpretation activities, and in both instances, more detailed responses in the written artifact resulted. The Blue Ridge group had a moment of inter-group centered discussion during their third use of the Case Interpretation Tool (Chunnel Tunnel – Chapter 6, Episode 7), when David suggested that the group explain what a service tunnel was "because they might not understand it," referring to others who may read their interpretation of the expert case in the future. The Ridge and Valley group also had a moment of inter-group centered discussion during their second use of the software (Mono Craters Tunnel), when Sam pressed Kenny to type that there was high pressure on the tunnel instead of in the tunnel to provide clarification for someone else reading the group's interpretation of the expert case "cause they might think it was in the tunnel" (Chapter 7, Episode 5). Consideration of an audience outside of the group did not occur until the second or third time groups used the Case Interpretation Tool to interpret an expert case even though they had commented on the interpretations of other groups following their first use of the Case Interpretation Tool.

8.1.2.5 Trend 5: The more a group recognized the connections between the software's scaffolds, the more in-depth the discussion and the more descriptive the responses than when only one of the software's scaffolds was used.

When the Blue Ridge group read the prompt and hint before answering the Solution Chosen prompt during their interpretation of the St. Gotthard case (Chapter 6, Episode 4), and when all groups read the Criteria and Constraints prompt followed by using the Criteria and Constraints Template, they were engaging in system-scaffolded discussion. In fact, we found that when groups read the prompt and referred to an additional software scaffold, those scaffolds together guided the group's discussion. In many instances, a group member would refer back to the scaffolds to support inclusion of more detail in a response or to suggest that the group had not fully responded to the prompt. However, when the Blue Ridge and Coastal Plain groups answered the Criteria and Constraints prompt without using the template before Mr. J. showed them the link during their first uses of the software (St. Gotthard Tunnel and Frejus Tunnel cases, respectively – Chapter 7, Episode 4)), they were only taking advantage of one of the software's scaffolds. We found that in most instances where only one scaffold was used (usually just reading the prompt), if the group was confused about what they were being prompted for, they remained so and responded using only very general descriptions.

<u>8.1.2.6 Trend 6: The more software and teacher share scaffolding responsibilities, the more effective the performance of the group they are supporting.</u>

The Case Application Suite was designed to share the scaffolding responsibilities with the teacher. However, the Case Application Suite was not designed to replace the teacher. In instances where groups took advantage of the software's system of scaffolds in concert with the teacher's scaffolding, better case interpretation capability resulted. The Ridge and Valley group used a combination of teacher scaffolding and software scaffolding as they interpreted expert cases. When they used both the prompts and Mr. J's in-the-moment scaffolding while interpreting the Queens/Midtown Tunnel case, their responses were very sophisticated, detailed, and descriptive (Chapter 7, Episode 4). However, this group may have depended a little too much on Mr. J's in-the-moment scaffolding and not taken enough advantage of the software's full system of scaffolds because when Mr. J's in-the-moment scaffolding was not available to them during their interpretation of the Mono Craters Tunnel case, they did not use more of the software's full system of scaffolds, and their case interpretation capability suffered (Chapter 7, Episode 5).

8.1.3 Factors That Seem To Influence Group Discussion And Participation In Collaborative Reasoning

Several factors seemed to influence how group discussions could ultimately be characterized, thus affecting group case interpretation capability. Among those were how willing a group was to ask for help when needed, how fully a group was able to reason about the expert case through their discussion, the amount of detail in the expert case, the skills that the teacher focused on early and reinforced, and the personalities, in particular, persistence, of group members. These factors also suggest important principles about the impact that environmental and intra-group factors can have on how group discussions are characterized and on group case interpretation capability.

8.1.3.1 Trend 7: Groups who seek help when they are confused, unsure, or at a point where intersubjectivity cannot be reached respond to prompts in more detail and reach and/or maintain intersubjectivity better than groups who do not.

During their fir use of the Case Interpretation Tool (Queens/Midtown Tunnel), the Ridge and Valley group constantly relied on Mr. J's in-the-moment scaffolding (Chapter 7, Episode 4). On at least three occasions, when the group reached an impasse, Daniel raised his hand, Michelle described the group's problem to Mr. J., and Mr. J. helped them to address their difficulty or struggle. This group showed sophisticated case interpretation performance for this case. However, when the Coastal Plain group clearly needed help generating design rules of thumb during their first use of the software (Frejus Tunnel) but decided not to talk to the teacher (Chapter 7, Episode 4), the result was the generation of a design rule of thumb that was not only unrelated to the expert case, but also judged by group members as being "horrible," and overall case interpretation suffered.

8.1.3.2 Trend 8: The more complete the reasoning of a group, the more likely a group will display more capable case interpretation and better interpretation performance.

For case interpretation in particular and case use in general, reasoning involves not only interpreting or applying an expert case, but it also involves the discussion that informs that interpretation or application. This is because much of the group's reasoning happens during their discussions. In Chapters 6 and 7, we've described examples that support the idea that when the group worked well together, focused on the task, and engaged in in-depth discussion about the expert case, they were able to reason about the case in more detail and with more specificity than when they did not. What allowed them to do this? The factor that seemed to have the greatest impact on a group's ability to reason was the amount of time they had to do the reasoning.

It is important, though sometimes difficult, to not allow time constraints to interfere with groups having the chance to use the Case Application Suite to reason about an expert case in such a way that they can, for example, describe lessons they can learn from the experts and figure out if and how those lessons can be applied to their challenge. Following the laptop shutdown during the Coastal Plain group's interpretation of the Frejus Tunnel case, Mr. J. told the them to skip down to the Lessons Learned prompt before they finished the How The Solution Was Carried Out prompt because there was not much time left in the class period. Unbeknownst to him, he prevented the group from taking advantage of the affordances that particular prompt provided to help them connect the expert problems and solutions in such a way that the lessons they could learn from the experts would be visible and describable in the Lessons Learned prompt. They floundered during the Lessons Learned prompt, because they weren't sure what they'd learned. When they had the opportunity to do this kind of reasoning during their interpretation of the Tecolote Tunnel case, they were able to make those connections and identify a design rule of thumb that was directly related to the expert case, included justification, and suggested how they might be able to apply it to the group's *Tunneling Through Georgia* challenge. The implication here is that groups should have enough time to do the reasoning, and in situations where time is constrained, the teacher should be aware and help the class understand that it may be better to have the detailed, in-depth discussion that allows the group to reason even if they run out of time rather than sacrifice completeness of reasoning in order to finish a task within the allotted time.

8.1.3.3 Trend 9: Expert cases that provide more specific details about problems, solutions, criteria, and constraints are easier for students to interpret than those that are less descriptive.

It can be difficult to find expert cases that include a lot of detail, especially if the expert cases are not written specifically for the audience that is interpreting it. However, if an expert case is written specifically for the audience interpreting it, the problems and solutions must be described in such a way that they provide all of the detail that groups need to be able to use them. The frustration the Ridge and Valley group expressed when they could not find the process the experts used to implement their solutions in the Mono Craters Tunnel case ("Well, it doesn't really say that much", "There's nothing to type!") may have impacted the group's ability to interpret the expert case as well as they were able to do with more descriptive cases (i.e., Queens/Midtown and Simplon Tunnel cases).

8.1.3.4 Trend 10: Skills that the teacher helps students focus on early, reinforces over time, and asks students to engage in over several activities seem to stay with students. Students seem to take the initiative to seek scaffolding for performing those skills.

Although there was no formal discussion of criteria and constraints at the beginning of the *Tunneling Through Georgia* Unit, Mr. J. focused on helping students understand the difference between criteria and constraints during the *Digging In* Unit. In addition, the activities in the *Digging In* Unit focused on helping students understand this difference as well as how criteria and constraints are used to inform decision making. This skill was reinforced by the Case Application Suite's system of scaffolds, and as a result of the focus on criteria and constraints by the teacher, classroom activities, and Case Application Suite, every group spent most of their discussion time across case activities discussing criteria and constraints.

8.1.3.4.1 Corollary 10.1: Scaffolding that doesn't match the reasoning focused on by the teacher and classroom activities isn't used

Although examples were provided for each prompt in the same frame as the hints, we see only one instance of groups using an example in the Case Application Suite as they worked in any of our data. During their use of the Case Application Tool, Mr. J. stressed that groups should look at and refer to the example of the Applying Our Rules of Thumb template so they could understand what they were being prompted for. Students had not used examples in the way we designed them to be used in the Case Application Suite during any of their other class discussions or activities in the *Digging In* and *Tunneling Through Georgia* Units, so students had not experienced using examples in this way. During student interviews, most students told us they did not use the examples in the software while using the Case Application Suite, and this is also consistent with our Fall 2002 study data, though in that study, we thought examples were not used because they could only be seen if accessed by choosing a menu option that was hidden from plan view.

8.1.3.5 Trend 11: Persistence makes a difference only when coupled with informed deliberation.

The personalities of group members can impact both the discussions that a group has and the group's ability to interpret an expert case. In fact, more persistent and/or aggressive group members can steer a group toward less capable or more capable case interpretation. When Sam insisted that Daniel type that high pressure was on the tunnel instead of in the tunnel during the Ridge and Valley group's interpretation of the Mono Craters Tunnel case (Chapter 7, Episode 5), his persistence and aggressiveness pushed the group toward more effective case interpretation. Coding results revealed that the group received the highest rating because they included the details Sam was so persistent about. However, when Kenny insisted in that same episode that the group use the law of gravity as justification for their design rule of thumb, although the group did not feel that this was a correct justification, Kenny's persistence pushed them toward less effective case interpretation. Their design rule of thumb was not given the highest rating possible because the justification provided by the group was incorrect.

8.1.4 Revisiting Group Discussion and Group Performance

Our analysis thus far has shown that two major factors had the most influence on group performance: the kinds or character of group discussions and the completeness of the group's reasoning. As Table 8.3 summarizes, when group discussions were informed, non-chaotic, and engaged, group performance increased; otherwise it decreased. Therefore, these three characteristics seem to affect group performance more than the others. This is evidenced by the fact that the Blue Ridge group's performance increased from their second use of the software to their third use and the Coastal Plain group's performance increased from the group's first use to their second use of the software even though these groups only used one scaffold (i.e., prompts). This is not to suggest that the system of scaffolds does not really make a difference; we have described many examples of groups using templates and hints to guide or spark more in-depth group discussion. The claim we are making here is that use of the system of scaffolds alone does not increase group performance, but the character of group discussion around those scaffolds does.

Table 8.3 also suggests that an increase in interpretation performance was also the result of groups reasoning about the expert case more fully. The impact that group discussion had on group interpretation performance and the Case Application Suite's role in supporting and guiding that discussion suggests that the more informed, engaged and non-chaotic the discussion when guided by the Case Application Suite's system of scaffolds, the more complete the reasoning will be that the group engages in.

Table 8.3 – Character Of Group Discussion During Case Interpretation Use Over Time and Its Impact on Group Performance

Name of Group	Character of Discussion During 1st use of Case Interpretation Tool	Character of Discussion During 2nd use of Case Interpretation Tool	Group Performance Across 1st and 2nd Use of Case Interpretation Tool	Character of Discussion During 3rd use of Case Interpreta-tion Tool	Group Performance Across 2nd and 3rd Use of Case Interpretation Tool
Blue Ridge	Informed, classification-focused, engaged, intra-group, system-scaffolded	Less-informed, classification-focused, disengaged, intra-group, system-scaffolded	Decrease	Informed, content-focused, disengaged, inter-group, single-scaffolded	Increase

Ridge and Valley	Informed, classification-focused, engaged, intra-group, system-scaffolded	Less-informed, classification-focused, disengaged, inter-group, system-scaffolded	Decrease	No Video	Decrease

Table 8.3 – Character Of Group Discussion During Case Interpretation Use Over Time and Its Impact on Group Performance (Continued)

Coastal Plain	Less-informed, chaotic, disengaged, intra-group, single-scaffolded	Informed, classification-focused, engaged, intra-group, single-scaffolded	Increase	No Video	No Change

8.1.5 Summary

This section sought to understand how case use skills develop over time by looking at the changes in group interpretation performance that occurred over time. An analysis of the coding results for group performance using the Case Application Suite and group discussions as described in the previous two chapters was presented to inform our first research question. Analysis of the data showed that the development of case use skills looks different for every group, and group performance improves or worsens from one episode to the next. Group performance and capability do not improve uniformly, as we expected. Instead, they fluctuate depending on several factors. What seems to influence these changes and indicate group interpretation capability the most are the group's discussions, which can be described or characterized as a combination of informed vs. uninformed, chaos-focused vs. classification-focused vs. content-focused, inter-group centered vs. intra-group centered, engaged vs. disengaged, and system-scaffolded vs. single scaffolded. Other factors that seem to influence the characterization of group discussions include how willing a group is to seek help when help is needed, how fully a group reasons about the expert case, the amount of detail in the expert case, the skills that are focused on early by the teacher and reinforced by the teacher, classroom activities, and software's scaffolding over time, and the personalities of group members. In addition, we were able to glean eleven principles about the development of group interpretation capability over time based on the full set of characterizations and factors that influence group discussions.

Later in this chapter, we will discuss the suggestions these principles make about our larger goal of understanding and supporting complex cognitive skill development. Before we do that, we will analyze how well individual students were able use case interpretation skills and how well individual students were able to interpret and apply expert cases in the absence of the Case Application Suite's system of scaffolds.

8.2 Applying Individual Case Use Skills In New Situations Over Time

Now, I address the second of my research questions, which focuses on carrying out case use skills in new situations over time:

> *How well are students able to apply case use skills in new situations over time?*

This research question analyzes the effects of the Case Application Suite on how well individuals are able to apply case use skills in new situations without the software's scaffolding. This question focuses on understanding how well individuals can carry out case use skills in situations where their use is appropriate. As part of our analysis, we analyzed results about individuals' ability to interpret and apply expert cases both before and after being exposed to the Case Application Suite. To do this, we began by looking at the My Case Summary Design Diary Pages for the Dust Bowl/Landslide and Lotschberg Tunnel cases. These helped us understand how capable individuals might be before being introduced to the Case Application Suite; they helped us establish starting points for student performance and capability. For some students, we had My Case Summary Design Diary Pages for both the Dust Bowl/Landslide and Lotschberg Tunnel cases; but for others, we had pages for one or the other expert case.

Then, we analyzed results about individuals' ability to interpret and apply expert cases after exposure to the Case Application Suite's system of scaffolds. To do this, we looked at Performance Assessments 1 and 2 for the Bald Head Island and Snowshoe Hare/Lynx Challenge, respectively. Remember, Performance Assessment 1 was given at the end of the *Tunneling Through Georgia* Unit, while Performance Assessment 2 was administered five months later at the end of the IRSU. Performance Assessment 1 revealed how well individuals could enact case use skills and reasoning without the Case Application Suite after having used it three times to interpret and once to apply expert cases. Performance Assessment 2 allowed us to understand to what extent individuals retained case use skills over time. During Performance Assessments 1 and 2, individuals discussed the cases as a group but wrote their analysis individually. We also looked at our analysis of the IRSU enactment and artifacts to inform and perhaps explain the improvement in interpretation, application, and assessment performance we saw across Performance Assessments 1 and 2.

We thought that individuals' abilities to use cases would improve across My Case Summary Design Diary Page use for the Dust Bowl/Landslide cases and the Lotschberg Tunnel case (Episodes 1 and 3). We also predicted that, because of their exposure to the

Case Application Suite, the multiple perspectives of those members in their small groups, and Mr. J's in-the-moment scaffolding, individuals' case use capability would increase from their last use of the My Case Summary Design Diary Page (Episodes 1 or 3) to Performance Assessment 1(Episode 8). However, there were five months between Performance Assessments 1 and 2 without individuals enacting case use skills as they had during the *Tunneling Through Georgia* Unit. Therefore, we thought that students would be able to perform case use skills in the absence of the Case Application Suite's system of scaffolds but with some degree of degradation.

8.2.1 Trends In The Effects Of The Case Application Suite On Individual Performance And Capabilities

Table 8.4 summarizes our analysis of individuals' ability to carry out case use skills over time. We found that variation existed in interpretation performance during My Case Summary Design Diary Page use for the Dust Bowl/Landslide and Lotschberg Tunnel cases (Episodes 1 and 3). Surprisingly, we found that individuals had some difficulty interpreting and applying the Bald Head Island case in the absence of the Case Application Suite's system of scaffolds during Performance Assessment 1 even though they'd used scaffolded interpretation and application skills in the context of Case Application Suite use several times (Episodes 4, 5, 6, and 7). Also from Performance Assessment 1, we found that students who led discussions and participation during Case Interpretation Tool use tended to lead group discussions during Performance Assessments 1 and 2. Some students who were not as vocal or active during initial Case Interpretation Tool use became more vocal or active over time while others did not, but we found that the amount of participation in group discussion during Case Application

Suite use in small groups did not tend to predict better interpretation, application, and assessment performance enactment and retention during Performance Assessments 1 and 2.

While we underestimated the time it would take for students to develop case use skills and become proficient at using them, surprisingly, Performance Assessment 2 data revealed that students were able to carry out and retain case use skills over time without the degradation we expected In addition, we found that belonging to a group that does not collaborate effectively does not necessarily mean that individual students are not learning and developing case use skills. Let's look at each of these findings in more detail.

Table 8.4 – Summary Of Changes In Student Performance Of Case Use Skills Over Time

Name of Student	Group Membership	Interpretation Performance Across My Case Summary Design Diary Page Use But Before Case Application Suite Use (Episodes 1 and 3)	Interpretation, Application, and Assessment Performance Across Last My Case Summary Design Diary Page Use and Performance Assessment 1 After Case Application Suite Use	Interpretation, Application, and Assessment Performance Across Performance Assessment 1 and Performance Assessment 2 (Five Months After Case Application Suite Use and Following IRSU Tools use)
Theresa	Blue Ridge	Increase	Decrease	Increase
Margaret	Blue Ridge	Inconsistent	Inconsistent	Increase
Billy	Blue Ridge	N/A	Decrease	Increase
David	Blue Ridge	N/A	Inconsistent	Increase

Table 8.4 – Summary Of Changes In Student Performance Of Case Use Skills Over Time (Continued)

Michelle	Ridge and Valley	Increase	Increase	Decrease (for interp.)/ Increase (for app.)
Sam	Ridge and Valley	Decrease	Increase	Decrease (for interp.)/ Increase (for app.)
Daniel	Ridge and Valley	Inconsistent	Increase	No Change
Kenny	Ridge and Valley	N/A	Inconsistent	Decrease
Sandy	Coastal Plain	N/A	Decrease	Increase
Chris	Coastal Plain	N/A	Inconsistent	Increase
Chad	Coastal Plain	N/A	Decrease	Increase
Melissa	Coastal Plain	Increase	Decrease	Increase

8.2.1.1 Trend 11: Every Individual Does Not Develop Complex Cognitive Skills At The Same Rate And In Response To The Same Scaffolding

Of the individuals we had information for, only five of them had My Case Summary Design Diary Pages that could be compared across episodes of teacher introduction and modeling (Episodes 1 and 3).

We thought there would be an increase in individual case interpretation performance across these episodes. However, we found variation, with Theresa, Michelle, and Melissa showing improved case interpretation performance, Sam showing declined performance, and Daniel showing inconsistent performance.

While we do not have video observations of students working on My Case Summary Design Diary Pages during episodes of teacher introduction and modeling, we do have Mr. J's introduction and modeling of case interpretation reasoning for those episodes. Like cognitive apprenticeship suggests, Mr. J. explained to the class what they should be looking for in the expert cases to complete the My Case Summary Design Diary Pages. However, unlike cognitive apprenticeship suggests, he did not model My Case Summary Design Diary Page completion by actually filling out a My Case Summary Design Diary page as they were reading an expert case together. Instead, he explained the kinds of questions students should be asking themselves as they read, but he did not do that questioning in the context of completing a My Case Summary Design Diary page with the class.

Our observations of our best teachers supporting students during case use from 2001 revealed that the teacher could help students overcome many of the difficulties associated with interpreting expert cases (i.e., making causal connections, understanding the role of artifacts in the expert case, identifying the lessons learned, etc.) by showing them how to break down the expert case, modeling for them the kinds of questions students should be asking themselves in the context of collaboratively reading and interpreting the expert case [Owensby & Kolodner, 2001]. Observations from our Fall 2002 study also revealed that Mrs. K.'s modeling of case interpretation skills as she filled out the template helped students understand how they should use the case to help them complete the template. Consistent with both sets of observations, if Mr. J. had done some additional modeling by actually completing a My Case Summary Design Diary Page with the class as he and the class read an expert case together, individuals who showed inconsistent or declined interpretation performance may have been able to interpret the Dust Bowl/Landslide and Lotschberg cases better.

Another explanation for this variation could be that those students who showed a decrease or inconsistency across these episodes may not have started with interpretation skills that were as developed as those who showed improvement. Maybe this was the result of not having used case interpretation skills at all prior to these episodes, not having as much experience using them, or not being as engaged with the task as those whose performance improved across My Case Summary Design Diary Page use. Regardless, variation existed in student case interpretation performance following teacher introduction and modeling.

8.2.1.2 Trend 12: Even After Repeated Exposure And Use Of Software-Realized Scaffolds, Students May Still Experience Trouble Enacting Skills In Its Absence

This principle resulted from comparing student case use performance and capability from My Case Summary Design Diary Page use to Performance Assessment 1. We were able to compare results for all twelve of our target students.

We found that seven of our target students experienced either inconsistent or declining interpretation and application performance from My Case Summary Design Diary Page use to Performance Assessment 1. Of the students who were in the Blue Ridge group, Theresa and Billy displayed decreased performance, while Margaret and David performed inconsistently.

In particular, coding results revealed that members of this group struggled with identifying expert solutions (Identifies Solutions (II)), identifying criteria (Understands Criteria (V)), identifying constraints (Understands Constraints (VI)), and identifying and articulating design rules of thumb (Rule of Thumb (VIII)). Notice that of these four dimensions, three of them are very well scaffolded in the Case Application Suite, namely, criteria and constraints (Criteria and Constraints template) and design rules of thumb (Rule(s) of Thumb template). In addition, Mr. J. focused on the difference between criteria and constraints during *Digging In*; the activities in *Digging In* focused on the importance of criteria and constraints in making informed design decisions; and student groups, in turn, focused most of their group discussions on identifying and describing criteria and constraints during Case Application Suite use. Furthermore, in student interviews, all twelve of our target students explained the difference between criteria and constraints and also explained what design rules of thumb were. In the next sub-section, we'll address why students may have struggled with these particular case use skills.

Of the students who were in the Coastal Plain group, Sandy, Chad, and Melissa showed an overall decrease in case use performance, while Chris performed inconsistently across these same episodes. Members of this group also struggled with identifying expert solutions, identifying criteria and constraints, and identifying and articulating design rules of thumb. However, the Ridge and Valley group tells a different story. While Kenny showed inconsistent performance, Michelle, Sam, and Daniel showed either improved or no changes in performance across these episodes. However, members of the Ridge and Valley group still struggled with identifying solutions and identifying constraints, two of the same struggles the Blue Ridge and Coastal Plain group members had.

Given this analysis of coding results, two questions arise. First, given all of this focus and help provided for criteria and constraints and design rules of thumb and given that these students knew what criteria, constraints and design rules of thumb were, why did so many students struggle with the same skills in the absence of the Case Application Suite's system of scaffolds? Second, why did three-fourths of the Ridge and Valley group show improved case use performance across these episodes while the remaining nine students showed declined or inconsistent case use performance?

8.2.1.2.1 Why Did So Many Individuals Struggle With Identifying Solutions, Criteria, Constraints, and Design Rules Of Thumb During Performance Assessment 1?

The case studies suggest several reasons why so many individuals struggled with identifying solutions, criteria, constraints, and design rules of thumb during Performance Assessment 1. First, they may have needed more opportunities to interpret expert cases in the absence of the Case Application Suite's system of scaffolds during the *Tunneling Through Georgia* Unit. While students interpreted expert cases using the minimal scaffolding of the My Case Summary Design Diary Page during the *Digging In* Unit, they did not interpret expert cases again in the absence of the Case Interpretation Tool's system of scaffolding again until Performance Assessment 1. Perhaps additional episodes of interpreting expert cases using the My Case Summary Design Diary pages interwoven with Case Interpretation Tool use may have helped individuals overcome the difficulties they experienced with identifying expert solutions, identifying criteria and constraints, and identifying and articulating design rules of thumb in the absence of the software's system of scaffolds. These additional episodes of My Case Summary Design Diary page use could have given individuals more deliberate practice at interpreting expert cases in the absence of the Case Interpretation Tool. Furthermore, these additional episodes could have given individuals more frequent opportunities to apply the strategies they'd learned during Case Interpretation Tool use in their small groups (e.g., employing a template to identify and organize criteria, constraints, and design rules of thumb .

Second, individuals may have needed the reminders that the Criteria and

Constraint and Rule of Thumb templates provided while they were using cases during Performance Assessment 1. Coding results from My Case Summary Design Diary page use (Episodes 1 and 3) revealed that many individuals did not identify criteria, constraints, or design rules of thumb during those episodes. In both situations, charts used to help individuals interpret expert cases did not explicitly prompt or remind them to identify criteria, constraints, or design rules of thumb. Instead, the My Case Summary Design Diary page prompted individuals to summarize the expert case, identify problems, solutions, and ways the solutions might be applicable to their challenge, while the chart used for Performance Assessment 1 prompted individuals to identify risks, management methods, and pros and cons for each of the management methods described in the Bald Head Island case. However, when the charts included prompting for design rules of thumb during Performance Assessment 2 by including a space on the chart marked **Rule(s) of Thumb,** most individuals identified them.

Third, individuals may have overly contextualized template use to Case Application Suite use, not recognizing that creating a template of criteria and constraints or design rules of thumb might have been a useful strategy during Performance Assessment 1. As Chapter 8 described, most groups were able to improve or maintain their ability to identify criteria, constraints, and design rules of thumb as they used the Criteria and Constraints Rule(s) of Thumb templates in the Case Application Suite repeatedly over time. However, students may have thought that what they learned using those templates as they worked in small groups was only useful when interpreting and applying expert cases using the software and not while interpreting and applying expert cases in its absence.

8.2.1.2.2 Why Did Three Individuals Show Improved Performance While Nine Individuals Showed Decline Or Inconsistent Performance

Despite a decline in performance for members of the Blue Ridge and Coastal Plain groups, Ridge and Valley group members' case use performance improved across their last use of the My Case Summary Design Diary Page and Performance Assessment 1. The data suggests two that the reason for this finding may have been because the Ridge and Valley group used Mr. J's in-the-moment scaffolding during group case use skills learning more than any other group. Recall that when this group was confused, they immediately turned to Mr. J. for help rather than using the system's scaffolds. For this group, his help seems to have been more useful than the scaffolding in the system.

<u>8.2.1.3 Trend 13: Student Participation In Group Discussions And Activities Is Not A Predictor Of Student Performance</u>

Looking back at the case studies in Chapters 6 and 7, it is easy to identify those students who led and participated more in group discussions and those who followed and participated less. Those students who led and participated more in group discussions during software use continued to lead group discussions during Performance Assessment 1. On the other hand, while most students who followed and participated less in group discussions during software use remained followers in group discussions during Performance Assessment 1, some became more active in group discussions and eventually became leaders in group discussions and participation by Performance Assessment 1. Whether leader or follower and whether followers remained followers or moved on to become leaders, leadership and participation in group discussions did not correlate with better interpretation, application, and assessment during Performance

Assessments 1 and 2. In fact, many students who were followers performed better at interpretation, application, and assessment during Performance Assessments 1 and 2 than those who were leaders in their small groups when using the software.

When we look at the students who were in the Blue Ridge Group, Theresa and David were the initial leaders. Over time, Billy moved from being more of a follower to becoming more of a leader and participating more in group discussions, while Margaret remained a follower and one who did not lead discussions within the group. However, Margaret performed slightly better than the rest of the group members on Performance Assessment 1, and she performed much better than her former group members on Performance Assessment 2.

Likewise, when we look at students from the Ridge and Valley group, Michelle, Sam, and Kenny led group discussions, while Daniel was more of a follower of group discussions, and these distinctions remained throughout their tenure as a group. Nonetheless, Daniel performed just as well as his group members on Performance Assessment 1, and he performed better than his former group members on Performance Assessment 2.

The same rings true when we look at members from the Coastal Plain group. We find Melissa and Chris led group discussion and participation during software use. Sandy, who did not really seem to follow group discussions during their first use of the Case Interpretation Tool (Chapter 7, Episode 4) became more of a leader during their second and third uses of the Case Interpretation Tool (Chapter 7, Episodes 5, 6, and 7, respectively). By Performance Assessment 1, she had become a leader in group discussions and participation. Chad, who also did not seem to follow group discussions during the group's first use of the Case Interpretation Tool, remained a follower of group discussions throughout Case Application Suite use. However, Sandy and Chad both performed just as well as the rest of their group members on Performance Assessment 1, and they performed better than Melissa and Chris on Performance Assessment 2.

While neither the data nor the case studies suggest why this finding occurred, it does suggest two things: First, just because a individual does not participate as much in group discussions does not mean that he/she is not learning or has diminished capability compared to individuals who are more vocal and participate more. Second, individuals are able to move from being less active to becoming more active in group discussions and activities. These suggestions support the perspective of legitimate peripheral participation [Lave & Wenger, 1991; Guzdial & Carroll, 2002], which espouses that lurking has a place within the larger context of communal learning as well as the idea that lurkers are able to move into the inner circle of activity.

8.2.1.4 Trend 14: Individuals Are Able To Carry Out And Retain Some Complex Cognitive Skills Over Time In The Absence Of Systematic Scaffolding

All twelve of our target students showed either increases or no change in their performance of case use skills across Performance Assessments 1 and 2 where individuals interpreted and applied expert cases in the absence of the Case Application Suite's system of scaffolds. Ten of the twelve individuals showed improved performance, while Daniel showed no change in performance. However, while Sam showed an overall decline in performance across Performance Assessments 1 and 2, he showed improved application and assessment performance across those same episodes. These findings are important because they support our hypothesis that individuals may be able to transfer case use skills to situations where their use is appropriate. It also suggests that they can retain case use skills over time, and it suggests that students learned interpretation, application, and assessment skills well enough to be able to use them later.

However, this finding is also surprising because, while we expected individuals to be able to perform case use skills after not having used them in this way for five months, we did not expect them to show improved performance at the end of that five-month period. Instead, we expected there to be some degradation in individuals' ability to use these skills across Performance Assessments 1 and 2. We saw in our analysis of IRSU artifacts that dyads were able to articulate lessons learned, describe outcomes, and make predictions during IRSU Tool use even though they were not explicitly prompted to do so. This suggests two things. First, although an activity may not explicitly support an entire set of skills, it might provide opportunities for individuals to use components of that skill. Using components of a skill could result in better performance of the skill itself. Second, this suggests that, while the environment had unexpected effects on group interpretation performance, the combination of activities in *Digging In* and *Tunneling Through Georgia*, enactments of case use skills learning by Mr. J. in 5th and 6th periods, and the Case Application Suite's coaching as students worked in small groups seemed effective at helping individuals and groups develop case use skills that they could apply in appropriate situations.

8.2.1.5 Trend 15: It Takes Time For Individuals To Develop Case Use Skills And Become Proficient At Using Them

Coding results show a lot of variation in performance, but that improvement took a lot more time than we expected. However, in the end, individuals' interpretation, application, and assessment skills had improved a great deal. Individuals started with different interpretation abilities, and ended at different places in their ability to apply case use skills.

Table 8.5, shows the Top 6 individuals for the last use of the My Case Summary Design, Performance Assessment 1, and Performance Assessment 2. We see that three individuals, Margaret, Melissa, and Sandy, started out performing interpretation skills fairly well during their last use of the My Case Summary Design Diary Page, and they ended with fairly sophisticated interpretation, application, and assessment performance for Performance Assessment 2. The table also reveals that three individuals, Billy, David, and Daniel did not start out as the top performers during their last use of the My Case Summary Design Diary Page, but they ended with fairly sophisticated interpretation, application, and assessment performance for Performance Assessment 2. With time, some students were able to dramatically improve their interpretation and application performance and capabilities. In addition, Table 8.5 suggests this improvement may not happen at the same time for every individual. While Billy and David do not enter the Top Six range until Performance Assessment 2, Daniel enters that range during Performance Assessment 1.

Table 8.5 – Top Six Performers for Last Use of My Case Summary Design Diary Page, Performance Assessment 1, and Performance Assessment 2 (In no particular order)

Top Six Performers for Last Use Of My Case Summary Design Diary Page	Top Six Performers for Performance Assessment 1	Top Six Performers for Performance Assessment 2
Sandy	Margaret	David
Margaret	Michelle	Billy
Kenny	Daniel	Sandy
Michelle	Kenny	Daniel
Melissa	Sam	Melissa
Chris	Melissa	Margaret

8.2.1.6 Trend 16: Ineffective Group Collaboration Does Not Predict How Well Individuals Will Learn Or Use Interpretation, Application, And Assessment Skills

As described in Chapter 7, one of the many difficulties experienced by the Coastal Plain group was their inability to collaborate during their first use of the Case Interpretation Tool (Frejus Tunnel - Chapter 7, Episode 4). However, members of the Coastal Plain group surprised us because they were able to use cases during Performance Assessments 1 and 2 in spite of their group's rocky start and ineffective collaboration. This not only suggests that Coastal Plain group members were able to learn and develop interpretation, application, and assessment skills amidst ineffective collaboration, but it also suggests that they were able to develop them enough to be able to use them in new situations and get better at using them in new situations over time.

8.2.2 Teasing Apart The Relationship Between Individual And Group Performance

Our analysis so far has revealed that even after having used the Case Application Suite, especially the Case Interpretation Tool many times, individuals still struggled with identifying solutions, criteria, constraints, and design rules of thumb during Performance Assessment 1. However, individuals' performance from Performance Assessment 1 to Performance Assessment 2 improved. Because individuals discussed the expert cases as a group before writing up their individual responses, our analysis has been about individual performance in light of group discussion. How can the individual be teased apart from the group? What is the relationship between individual and group performance? In this section, we will begin to tease this relationship apart and understand its impact on individual performance during Performance Assessments 1 and 2.

Looking back at the analysis of our first research question, we saw that an increase in group performance was linked to group discussion that was informed, non-chaotic, and engaged. Furthermore, we saw that the character of the discussion had a major impact on how fully the group was able to reason about expert cases. Therefore, whether the discussion was informed, non-chaotic and engaged and the completeness of a group's reasoning directly affected group performance. When we analyze our second research question, we see three factors that seem to influence individual performance the most during performance assessments. The completeness of reasoning done by both the group and the individual influenced individual performance during performance assessments. Coding results for My Case Summary Design Diary Pages show that, based on their individual performance, Margaret, Sandy, Kenny, Michelle, Melissa, and Chris were able to do interpretation reasoning fairly well prior to Case Interpretation Tool use in their respective groups; we have already described the impact that completeness of reasoning has on group performance.

However, after the reasoning has been carried out, two other factors seem to play a large role in individual performance during Performance Assessments 1 and 2. The first of these involves what an individual takes away from the group discussion and reasoning, while the second involves what an individual feels should be explicitly expressed or written down. What an individual takes away from the group discussion and reasoning is the result of individual capability and understandings. For example, during Performance Assessment 1, our analysis of the Blue Ridge group's discussion revealed that they had very informed, engaged discussion about Criteria and Constraints in the expert case and they did some sophisticated reasoning about those criteria and constraints. Yet, Margaret was the only group member to explicitly express any of the ideas from that discussion in her performance assessment packet. While we have no way of knowing what each individual understood as a result of the group's discussion of criteria and constraints, our data does show that while some individuals expressed more of that understanding more explicitly, others did not. This is why performance and capability are not synonymous.

Failure of a group to reason completely during performance assessment group discussion may be the result of not having the software available to guide the group's discussion of an expert case. However, even if the discussion is informed, non-chaotic, and engaged, what an individual takes away from a group discussion can be affected by having peers available. During Performance Assessment 1, several groups had members who would ask the rest of the group to repeat a problem or solution identified or to explain how a particular problem and solution were connected. Our data does not give us insight into what each individual took away or understood from the group discussion. As such, it is difficult to understand individual capability. What we do have is what each individual wrote in their own performance assessment packet.

When writing an individual response in their performance assessment packets, failure of the individual to reason completely may be the result of not having the multiple perspectives of peers available during that writing, encouraging the individual to include more detail, to be more specific, or to justify claims and ideas. During their use of the Case Interpretation Tool, groups would sometimes have animated discussions about how an idea should be explicitly expressed, as Sam did when he insisted that Kenny type that there was high pressure on the tunnel as opposed to in the tunnel. While there was discussion about the expert case (i.e., which problems were most important, etc.), we heard members of several groups say, "We have to write up our own answers." As a result, the perspectives of other members about what to write down or how to express it was not available to individual members of the group as they wrote in their performance assessment packets. All of these factors suggest that the trends presented in this section may be entangled by the relationship between the individual and the group. Because the expert case was discussed as a group and because the data does not help us understand what reasoning an individual may have done on their own following group discussion, we were not able to fully get at their individual capabilities.

8.2.3 Summary

We presented evidence of how well individuals were able to apply interpretation, application, and assessment skills over time, and our analysis yielded six principles. As we saw with group performance previously, individual performance was varied, suggesting that individuals start and end in different places and their capabilities and performance change at different times. Some individuals started out performing well on My Case Summary Design Diary Pages and ended with sophisticated performance on Performance Assessment 2. Other individuals did not start out performing well, but by Performance Assessment 2, they were some of the top performers. This suggests that it takes time for individuals to develop case use skills and to perform them well in new situations.

Most individuals experienced difficulties identifying expert solutions, criteria, constraints, and design rules of thumb in the absence of the Case Application Suite's system of scaffolds, despite the detailed scaffolding used by groups during Case

Interpretation and Case Application Tools use. Several potential reasons why individuals may have experienced difficulty with this subset of skills were described. In spite of those difficulties, individuals were able to perform and retain case use skills over time, and most individuals performed better for Performance Assessment 2 than for Performance Assessment 1 although they had not used interpretation, application, and assessment skills in that way in five months.

Our analysis also revealed that a relationship exists between individual and group performance, especially in the context of Performance Assessments 1 and 2. When groups engaged in discussion about an expert case during performance assessments, those discussions impacted how fully the group was able to reason about the expert case. Following group discussions, as individuals wrote up their own answers in the performance assessment packets, additional reasoning performed by the individual influenced what an individual took away or understood from both group discussion and reasoning as well as their own reasoning (i.e., an individual's capability). While we do not have data to help us understand individual reasoning and capability, performance assessment packets do tell us what an individual chose to express explicitly based on what they saw as "take-aways". As such, individual packets reveal individual performance.

We will now turn to our final research question, which uses our analysis to not only make suggestions about how to support and promote case use skill development, but also seeks to accomplish our larger goal of making suggestions about supporting and promoting the development of complex cognitive skills. We also make suggestions for designing and integrating software into a learning environment where software and teacher share scaffolding responsibilities.

8.3 Difficulties Groups and Individuals Face When Learning And Applying Case Use Skills And The Suggestions Those Difficulties Make For Software In Support of Complex Cognitive Skills

In our quest to explore and understand the development and enactment of case use skills in middle-school project-based inquiry science classrooms, we have analyzed group and individual case application performance and capability. For both, we have found variation in performance as groups learned and developed case use skills and as individuals have used these skills with varying degrees of sophistication. In this section, we seek to describe the difficulties groups and individuals have when learning case use skills versus carrying out those skills in new situations. Looking at the difficulties individuals face in both of these situations will uncover suggestions about how software can be used to support case use skill development in particular as well as the development of other complex cognitive skills.

This section seeks to answer our final research question:

What difficulties do learners have as they learn case use skills and as they apply case use skills in new situations? What do these difficulties suggest about how software might further support cognitive skill development using a cognitive apprenticeship framework?

In section 8.2.2, we teased apart the differences between performance for a group and for individuals. In turn, we were able to make inferences about group and individual performance and its relationship to individual capability. What we uncovered was that what seems to most impact both performance and capability for a group are the kinds or character of discussions a group has and how complete the reasoning is that the group does. For an individual, we uncovered that two factors most impact capability. The first is the completeness of the reasoning an individual does when working alone, or if discussing ideas in a group but writing up individual responses (i.e., Performance Assessments 1 and 2), the completeness of the group's reasoning. The second factor is what the individual takes away or understands from the reasoning he/she has done alone or with the group based on individual capability. We also uncovered that the factor that most affects performance for an individual is what he/she chooses to explicitly express about what was taken away from the reasoning.

These factors (i.e., character of discussion, completeness of reasoning (by individual or group), what an individual takes away from the reasoning based on individual capability, and what is expressed explicitly from what was taken away) are in fact also the difficulties that individuals and groups face when learning case use skills and when applying them in new situations.

8.3.1 Factors That Affect Performance And Capability As Difficulties Groups and Individuals Face When Learning And Applying Case Use Skills

Our analysis has revealed that the factors that affect group and individual performance are the same things groups and individuals have difficulties with. When groups and individuals struggle in those areas, their performance suffers, so it makes sense that these factors would also be the difficulties groups and individuals face when learning and applying case use skills. As we've shown in the case studies, groups aren't always successful at having informed, non-chaotic, engaged discussions because so many things can interfere with or prevent that kind of discussion (e.g., personalities of group members, length and number of interruptions, ability of group to collaborate effectively, etc.). Furthermore, if it is difficult to have these kinds of discussions with the software available to guide the discussion, it could also be difficult to have informed, non-chaotic, engaged discussions when software is not available to guide that discussion.

Completeness of reasoning describes how well groups and individuals are able to reason about an expert case. For groups, this idea is tied to group discussion because most of the reasoning done by groups using the Case Interpretation Tool or during Performance Assessment 1 happened through group discussion. For an individual, completeness of reasoning refers to how well an individual is able to "think like a group" when working alone. We discussed individuals' abilities to think like a group as a by-product of collaboration in Chapter 2. We've described examples from our data (i.e., Blue Ridge group's third use of the Case Interpretation Tool – Chunnel Tunnel, Chapter 6, Episode 7) where a group was able to reason fully about an expert case as a result of having informed, non-chaotic, engaged single-scaffolded discussions. On the other hand, we've also described examples of groups who not only had difficulty having these kinds of discussions, but also experienced difficulty reasoning about the expert case fully (i.e., Coastal Plain group's first use of the Case Interpretation Tool – Frejus Tunnel, Chapter 7, Episode 4). As a result, they weren't able to interpret the expert case in such a way that the lessons they could learn from it were visible, and their performance suffered. We have no data to give us clues about how individuals were able to reason about expert cases.

For an individual, it can sometimes be difficult to know what should be gleaned from a group discussion, i.e., what the “take-aways” are. While we do not have data that provides insight into what may have been difficult for individuals to take away from group discussions, we do know that establishing and maintaining intersubjectivity within a group is difficult [Roth, 1995]. This is because members of a group may give different meanings to terms, view the group’s challenge differently, or interpret a group discussion differently.

An individual may also experience difficulty trying to figure out what should be written down and what should not based on what they’ve taken away from the group discussion and/or the reasoning they’ve done individually. This difficulty may be the result of personal preferences. Some individuals are more wordy while others are more succinct. Some individuals like to include a lot of detail while others like to summarize. Some individuals keep many of the details in their heads while others need to write them down in order to remember them. However, when responding to prompts or creating artifacts that may be used by the same individual or by someone else long after the artifact has been created, the more specificity, detail, and explanation of reasoning included in the artifact, the more likely that the artifact will be useful when it is retrieved in the future. In general, groups more likely to be able to overcome this difficulty because they have the perspectives and input of the group to push them toward being more specific and explicit when describing the group’s reasoning in an artifact. This is not always the case, and often groups don’t always express the in-depth discussions and sophisticated reasoning they do during their group discussions in their written artifacts.

8.3.2 Describing The Relationship Between These Difficulties And Their Impact On Group and Individual Performance And Capabilities

We've already shown that during Case Interpretation Tool use, the more informed, non-chaotic, and engaged the group discussion, the more likely the group was to reason more fully about the expert case. We've also shown that group reasoning revealed through group discussion was a better indicator of group capability than written work because groups did not always express the specificity and detail of their discussions in written artifacts. However, the written artifact was an indicator of interpretation, application, and/or assessment performance because it could be coded and analyzed using some form of consistent measurement.

For an individual, we've shown that during Performance Assessments 1 and 2, group capabilities based on the group's discussion and any additional reasoning done by the individual affect what an individual might take away from that discussion and the individual reasoning. This suggests that what an individual takes away from group discussion and individual reasoning is an indicator of what the individual is capable of doing, i.e., individual capability. However, in our study, the data does not allow us to understand what individuals took away from group discussions and their own reasoning. Instead, we have their written artifacts (i.e., performance assessment packets). From these, we've shown that individual performance is based in part on what an individual chooses to express explicitly in a written artifact.

The following set of trends, based on what we've found through our analysis, express the connections between individual and group performance and capability in our work. At the same time, these trends depict the relationship between the different factors that impact performance and capability.

- Group capability is the result of the character of group discussion and the completeness of the group's reasoning.
- Group performance is the result of group capability in light of what the group negotiates to express explicitly,
- Individual capability is the result of the group's capability and the completeness of the reasoning an individual does on his/her own.
- Individual performance is the result of individual capability in light of what an individual chooses to express explicitly

These trends are important because they describe what seems to impact capability and performance, and in the future they may help us begin to make connections between seemingly separate outcomes (i.e., character of group discussions and what an individual chooses to express explicitly) in a more logical way. For now, they help us visualize the relationships between group and individual capabilities and performance. They also help us understand which difficulties or factors we can address, and they allow us to predict which outcomes we can impact by improving certain factors. Given this set of trends, what do these factors or difficulties suggest about how the Case Application Suite might better support case use skills? What do they suggest about designing software in support of complex cognitive skill development using cognitive apprenticeship as a framework?

8.3.3 How Can The Case Application Suite Better Support Case Use Skill Development?

Our analysis thus far has uncovered the difficulties groups and individuals have learning case uses skills and applying them in new situations over time. Our analysis also makes suggestions about how the Case Application Suite might better support the development of case use skills by addressing those difficulties. In particular, groups sometimes had difficulties having informed, non-chaotic, engaged discussions. As a result, they sometimes found it difficult to reason about an expert case in such a way that they could, for example, articulate design rules of thumb, include specificity and detail in their responses, or justify their ideas.

If we could, for example, somehow help groups have more informed, non-chaotic, engaged discussions, we should expect to see an increase in group capability. If we could also somehow able to help the group do a better job of expressing their ideas using more detail, specificity, and justification, we should also expect to see an improvement in group performance. An improvement in group performance would occur as more of a group's capability is expressed in their written artifacts. The same is true of individual performance. Therefore, the Case Application Suite could better support groups as they discuss and reason about expert cases by drawing their attention to the full system of scaffolds. This could help groups who have informed, non-chaotic, engaged discussions to push their reasoning about an expert case by using the hints, examples, and templates designed to model, remind, and organize. It could also help groups include more specificity, detail, and justification in their responses, helping them to make better choices about what to explicitly express from the reasoning they do.

We could accomplish this by including phrases in the prompts that remind students about the help available to them, i.e., "Use the criteria and constraints template to identify and describe criteria and constraints", "Read the hints to learn more about design rules of thumb", or "Notice the level of detail in the example—try to include that same level of detail in your response". As groups get better at reasoning about expert cases and making that reasoning more explicit, they will most likely rely less and less on these scaffolds, but they will always be available if they are needed.

In addition to drawing the group's attention to the full system of scaffolds, we could also support better group discussion by including hints that encourage groups to engage in practices that are more likely to promote informed, non-chaotic engaged discussion. For example, we might include a hint that reads, "Use the expert case to identify as many criteria and constraints as you can" or "Discuss among your group why the solution the experts chose was the best one given the criteria and constraints they had to consider". Hints like these provide the support some groups may need in order to push their discussions toward being more informed, less chaotic, and more engaged.

8.3.4 How Can The Teacher Better Support Case Use Skill Development?

Our third research question focuses only on how software can better support complex cognitive skill development with case application being an instance of a complex cognitive skill. However, the fact that we use cognitive apprenticeship as a framework means that both the software and teacher as "experts" bear the weight of supporting learners. As a result, our analysis would be incomplete if we did not include suggestions our study revealed about how a teacher can better support students as they are developing and applying interpretation, application, and assessment skills. First, teachers should be sure to model the full set of case use skills for students prior to software use. Most helpful would be for teachers to model those skills in the context of completing a My Case Summary Design Diary Page along with the class, and then using that page to apply its lessons to some problem, explaining the processes involved in interpreting and applying expert cases along the way. Second, continuously encouraging groups to use the full system of scaffolds and to include specificity and detail in their responses may push students toward more informed, non-chaotic, more engaged discussion, more complete reasoning, and more explicit description of that reasoning in Case Application Suite artifacts. Let's look at what group and individual difficulties suggest about designing software in support of complex cognitive skill development.

8.3.5 Suggestions That Group/Individual Difficulties Make For Software In Support of Complex Cognitive Skill Development

What do these difficulties suggest about how software might further support complex cognitive skill development using cognitive apprenticeship as a framework? They make three suggestions: the software and teacher each have particular strengths, software is capable of coaching groups learning complex cognitive skills of which case use is one, and software can and should be designed to support groups and individuals in situations where teachers are uncomfortable or not as skilled.

8.3.5.1 Suggestion 1: When Designing Software To Coach Complex Cognitive Skill Development In A Cognitive Apprenticeship Environment, Include Scaffolding That Encourages Students To Employ The Teacher's In-The-Moment Scaffolding Because The Software And Teacher Each Have Strengths That Are Useful For Supporting Students As They Develop Complex Cognitive Skills In This Kind Of Environment.

Both the software and the teacher have roles and strengths in a project-based inquiry environment that uses cognitive apprenticeship as a framework for complex cognitive skills learning. The software provides structure, organization, prompting, reminders, and consistency as students are working. It serves as a coach, alleviating the teacher's inability to provide the same scaffolding to every group and individual all the time as they are working. However, in situations that call for more specific kinds of help than generic but detailed software-realized scaffolding can provide, the teacher's in-the-moment scaffolding is a strength. For example, Mr. J. was able to help groups make specific connections and break down specific problems about a particular expert case on the fly in ways that the software could not because it was designed to be general enough to be useful across many different expert cases. Both of these strengths, when used at appropriate times, can help groups and students develop complex cognitive skill, as the Case Application Suite's system of scaffolds was able to do, especially when used in concert with Mr. J.'s in-the-moment scaffolding.

<u>8.3.5.2 Suggestion 2: Integrating Software Into A Cognitive Apprenticeship Environment To Play The Role Of "Expert" In The Environment Can Be An Effective Approach Because Software Is Able To Coach Students Via Scaffolding To Learn Complex Cognitive Skills</u>

There were many unexpected turns during our study, but in spite of those, we showed that the Case Application Suite was able to support students as they learned case use skills in such a way that they could apply those skills in the Suite's absence to varying degrees of sophistication. Therefore, it stands to reason that software can be design to coach other complex cognitive skills. In fact, as described in Chapter 3, we have designed such tools in SMILE to support the development of other complex cognitive skills such as designing an experiment (Experiment Plan Tool) and analyzing results from an experiment (Experiment Result Tool). However, software designed to coach complex cognitive skill development should include prompting that points students to all of the scaffolding available to them. Software scaffolding should spark and promote more informed, non-chaotic, engaged group discussion, helping students reason about the complex cognitive skill in more productive ways by enacting the suggestions made in Section 8.3.3. These suggestions consist of including phrases in the prompts that remind students about the full system of scaffolds available to them and including hints that encourage groups to engage in practices that are more likely to promote informed, non-chaotic, engaged discussion.

8.3.5.3 Suggestion 3: Software Designed To Support The Development of Skills Regardless Of A Teacher's Level Of Comfort With A Skill Is Important Because The Quality Of Support Students Have Access To Should Not Be Limited By How Well Or How Completely A Teacher Models Those Skills

In Episode 5, we described Mr. J.'s facilitation of a class discussion where the lessons learned across expert cases and *Tunneling Through Georgia* activities were gleaned and ways of applying those lessons were discussed. We also saw that the lessons gleaned and the ways those lessons could be applied were not as complete or even as accurate as they could have been. However, the Rule of Thumb template and Applying Our Rule(s) of Thumb Template were able to stand in the gap and help learners articulate and analyze design rules of thumb in such a way that the ways they could be applied were visible to learners. As such, software can and should be designed to support learners even when the teacher is not as comfortable or as skilled at modeling or supporting them during complex cognitive skills learning and development.

8.4 Summary

This chapter presents answers to our research questions based on our analysis and interpretation of results. Our first research question sought to understand the effects with the Case Application Suite by analyzing how groups case use capabilities developed over time. Analysis of Case Interpretation Tool artifacts and video observations revealed that the development of case use skills looks different for every group, and group performance improves or worsens from one episode to the next. Group performance and capability do not improve uniformly, as we expected; instead, they fluctuate. This fluctuation depends on several factors, but what seems to influence these changes and indicate group interpretation capability the most are a group's discussions and how fully the group is able to reason about the expert case. The completeness of a group's reasoning and a group's interpretation capability are revealed through their discussions, which can be described or characterized as a combination of informed vs. uninformed, chaos-focused vs. classification-focused vs. content-focused, inter-group centered vs. intra-group centered, engaged vs. disengaged, and system-scaffolded vs. single scaffolded. Factors that seem to influence the character of group discussions include how willing a group is to seek help when help is needed, how fully a group reasons about the expert case, the amount of detail in the expert case, the skills that are focused on early by the teacher and reinforced by the teacher, classroom activities, and software's scaffolding over time, and the personalities of group members. From this analysis, we were able to glean eleven trends about the development of group interpretation capability over time.

Our second research question focused on the effects of the Case Application Suite by examining how well individual students were able use interpretation skills and how well individual students were able to interpret and apply expert cases in the absence of the Case Application Suite's system of scaffolds. Our analysis revealed that individual performance was also varied, with individuals starting and ending in different places and their capabilities and performance. During Performance Assessment 1, most individuals experienced difficulties identifying expert solutions, criteria, constraints, and design rules of thumb in the absence of the Case Application Suite's system of scaffolds, despite the detailed scaffolding used by groups during Case Interpretation and Case Application Tools use. Several potential reasons why individuals may have experienced difficulty with this subset of skills were described. Surprisingly, individuals were able to perform and retain case use skills over time, as most individuals performed better for Performance Assessment 2 than for Performance Assessment 1 although they had not used interpretation, application, and assessment skills in that way in five months.

Given this improvement with no LBD in between, we looked back at the IRSU to understand more about what may have occurred during that unit to explain the results. When we looked at Mr. J.'s enactment of the IRSU, we saw that he modeled for the whole class how to describe outcomes that occur as a result of doing or not doing something, and he indirectly modeled how to articulate lessons learned based on those outcomes. When we analyzed IRSU Tools artifacts, we saw that dyads also described outcomes that occurred as a result of doing or not doing something, which is very similar to the interpretation sub-skill of describing outcomes that occur or could occur as a result of addressing or failing to address constraints. IRSU Tools artifacts also revealed that dyads articulated lessons learned some with the same form used in the design rule of thumb template. Dyads also made predictions, many of which were found within the lessons learned that they identified. Surprisingly, dyads described outcomes, identified lessons learned, and made predictions without explicit prompting from the IRSU Tools.

Our analysis also examined the relationship between individual and group performance, especially in the context of Performance Assessments 1 and 2. When groups engaged in discussion about an expert case during performance assessments, those discussions impacted how fully the group was able to reason about the expert case. Following group discussions, as individuals wrote up their own answers in the performance assessment packets, additional reasoning performed by the individual influenced what an individual took away or understood from both group discussion and reasoning as well as their own reasoning (i.e., an individual's capability). While we do not have data to help us understand individual reasoning and capability, performance assessment packets do tell us what an individual chose to express explicitly based on what they saw as "take-aways". As such, individual packets reveal individual performance.

Our final research question examined the difficulties groups and individuals faced when developing and applying case use skills. These difficulties were analyzed not only to make suggestions about how to support and promote case use skill development, but also to accomplish our larger goal of making suggestions about supporting and promoting the development of complex cognitive skills. Looking back at the answers to our first two research questions, we learned that the same factors that most affect group and individual performance and capabilities (i.e., the character of group discussions, the completeness of a group's reasoning, the completeness of individual reasoning, and what an individual chooses to explicitly express) are also the difficulties that groups and individuals face. Not every group has informed, non-chaotic engaged discussions; not every group used the system of scaffolds in such a way that they were pushed to reason more fully about the expert case through their discussion; not every individual chose to write down what came out of group discussions and individual reasoning. From this, we were able to describe four trends that describe the relationship between group performance and capability, group capability and individual capability, and individual capability and individual performance. These trends help us understand the connections between group and individual performance and capability, which are not synonymous, and they allow us to make predictions about what impact addressing a particular difficulty should have. For example, if we are able to help individuals express more of the reasoning the group has done and more of their own individual reasoning, their written artifacts could be a more accurate reflection of their individual capabilities.

We analyzed how the Case Application Suite could better support case use skill development, and found that we could accomplish this by helping groups have more informed, non-chaotic, engaged discussions and pushing their reasoning by drawing their attention to more of the full set of scaffolds. Ways we might accomplish this include adding more explicit including hints that encourage groups to engage in practices that are more likely to promote informed, non-chaotic, engaged discussions and including hints that explicitly remind groups about the help available to them.

We also made suggestions for designing and integrating software into a learning environment where software and teacher share scaffolding responsibilities. The software and the teacher have particular strengths when serving as more capable "experts" in a cognitive apprenticeship, with the software providing consistent scaffolding that every group can use simultaneously to organize, structure, and remind them about important aspects of interpreting and applying expert cases, while the teacher can provide in-the-moment scaffolding when groups and students have particular difficulties or needs while interpreting or applying a specific expert case. As such, software in support of complex cognitive skill development should encourage students to employ the teacher's in-the-moment-scaffolding as well as the software's system of scaffolds. Additionally, software designed to coach students to learn complex cognitive skills in an environment that uses cognitive apprenticeship as a framework like Learning By Design does can be effective as we've shown in this work that software is able to take on a particular role within that environment. Finally, software should be designed to support complex cognitive skills in such a way that it can do so even if the teacher is uncomfortable with modeling or coaching those skills or if the teacher is not at skilled at carrying out the skill so the help students have available to them is not limited by how well or how completely the teacher models those skills. Now, we will turn our attention back to the hypothesis we presented in Chapter 1, and conclude with directions for future work.

CHAPTER 9

DISCUSSION

We have examined the development of case use skills in a project-based, inquiry environment using cognitive apprenticeship as a framework. We have interpreted coding results and video observations to understand how groups and individuals develop and carry out case use skills and to understand what influences how well they are able to develop and use those skills over time. But we also wanted to use this study as a first step in accomplishing a larger goal, understanding more about how we might support the development of other complex cognitive skills. In this chapter, we attempt to do that, beginning by assessing the limitations of the Case Application Suite, then analyzing what our results suggest about our initial hypothesis, and finally putting forth suggestions about future work toward supporting development of complex cognitive skills.

9.1 Limitations Of The Case Application Suite

While the Case Application Suite did indeed provide important kinds of support to students as they learned and developed case use skills, there were some things the software could have done better and some kinds of help it did not provide. With respect to fulfilling the goals we set for it, we realize now that the current design of the Case Application Suite failed to make the purpose and function of the full system of scaffolds obvious. It was not always obvious that templates were available to help groups articulate their responses, nor was it always clear that the examples could be used after reading the prompt and/or hint if the group was still confused about what they were being prompted for. We also found that while the Case Application Suite's prompting helped to focus group discussion for well-presented descriptive narratives, it didn't provide enough help at searching through more poorly-presented descriptions to find relevant information. In addition, we found that we didn't have enough backup in the software to make up for teachers who couldn't or didn't model case use skills well. While it had some nice examples of responses to prompts, it was missing a discussion about how those example responses were articulated and how the expert case was used during that articulation. Although it was an important interpretation sub-skill, the software did not prompt groups to describe outcomes that occurred as a result of the experts addressing or failing to address constraints. Finally, really giving attention to developing a set of cognitive skills takes a lot of time, and not all teachers recognize the benefit of focusing on skill development. Using a software tool to help with that development adds additional time in classrooms where computers are not used on a regular basis and makes clear the time being used for skill development. Because of the time component, our teachers didn't always use the tools at times when they would have been beneficial. We discuss these limitations and attempt to abstract out principles that can be applied to the next generation of software aimed at supporting complex cognitive skill development.

9.1.1 Limitation 1: Design And Presentation Of Scaffolding: Case Application Suite Did Not Draw Groups' Attention To The Full System Of Scaffolds

The Case Application Suite's system of scaffolds consisted of prompts, hints and examples for each prompt, templates/charts, and the structure of the Case Application Suite's tools. Of these five scaffolds, all were consistently visible on the computer screen except the templates and charts, which were accessed by clicking on a link that was anchored to the prompt they were associated with. We were therefore surprised that the prompts and templates/charts were the most consistently used scaffolds out of the entire set of scaffolds—why was this the case?

We think this had to do with the way the teacher introduced the software and what he focused on as important. During their first use of the Case Interpretation Tool, groups were instructed to read the prompts in the middle frame to understand the expert case, and as they worked, Mr. J. went from group to group and explicitly pointed out the templates and suggested their use. Only once, however, did he provide suggestions about using the hints and examples as he answered group questions and coached them through using the software – when he was trying to help them understand how to use the Applying Our Rules of Thumb template.

In addition, because we thought that the groups would see the hints and examples and recognize their usefulness, we did not give instructions to the teacher, nor did we provide a tutorial for the students that explicitly pointed out the hints and examples and how they might be used. The result of all this was that except when explicitly directed there, students rarely looked at the right frame that held the hints and examples..

The **"Just Because You Build It Doesn't Mean They Will Use It"** Principle arose from this limitation: **Don't expect students or teachers to recognize the usefulness of provided scaffolding by themselves. Unless the software or some agent in the learning environment draws students' attention to the help that is available at times when they need it, students may not use it**. Following this principle means finding some way to draw students' attention to the scaffolding available to them and its usefulness. This could happen by formally introducing them to each piece of the scaffolding and providing opportunities to practice using it or by creating a graphic or animated agent to draw their attention to relevant scaffolding at the right times or including language in the prompts that explicitly directs them to use different scaffolds.

9.1.2 Limitation 2: Cases Aren't Always Written Well. The Case Application Suite Did Not Provide Help With Finding Information That Was Not Presented Well Or In Great Detail In The Expert Case

The prompts in the Case Interpretation Tool were designed generically so that the same set of prompts could be used to interpret multiple cases. However, as Case Study 2 showed, when the Ridge and Valley group used the Case Interpretation Tool to interpret the Mono Craters Tunnel case, which was not as descriptive as some of the others, they could not find the information needed to respond to all of the Tool's prompts. As a result, they became frustrated with the task and began to lose focus and engagement with the discussion.

This limitation suggests the **"One Size Does Not Fit All" Principle: Software prompting needs to take into account the descriptiveness of the content students are using**. This principle could be enacted by designing additional or alternative prompts and/or hints for content that is not as completely or as clearly written, by designing hints specific to cases that are being interpreted, or coming up with guidelines to be followed by content authors to make sure content is complete and clearly written. Each has its difficulties and trade-offs.

9.1.3 Limitation 3: Teachers' Skills And Values Vary And Don't Always Match What We Expect. The Case Application Suite Assumed Every Teacher Would Model Targeted Cognitive Skills Appropriately.

We designed the Case Application Suite to coach students while they were working in small groups in the ways cognitive apprenticeship suggests. We left other cognitive apprenticeship responsibilities to the teacher, in particular the responsibility of modeling case use skills. As Chapter 6 reports, even the master teachers we work with won't necessarily carry out roles in the classroom that we expect of them. Instead of fully modeling and going over each subtask of case use, Mr. J. focused his modeling only on interpretation and initial steps in application. Students developed some capability in applying cases, but the literature on skill development suggests that they would have better developed those capabilities if they'd had those skills explicitly modeled for them.

The "Too Many Cooks Do NOT Spoil The Broth" Principle arises from this limitation: Software should include scaffolding that models the complex cognitive skills it supports. This could be accomplished by including an annotated example with each prompt that not only shows a "model" response, but that also shows how that response was created. Software could also include more help with stepping students through accomplishing tasks, providing justification and logic for each step. In these ways, the software would be able to fill in for the teacher who doesn't model complex cognitive skills well enough. Of course, the conundrum presented by Principle 1 still holds. If the teacher doesn't recognize the value in a skill or the way the software can help its development, students may not recognize the value of the scaffolding either.

9.1.4 Limitation 4: Difficulty of Tool Use And Skill Development: Case Application Suite Added Additional Strain On Time Devoted To Classroom Activities

The Case Application Suite took a lot of time to use. It took four class periods for students to use the Case Interpretation Tool and one class period to use the Case

Application Tool for a total of 5 class periods; the Solution Assessment Tool was not used at all because there was not enough time. While five days may not seem like a lot of time to use software in support of a set of complex cognitive skills like case use skills, when integrated into a set of units whose activities are designed to fill a semester, it becomes difficult for a teacher to decide whether they should sacrifice an activity in the unit to use the software or vice versa. If the Case Application and Solution Assessment Tools had been used as much as the Case Interpretation Tool was, up to ten days would have been devoted to software use.

Oft times, when faced with the dilemma of either using software-realized scaffolding that can help students develop skills better than a unit alone or completing all of the activities in a unit, teachers will often look at the software as an optional piece instead of the integral piece that it is. No matter how much software-realized scaffolding you provide and no matter how helpful or supportive that scaffolding is, if students are not provided with the time it takes to use that scaffolding in support of complex cognitive skill development, they may not be able to use those skills as well as they would if given the proper amount of time. There is really no way to recover from not having the time to develop skills appropriately because time is the crucial ingredient that is needed in order to develop skills and be able to use them well. Students need deliberate practice in authentic contexts and that practice takes time. The **"All We Need Is More Time"** Principle arose from these limitations: **Software tools in support of complex cognitive skill development should be integrated into classroom activities in such a way that students have multiple opportunities and are given the time it takes to use all of the tools and to develop the skills those tools support.**

When the full set of software tools is not used or some tools are used more than others, students are not given opportunities to carry out the full set of skills while being coached and supported along the way. This could result in students having very sophisticated capability in a subset of skills that was more supported over time, while displaying rudimentary capability for some other skills that were unsupported or less supported. Coding results for Performance Assessment 1 showed that students performed better at interpreting an expert case than they did at applying an expert case to their island challenge or assessing their solution by making recommendations to the construction company. Although many students ran out of time before they could make recommendations to the construction company, perhaps another factor was that their application and assessment skills weren't as developed as their interpretation skills because they had not been able to use the Case Application and Solution Assessment Tools in support of application and assessment skills like they'd used the Case Interpretation Tool in support of interpretation skills. Therefore, a balance has to be achieved so that students have enough time to use software tools in support of complex cognitive skills and also time to develop those skills.

9.1.5 Are Case Interpretation and Application Too Hard For Real Students In Real Classrooms?

So far, the analysis of results has revealed that students engaged in case use with various levels of sophistication and that they experienced some difficulties interpreting and applying expert cases, both during Case Application Suite use and in its absence during performance assessments. Possible reasons for the variation and difficulties have also been described including things the teacher could have done better in the enactment (e.g., modeling case use skills by actually interpreting an expert case for the class using the My Case Summary Design Diary Page), the character of group discussions, the depth of reasoning groups and individuals engaged in, and limitations of the software. However, another possibility exists that could explain why groups and individuals experienced the variation and difficulties they experienced when interpreting and applying expert cases: Could it be that interpretation and application are just too hard for real students in real classrooms?

Looking back to the case studies, Episodes 1 and 3 suggest that the answer to this question might be "No." During the Digging In unit, groups interpreted either the Dust Bowl or Landslide case, and individuals wrote up their interpretations using the My Case Summary Design Diary Page. Then, groups presented what they'd learned about the cases to the class and Mr. J. facilitated a class discussion helping students draw out more lessons they could learn based on the expert cases. Following the class discussion, groups incorporated ideas from the presentations and used the lessons they'd learned from the expert case and the discussion to design, build, and test models of erosion in stream tables. Later, they were able to take what they'd learned so far from the expert cases, small group and class discussions, and their models of erosion in stream tables to design, build, and test models of one particular erosion management method and a final management model that combined multiple erosion management methods.

These activities suggest that individuals and groups can interpret and apply expert cases, but that these skills are really hard to do without a lot of help. While there was a lot of scaffolding available for individuals/groups to use during both *Digging In* and *Tunneling Through Georgia* (with more detailed scaffolding available during the latter), *Digging In* offered an additional scaffold that *Tunneling Through Georgia* did not offer: immediate feedback from an artifact. For example, after interpreting the Dust Bowl and Landslide cases, groups were able to apply the lessons they'd learned to their models in stream tables. These models provided feedback for groups and helped them to refine their understanding of what they'd learned from the expert cases. When modeling erosion in stream tables, they were able to see how water moves dirt down a hill. When modeling retaining walls as an erosion management method in stream tables, they were able to see how well a retaining wall could hold back sliding dirt and when it became ineffective. These artifacts gave students a first-hand experience they could interpret and it provided feedback that could be used to reinterpret the lessons they'd learned from the expert cases. However, in the *Tunneling Through Georgia* unit, groups do not have an artifact that they can test or a simulation they can run to get the kinds of feedback they were able to get from their models in stream tables during *Digging In*. Instead, the only project artifact that groups have are the design plans they created. Because they cannot build and test their design plans, groups instead make predictions about how they think their solutions would work if they were able to actually build and test them. Perhaps including a simulation tool in SMILE that students could use to address the *Tunneling Through Georgia* challenge would be helpful. The simulation tool would allow groups to design and "build" a tunnel using their design plans and would provide the kind of feedback and experiences that building models in stream did during *Digging In*.

9.2 Assessing Our Hypothesis

In Chapter 1, we presented a hypothesis about the enactment of case use skills in project-based inquiry learning situations:

If learners in project-based inquiry classrooms are able to understand, engage in, and carry out the processes involved in interpreting and applying cases effectively, then they will learn those processes and be able to read an expert case for understanding, glean the lessons they can learn from it, and apply those lessons to their question or challenge. Furthermore, they may also be able to transfer interpretation, application, and assessment skills to other learning situations where application of cases is appropriate.

We will analyze the hypothesis in parts to see what our study suggests about its validity.

9.2.1 If Learners in project-based inquiry classrooms are able to understand, engage in, and carry out the processes involved in interpreting and apply cases effectively…

Results show that students were able to understand, engage in, and carry out the processes involved in interpreting and applying expert cases effectively. For our study, we used Learning By Design, an approach to middle-school science that uses design as a vehicle for helping students learn science content and practices, and students engaged in two of LBD's units: *Digging In* and *Tunneling Through Georgia*. Remember in *Digging In,* the challenge was to design a basketball court and the surrounding area in such a way as to keep the hill from eroding onto the basketball court, while in *Tunneling Through Georgia*, the challenge was to design one of a set of tunnels that would run across the state of Georgia. Students engaged in and carried out interpretation skills two ways: using My Case Summary Design Diary pages and using the Case Interpretation Tool. Although the design diary pages do not provide a lot of detailed scaffolding, they are not simply worksheets that focus on drill and practice. Instead, the My Case Summary

Design Diary page helps students reason about expert cases as they understand the problems the experts faced, solutions used to address those problems, and ways those solutions can be applied to their challenge. Using these, students were able to apply what they'd learned from those expert cases to their models of erosion and their models of erosion management methods in stream tables.

However, because the page real estate of the My Case Summary Design Diary page does not really allow for more detailed scaffolding, students may not always make the deeper connections they were sometimes able to make using the Case Interpretation Tool in their small groups without explicitly being told to do so by the teacher. When using the My Case Summary Design Diary Page, students might connect problems and solutions on the page, but sometimes, they didn't. Instead, some students looked at the Problems That Arose Column as one list of problems and the Solutions Chosen column as separate list of solutions and not necessarily as a list of solutions that addressed those particular problems. It seemed that when groups used the Case Interpretation Tool, they didn't have those same issues because of the detailed scaffolding available to them as they worked.

Sometimes they carried out interpretation skills with a great deal of sophistication, and sometimes they did not, but we were able to identify factors that seemed to influence their performance. Factors like using the written expert case to inform their discussions, focusing on classifying ideas or using the content of the case to articulate ideas, engaging more than half of the group in the discussion, considering the audience outside of the group, using multiple scaffolds in concert to guide discussion or using both software and teacher as scaffolds seemed to prompt more effective case interpretation. When groups had informed, non-chaotic, engaged discussions, they seemed to understand the task they were engaging in (i.e., interpreting or applying an expert case) and carried out those processes with a great deal of sophistication. However, factors like using memories of the expert case, engaging in ineffective collaboration resulting in chaotic discussions, failing to engage most group members in the discussion, using only one scaffold to guide discussions, or failing to ask for help when confused seemed to foster ineffective interpretation. Analysis of data revealed that when groups were unable to overcome those factors, they had a negative impact on group performance.

9.2.2 …then they will learn those processes and be able to read a case for understanding, glean the lessons they can learn and apply those lessons to their question or challenge.

Coding results for individual My Case Summary Design Diary pages as well as Case Interpretation Tool and Case Application Tool group work showed that groups and individuals were able to learn and develop interpretation and application skills. Although that development did not improve uniformly as we predicted, students and groups were able to read an expert case for understanding, glean the lessons they could learn from those cases in the form of design rules of thumb, and apply those lessons to their challenge. We saw that the Case Application Suite was effective at supporting groups while they learned and developed case use skills. In addition, we saw evidence of changes in group discussions. While there was variation in the kinds of discussions groups had and their abilities and performance over time, we were able to characterize their discussions as well as the factors that influenced those discussions and their interpretation and application performance and capabilities.

Not only did students learn and develop case use skills, but they also carried them out them in the absence of the Case Application Suite's system of scaffolds. While individuals did not perform as well at identifying expert solutions, criteria, constraints, and design rules of thumb as we hoped, performance assessment results (especially results for Performance Assessment 2) nonetheless show that students did learn those processes to varying degrees and were able to read cases for understanding, glean the lessons they could learn, and apply those lessons to their challenges.

9.2.3 Furthermore, they may also be able to transfer interpretation, application, and assessment skills to some other learning situations where application of cases is appropriate.

While performance assessment results support the second part of our hypothesis, that students learned case use skills, they also reveal how well they could use those skills when help wasn't available. Though the instructions for the performance assessments described the tasks students needed to perform to complete the performance assessment, students weren't told to use the expert case to fill out the chart or to use what they'd gleaned from the interpretation phase during the application phase. The words interpret and apply were never used, so students had to make that connection for themselves when describing and articulating their plans and recommendations. As such, the performance assessments also show evidence that students were able to use interpretation and application skills with minimal scaffolding available in situations different from those in LBD where they used and learned case use skills.

In addition, performance assessment results also reveal that students could use these skills even after not having used them for a long time. During the IRSU, students did not use the Case Application Suite. Instead, they used 5 tools developed by Mr. J. that indirectly supported a few of the same case interpretation skills as the Case Interpretation Tool, but largely focused on different reasoning skills. In spite of this, coding results from Performance Assessment 2 revealed that students were able to retain and use interpretation and application skills in the absence of the Case Application Suite's system of scaffolds even after not having used those skills for 5 months. Surprisingly, most students performed just as well or better on Performance Assessment 2 than they had on Performance Assessment 1, and interpretation and application performance showed less disparity.

9.2.4 Back To The Full Hypothesis

Students were able to understand the process of interpreting and applying expert cases, and they were able to engage in those processes as they carried them out in the *Digging In* and *Tunneling Through Georgia* Units. Both students and groups also demonstrated the ability to read a case for understanding, glean the lessons that could be learned, and apply those lessons to a challenge during their use of the My Case Summary Design Diary pages Case Interpretation and Case Application Tools. They were also able to use those skills in situations outside of Learning By Design and in situations that did not specifically prompt them to use interpretation and application skills. On the other hand, there is a lot of variation in the data. Groups and students displayed different levels of ability when engaging in and carrying out case use skills over time. Furthermore, even though students were able to enact case use skills in new situations, many of them still struggled with the same skills (i.e., identifying expert solutions, identifying criteria and constraints, and articulating design rules of thumb). This suggests that there is much more to be learned about how those processes are learned and to what degrees of sophistication.

9.3 Future Work

As we think about future work, it is worth remembering that our hypothesis was a weaker version of a stronger claim, that learning the skills involved in reading and interpreting and applying the lessons of expert cases would eventually result in the development of more broadly-applicable case-based reasoning skills. The future work we suggest thus takes two broad directions: (1) additional work addressing our hypothesis and (2) additional work aimed at investigating the broader claim.

Looking at the hypothesis we addressed in the current study, two major directions come to mind. From the perspective of design, we could address the limitations of the Case Application Suite: investigating good ways to help students appreciate the full set of affordances of the software's scaffolding, how to help students glean what's implied even when cases aren't written well, and how to provide modeling better. From the perspective of use, we might investigate how to better integrate its use into classroom activities and look at the benefits of working more closely with teachers to help them learn better how to model and to understand the value in learning case use skills. It would be interesting to re-run this study to see the extent to which addressing the limitations decreases the variation in group and student capabilities and increases student success.

Moving forward with the larger hypothesis, I see several other interesting directions. From a cognitive capability perspective, we could develop a study that would allow us to look more closely at the particular skills that are being developed, how they are being developed, and the order in which they are being developed. However, I am not convinced that the classroom would be the best environment for this kind of study because of all of the variables that cannot be isolated and controlled in a classroom setting. Perhaps running a more controlled isolated study where students and groups interpret and apply a series of expert cases, both with and without the Case Application Suite, would help us being to say something about the processes students and groups use to interpret and apply expert cases and how those processes differ or match during these different scenarios. These results could be used to inform the Case Use Skills Tree, the software, and perhaps even the coding schemes used to assess the results.

However, the idea that appeals to me most is to take the lessons learned from this study to generalize our understanding of complex cognitive skill development in other domains. Because of the prevalence of interpreting and applying experiences in everyday life as well as in more technical situations, it is my belief that interpretation and application skills are used in many different areas of problems solving as well as during moments of creative expression. As a musician, I have seen, recognized and appreciated a horn player using the melody line from one piece while playing another. As a vocalist, I have imposed the vocal line of one singer into the vocal line of another. In both cases, the horn player and I have interpreted a work, recognized and learned the parts of the work that were interesting and potentially useful to us in the future, recognized that a part of the original work could be applied to the new work, integrated that part into the new work, and assessed its integration based on the recognition of that application by other musicians. Generally, this interpretation and application is done in the context of learning pieces considered to be seminal musical works or the works of the "masters."

The application can be done either within another seminal work or within an original composition. Surprisingly, the last three steps are often done on the fly—hence, the beauty of jazz improvisation.

As such, I am interested in understanding how jazz studies majors interpret the works of master instrumentalists and vocalists such as John Coltrane, Miles Davis, Charlie Mingus, Max Roach, Ella Fitzgerald, Sarah Vaughn, Carmen McRae, and others in order to understand the theory and approaches these masters used to construct and/or compose these seminal works. Then, I want to understand how jazz studies majors use the lessons they've gleaned to develop their abilities to apply those theories and approaches to their own compositions and improvisations of other seminal works. In addition, I am interested in understanding if and how software can be introduced into environments like music composition and improvisation classes to help students interpret the works of the masters and apply what they've learned to their own compositions and improvisations as they are creating them. For example, by studying Miles Davis's use of a modal scale in "So What?," we can understand how this work is interpreted to understand what makes up a modal scale and how it is constructed. With this understanding of its structure and its use in the work, we can begin to examine how Davis's approach is the same as or different from other pieces that use modality. In addition, we can begin to explore how Davis's approach can be applied to seminal works not written in a modal scale like John Coltrane's "Naima." Eventually, we can explore how adapting the structure impacts the modality, possible creating new representations of the modal scale in original compositions. I believe that this kind of exploration will help me understand how interpretation and application skills develop, change, and are used in different domains, particularly artistic ones, and I can compare and contrast interpretation and application skills across more technical and more artistic endeavors. I hope to have more to say about this in the future.

APPENDIX A

BALD HEAD ISLAND PERFORMANCE ASSESSMENT

Bald Head Island Challenge

Your team is the lead design team for a construction company. The construction company is planning to built 2 subdivisions on a small island off the coast of Georgia. The company has determined that the structure of the island is very similar to the structure of the Bald Head Island. The company would like each subdivision to be completed in 5 months, making the total amount of time to build both subdivisions 10 months. The company has 2 million dollars to spend on this project. Assume each test you run will cost the company $10,000.

Your team has been asked to do the following:

- Find and describe the risk factors involved in building the subdivisions on this island. Be sure to explain why you feel these are risk factors.
- Identify and describe possible ways to manage the risk factors mentioned in the previous bullet. Describe the pros and cons of each management method.
- Design a plan to test the management methods you have identified and described.
- State rules of thumb for identifying and managing the risks involved with this project.

Use the chart to help you complete the tasks described above.

APPENDIX A

BALD HEAD ISLAND PERFORMANCE ASSESSMENT

THE OUR CASE SUMMARY CHART (CONTINUED)

Our Case Study

Describe the risk.	Why is this a risk?	What are ways to manage the risk?	Pros	Cons

APPENDIX A

BALD HEAD ISLAND PERFORMANCE ASSESSMENT

(CONTINUED)

Part II.

- Design an overall plan for construction of the subdivisions, including sketches and/or descriptions of:
  - Material needed to construct the subdivisions and implement the management methods
  - Where subdivisions should be built
  - Which management methods should be used and where those management methods should be implemented
  - Timeline for implementation of plan with costs factored in
  - Any other information you feel is important

- Make recommendations to the construction company that include the following:

  - Describe why you feel the company should/shouldn't continue with this project.
  - Describe your team's expert opinion with respect to the company's time constraints and budget for this project. Be sure to explain why.
  - Describe any changes or additions your team feels should be made to the company's constraints, budget, or your plan. Be sure to explain why.

Use the attached sheets to help you complete the tasks describe above.

APPENDIX A

BALD HEAD ISLAND PERFORMANCE ASSESSMENT

(CONTINUED)

Our Plan

Our Recommendations

APPENDIX B

SNOWSHOE HARE/LYNX PERFORMANCE ASSESSMENT

Four years ago, the cheetah was listed as a threatened species on federal lands in Africa, protected by the Endangered Species Act. The cheetah's main prey is the Grant gazelle, a herbivore, and also an endangered species. Now, the International Wildlife Preservation Summit has agreed to consider changes to land management activities that further endanger the cheetah. Research has shown that threats to the cheetah are similar to threats facing the Canada lynx, while threats to the gazelles are similar to threats facing the Snowshoe hare. Your team has been selected to uncover the issues or threats that may have contributed to the cheetah's endangerment and to make recommendations to the Summit to help save the cheetah.

For Part I, your team has been asked to do the following:

- Find and describe the issues that contribute to the cheetah's endangerment,
- Identify and describe the possible ways to address the issues mentioned in the previous bullet. Describe the pros and cons of each.
- Identify rules of thumb for identifying and addressing the issues described.
-

Use the chart to help you complete the tasks described above.

APPENDIX B

SNOWSHOE HARE/LYNX PERFORMANCE ASSESSMENT

(CONTINUED)

Describe the Issue/Threat.	Why is this an issue/threat?	What are ways to address this issue/threat?	Pros	Cons

Rule(s) of Thumb:

APPENDIX B

SNOWSHOE HARE/LYNX PERFORMANCE ASSESSMENT

(CONTINUED)

Part II.

For Part II, your team's task is to:

- Develop a plan for saving the cheetahs from endangerment. Include materials, tools, supplies, amount of time, money, and any other criteria/constraints you would like to address.
- Write a formal letter to the International Wildlife Preservation Summit giving your team's recommendations for addressing the threats facing the cheetah.
    - Be sure to explain why your team is making the recommendations and how they can help to save the cheetah from endangerment.

Use the attached sheets to help you complete the tasks described above.

APPENDIX B

SNOWSHOE HARE/LYNX PERFORMANCE ASSESSMENT

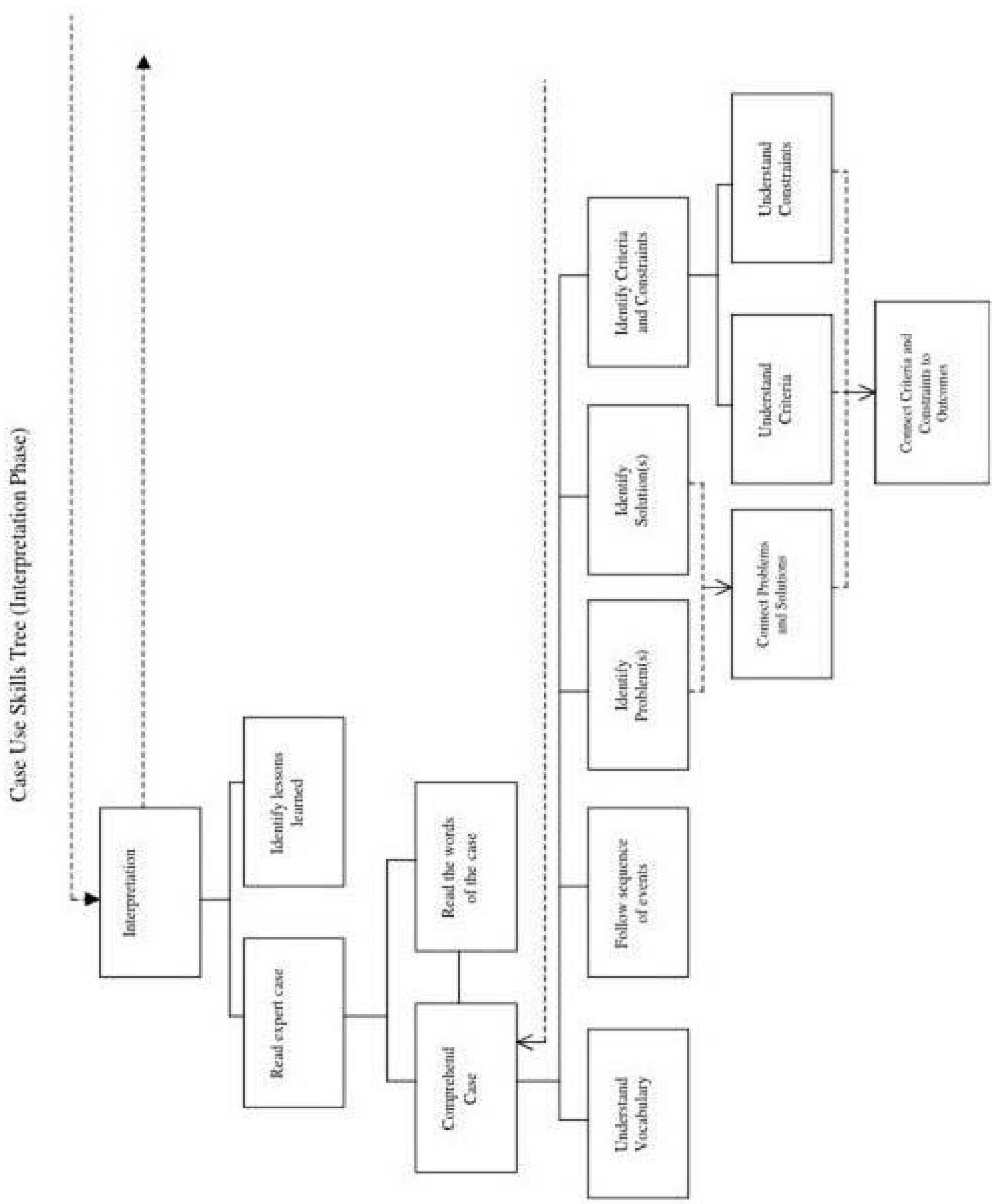
(CONTINUED)

Our Plan

Our Letter To the International Wildlife Preservation Summit

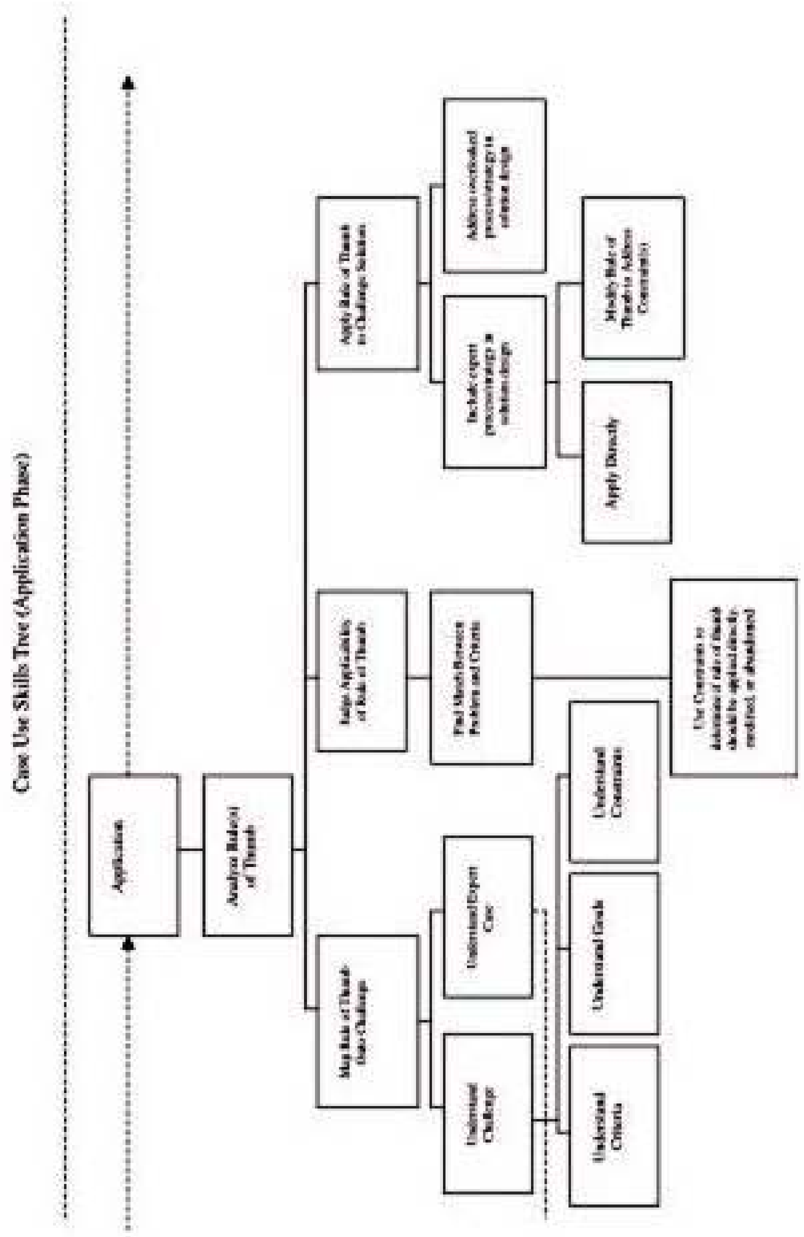
APPENDIX C

CASE USE SKILLS TREE



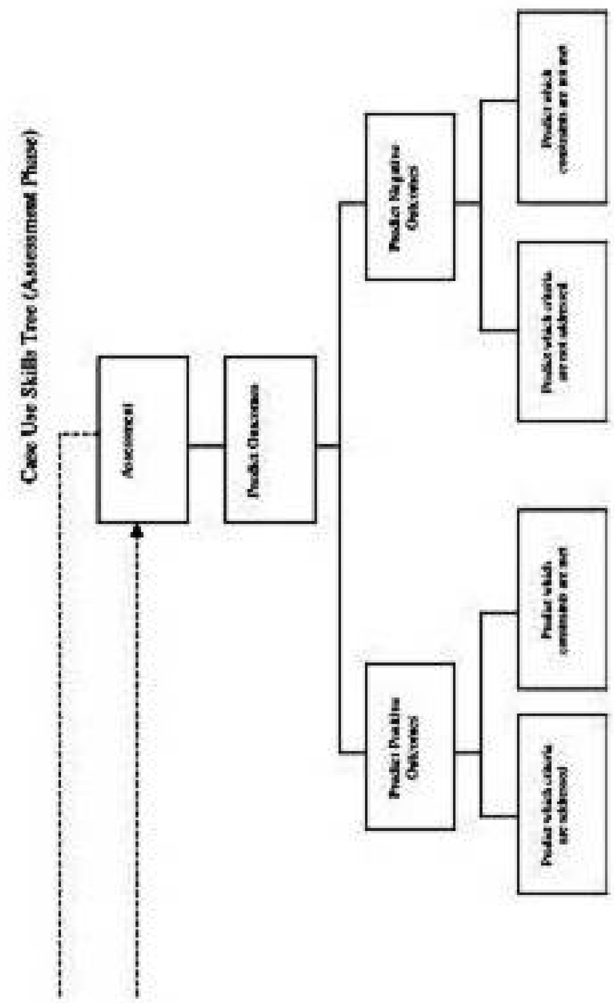
APPENDIX C

CASE USE SKILLS TREE (CONTINUED)



APPENDIX C

CASE USE SKILLS TREE (CONTINUED)



APPENDIX D

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 1 (VIDEO)

Performance Assessment tasks: Coding for Case Interpretation—Part I

Additional notes are fine and can be recorded on the coding sheet.

Within an episode, the context of the group can be characterized as one that:

Recognizes that the case should be used to solve the challenge

Not at all	At least one of the members of the group reads the case	At least one member of the group reads the case and states that the case should be used to help the group identify the risks	At least two of the members of the group read the case and identify several risks directly from the case	All group members read the case and identify a majority of risks directly from the case.
1	2	3	4	5

Makes direct reference to the case to justify an argument or position

Not at all	At least one of the members of the group mentions an example from the case as evidence to support or refute an idea	At least one member of the group points to an example in the case as evidence to support or refute an idea	At least two of the members of the group point to examples in the case as evidence to support or refute an idea	All group members point to examples in the case as evidence to support or refute most ideas
1	2	3	4	5

APPENDIX D

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 1 (VIDEO) (CONTINUED)

Able to identify expert problems

Not at all	At least one of the members of the group mentions a problem the experts encountered	At least one member of the group points out problems the experts encountered and identifies why those can be considered problems	At least two of the members of the group point out problems the experts encountered and identify why those can be considered problems	All group members point out problems the experts encountered and identify why those can be considered problems
1	2	3	4	5

Able to identify expert "mistakes"

Not at all	At least one of the members of the group mentions an outcome was unfavorable	At least one member of the group points out that an outcome was unfavorable and that it was due to expert error	At least one member of the group points out that an outcome was unfavorable and articulates the error the experts made	More than one member of the group points out that an outcome was unfavorable and articulates the error the experts made
1	2	3	4	5

APPENDIX D

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND PERFORMANCE ASSESSMENT PART 1 (VIDEO) (CONTINUED)

Able to identify relevant aspects of the case that can be applied to the challenge

Not at all	At least one member of the group identifies a managemen t method from the case	At least one member of the group identifies a management method from the case and suggests that the group use that management method	At least one member of the group identifies a management method from the case, suggests that the group use that strategy, and the group discusses the feasibility of applying that method to their challenge	*Most group members identify management methods from the case, suggest that the group use those management methods, and the group discusses the feasibility of applying that method to their challenge*
1	2	3	4	5

Identifies risks based on prior experience with another LBD/software case

Not at all	At least one member of	At least one member of the	At least one member of the	More than one member of the

	the group mentions a risk and mentions an LBD case that had the same risk	group mentions a risk, makes reference to a specific LBD case that had the same risk	group mentions a risk, makes reference to a specific LBD case that had the same risk, and explains why both of those cases have the same risk	group consistently mentions a risk, makes reference to a specific LBD case that had the same risk, and explains why both of those cases have the same risk
1	2	3	4	5

APPENDIX D

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND PERFORMANCE ASSESSMENT PART 1 (VIDEO) (CONTINUED)

Able to identify criteria and constraints

Not at all	At least one member of the group mentions a criteria or constraint	At least one member of the group mentions a criteria and/or constraint and identifies the role that the criteria or constraint will play with respect to their outcomes	At least one member of the group mentions a criteria and/or constraint, identifies the role that the criteria or constraint will play with respect to their outcomes, and the group discusses the feasibility of that role	More than 2 members of the group mentions a criteria and/or constraint, identifies the role that the criteria or constraint will play with respect to their outcomes, and the group discusses the feasibility of that role
1	2	3	4	5

APPENDIX D

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 1 (VIDEO) (CONTINUED)

Uses the case to understand the context of the risks

Not at all—looks for keywords and writes them down	At least one member of the group mentions a cause specific to the case for a particular risk	At least one member of the group mentions a cause specific to the case for a particular risk and suggests that the same context applies to or is different from the group's challenge	At least one members of the group mention two or more causes specific to the case for particular risks, suggest that the same context applies to or is different from the groups challenge, and articulate that connection or lack of connection between the context of the case and the challenge	More than one member of the group mentions two or more causes specific to the case for particular risks, suggests that the same context applies to or is different from the groups challenge, and articulates that connection or lack of connection between the context of the case and the challenge
1	2	3	4	5

Identifies rules of thumb

Not at all	Identifies rules of thumb with no causality	Identifies rules of thumb with causality, but causality is not relevant	Identifies rules of thumb with relevant causality	Identifies rules of thumb with relevant causality that hints way(s) to apply the rule of thumb in the future
1	2	3	4	5

APPENDIX E

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 1 (WRITTEN)

Case Interpretation Coding – Written Part 1

Risk Number – Enter a number for each risk listed in the risk column of the student chart in the risk number column. For each risk, in the Risk column, enter a rating for the risk and a number for the Nature of Risk (if applicable).

Risk

No risk identified.	Risk identified	Risk is identified and is relevant to the task.	Risk is identified, is relevant to the task, and is justified (via the Why is it a risk column)	Risk is identified, is relevant to the task, and contains a correct justification of the risk.
0	1	2	3	4

Nature of Risk – This measure is used to categorize the risk(s) identified. Enter a number for each risk, and only a 1 or 2 if a risk is present. If no risk is present, enter a 0.

1 – Nature – student writes about a problem/risk that occurs in nature and of which the experts have no control over.

2 – Expert – student identifies a problem that occurred as a result of the experts implementing a solution

APPENDIX E

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 1 (WRITTEN)

(CONTINUED)

Management Method Number – Enter a number for each management method listed in the Ways to Manage This Risk column of the student chart. This should be a two digit number-the first digit should be the Risk Number that it is matched up with, and the second digit should be a chronological numbering of the management method (1 for the first management method listed, 2 for the second, etc.). So, enter 11 in the Management Method Number column if the management method is matched up with the 1st risk and if this management method is the 1st in the list of management methods.

Management Method

No management method listed.	Management method identified.	Management methods is identified and is relevant to the problem it is matched with.	Management method is identified, is relevant to the problem it is matched with, and is justified in the context of the group's challenge.	Management method is identified, is relevant to the problem it is matched with, is justified in the context of the group's challenge, and suggests a way or way(s) that this management method can be implemented
0	1	2	3	4

APPENDIX E

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 1 (WRITTEN)

(CONTINUED)

Origin of Risk – This measure is used to characterize the management methods identified. Enter a number for each management method, and only a 1, 2, or 3 if a management method is present. If no management method is present, enter a 0.

1 – The management method identified is derived from the Bald Head Island case.
2 – The management methods identified is derived from personal or outside experience.
3 – The management method identified is derived from an LBD experience.

Pro

No pro identified.	Pro identified.	Pro identified is with respect to management method.
0	1	2

Pro Type – This measure is used to not only characterize the pros identified, but it can also be used to identify if multiple pros are identified for a given management method. Enter a number for each pro, and only enter a 1 or 2 if the Pro column contains a 1 or 2. If the Pro column contains a 0, enter a 0 for Pro Type.

1 – Goal – The pro emphasizes the satisfaction of the overall task or goal.
2 – Criteria and Constraint – The pro emphasizes the satisfaction of the criteria or constraints

APPENDIX E

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND PERFORMANCE ASSESSMENT PART 1 (WRITTEN) (CONTINUED)

Con

No con identified.	Con identified.	Con identified is with respect to management method.
0	1	2

Con Type – This measure is used to not only characterize the cons identified, but it can also be used to identify if multiple cons are identified for a given management method. Enter a number for each con, and only enter a 1 or 2 if the Con column contains a 1 or 2. If the Con column contains a 0, enter a 0 for Con Type.

1 – Goal – The con emphasizes the lack of satisfaction of the overall task or goal.

2 – Criteria and Constraint – The con emphasizes the satisfaction of the criteria or constraints.

APPENDIX E

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND PERFORMANCE ASSESSMENT PART 1 (WRITTEN) (CONTINUED)

Rule of Thumb Number – Enter a number for each rule of thumb listed on the back of the Bald Head Island Challenge Chart. For each rule of thumb, in the Rule of Thumb column, enter a rating for the rule of thumb and a number for the Causality Type (if applicable).

Rule of Thumb

No rule of thumb identified.	Rule of thumb identified.	Rule of thumb is identified and includes causality.	Rule of thumb is identified, includes causality, and suggestions for way(s) it can be applied.
0	1	2	3

***Causality Type** – This measure is used to characterize the type of causality present in student created rules of thumb. Enter a number for each rule of thumb, and only enter a 1 or 2 if the Rule of Thumb column contains a 1, 2, or 3. If the Rule of Thumb column contains a 0, enter a 0 for Causality Type.*

1 – Process – The rule of thumb involves describing some process that should be used to accomplish a task.

2 – Criteria and Constraint – The rule of thumb involves describing how to satisfy a criterion or constraint.

APPENDIX F

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 2 (VIDEO)

Performance Assessment tasks: Coding for Case Application—Part II Video

Additional notes are fine and can be recorded on the coding sheet.

Within an episode, the context of the group can be characterized as one that:

Identifies issues or problems not explicitly stated in the case

Not at all	At least one member of the group mentions an issue or problem not explicitly stated in the case (like transportation or recreation)	At least one member of the group mentions an issue or problem not explicitly stated in the case, and the group discusses the feasibility of the issue or problem	At least two member of the group mentions an issue or problem not explicitly stated in the case, and the group discusses the feasibility of the issue or problem	All group members mention issues or problems not explicitly stated in the case, and the group discusses the feasibility of the issue or problem
1	2	3	4	5

APPENDIX F

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND PERFORMANCE ASSESSMENT PART 2 (VIDEO) (CONTINUED)

Able to identify relevant aspects of the case that can be applied to the challenge

Not at all	At least one member of the group suggests applying a management method from the group's chart or the expert case to their plan/design.	At least one member of the group suggests applying a management method from the group's chart or the expert case to their plan/design and the group discusses the feasibility of applying the management method.	At least one member of the group uses a pro or con from the group’s chart or directly from the case to support or refute use of the management method in the group’s design/plan.	More than one member of the group uses a pro or con from the group’s chart or directly from the case to support or refute use of the management method in the group’s design/plan.
1	2	3	4	5

APPENDIX F

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 2 (VIDEO) (CONTINUED)

Suggests incorporating a solution found in the case

Not at all	At least one member of the group mentions using a management method in the case (can also be listed on their chart--as long as it's from the case)	At least one member of the group mentions using a management method in the case and justifies it using the pro/con columns in their chart or using the case	At least one member of the group mentions using a management method in the case, justifies it using the pro/con columns in their chart or using the case, and the group discusses the feasibility of using that management method	More than one member of the group mentions using a management method in the case, justifies it using the pro/con columns in their chart or using the case, and the group discusses the feasibility of using that management method
1	2	3	4	5

APPENDIX F

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND PERFORMANCE ASSESSMENT PART 2 (VIDEO)

Notices that a management method used by the experts cannot be applied as is but must be adapted

Not at all	At least one member of the group mentions that a management method needs to be adapted to be used in the group's plan/design	At least one member of the group mentions that a management method need to be adapted to be used in the group's plan/design and uses either the case or the group's chart to justify that adaptation	At least one member of the group mentions that a management method need to be adapted to be used in the group's plan/design, uses either the case or the group's chart to justify that adaptation, and the group discusses the feasibility of that adaptation	More than one member of the group mentions that a management method need to be adapted to be used in the group's plan/design, uses either the case or the group's chart to justify that adaptation, and the group discusses the feasibility of that adaptation
1	2	3	4	5

APPENDIX F

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND PERFORMANCE ASSESSMENT PART 2 (VIDEO)

Applies the case to the challenge using rules of thumb

Not at all	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, and justifies the use of the rule of thumb.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.	More than one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.
1	2	3	4	5

APPENDIX F

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 2 (VIDEO)

Notices that a solution used by the experts cannot be applied as is but must be adapted

Not at all	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, and justifies the use of the rule of thumb.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.	More than one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.
1	2	3	4	5

APPENDIX F

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 2 (VIDEO)

Justifies use, modification, or abandonment of an expert solution based on criteria and constraints of their challenge

Not at all	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, and justifies the use of the rule of thumb.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.	More than one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.
1	2	3	4	5

APPENDIX F

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND PERFORMANCE ASSESSMENT PART 2 (VIDEO)

Applies a solution used by the experts directly to their challenge

Not at all	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, and justifies the use of the rule of thumb.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.	More than one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.
1	2	3	4	5

APPENDIX F

FALL 2002 STUDY CODING SCHEME FOR BALD HEAD ISLAND

PERFORMANCE ASSESSMENT PART 2 (VIDEO)

Suggests that an expert solution should be abandoned

Not at all	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, and justifies the use of the rule of thumb.	At least one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.	More than one member of the group mentions that a rule of thumb created by the group should be addressed in the group's plan/design, justifies the use of the rule of thumb, and the group discusses the feasibility of that use.
1	2	3	4	5

APPENDIX G

CURRENT CODING SCHEME

Problem Number – Enter a number for each problem listed in the "Problems That Arose" or "Risk" column of the student chart in the problem number column. For each problem, in the Problem column, enter a rating for the problem and a number for the Nature of Problem (if applicable).

I. Identifies problems – Provide a rating for each problem listed

No problem identified	Provides a general description of problem	Provides a description about a specific aspect of a problem	Provides a description about a specific aspect of a problem and includes correct causality
1	2	3	4

Nature of Problem – This measure is used to categorize the problem(s) identified. Enter a number for each risk, and only a N or E if the problem identified comes from the case. If no problem is present, enter a O.

N-Nature-student writes about a problem that occurs in nature and of which the experts have no control.
Example: "The shoreline was eroding"
E-Expert-student identifies a problem that occurred as a result of the experts implementing a solution.
Example: "The channel was dredged causing the island to accrete very rapidly"
O-Other-student writes about a problem that does not fall in either of the first two categories.

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

Solution Number – Enter a number for each solution listed in the "How Problems Were Managed", "Ways To Manage This Risk", or artifact column/text box. This should be a two digit number—the first digit should be the Problem Number that the solution addresses, and the second digit should be a chronological numbering of the solution (1 for the first solution listed, 2 for the second, etc.). So, enter 11 in the Solution Number column if the solution is matched up with the 1^{st} problem and if this solution is the 1^{st} in the list of solutions.

II. Identifies solutions – Provide a rating for each solution listed

No solution identified or solution identified does not address problem listed or problems related to the case	Provides a general description of solution	Provides a description of a solution that includes the benefit it was supposed to have or the criteria/constraint it was supposed to address.	Provides a description about a solution that includes the benefit it was supposed to bring or the criteria/constraint it was supposed to address, and some detail about how it was implemented
1	2	3	4

III. Specifies Implementation– Describes the implementation provided. Code only if rating of 4 is given for Identifies Solution. Provide a rating for each solution listed

General Implementation given with no description of tools/technology or implementation steps.	Implementation provided with implementation steps but no description of tools/technology or with description of tools/technology but no implementation steps	Implementation provided with implementation steps and tools/technology used	Implementation provided with implementation steps, tools & technology used & justification for steps, tools, and technology used
1	2	3	4

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

Implementation Type – This measure is used to characterize the type implementation students describe. Enter a number for each rule of thumb, and only enter a T, P or H if the Specifies an Implementation column contains a 2, 3, or 4. If the Specifies and Implementation column contains a 1, enter a 0 for the Implementation Type.
T—Technology – Implementation focuses more on the tools that were used in the solution than it does on a sequence of steps being carried out. Ex: "The scientists used shields to dig through rock that had been broken up by blasts. They also inserted pressurized air to push water out of the tunnel."
P—Process—Implementation focuses more on the sequence of steps being carried out than the tools used in the solution. "Ex: "The solution that they came to for the filling of the water inside the tunnel was that they used two drainage tunnels that carried the water that was filling the tunnel up." Or "Due to high water pressure on the tunnel, holes were drilled into the tunnel walls that led to pipes to carry the water away."
H—Hybrid—Implementation includes the sequence of steps carried out to implement the solution and includes the tools that were used at each step in the solution.

IV. Connects problems and solutions to apply to challenge

No connection of problems and solutions—either list a problem or a solution without explicitly stating how the solution addresses the problem	Solution is described and it is stated explicitly how the solution addresses the problem	Solution is described explicitly stating how the solution addresses the problem and justification is provided	Solution is described explicitly stating how the solution addresses the problem, justification is provided, and implementation details are given
1	2	3	4

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

Criterion Number – Enter a number for each criterion listed. For each criterion in the Understands Criteria column, enter a rating for the criterion.

V. Understands criteria

No criteria mentioned or Lists constraint as criteria	Provides general description of criteria	Describes objective that the experts/group would like to address	Describes objective that the experts/group would like to address and provides justification for choosing that criteria
1	2	3	4

Constraint Number – Enter a number for each constraint listed. For each constraint in the Understands Constraints column, enter a rating for the constraint.

VI. Understands constraints

No constraints mentioned or lists criteria as a constraint	Describes a general constraint	Describes a specific constraint and what the constraint affected	Describes a specific constraint, what the constraint affected, and provides justification for choosing that constraint
1	2	3	4

VII. Connects constraints to outcomes

Does not describe the outcome if a constraint is addressed (or not addressed)	Describes the outcome if a constraint is addressed (or not addressed)	Describes the outcome if a constraint is addressed (or not addressed) and why that constraint is

		addressed
1	2	3

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

Rule of Thumb Number – Enter a number for each rule of thumb listed. For each rule of thumb, in the Rule of Thumb column, enter a rating for the rule of thumb and a number for the Causality Type (if applicable).

VIII. Rule of Thumb

No rule of thumb identified	Rule of thumb identified	Rule of thumb is identified and includes correct causality and justification	Rule of thumb is identified, includes causality and justification, and suggestions for way(s) it can be applied
1	2	3	4

Rule of Thumb Carried Over From Interpretation – This measure is used to characterize whether a rule of thumb listed in a case application is one that was created during the case interpretation phase or whether it is a new rule of thumb. Enter a + if this rule of thumb is one that was carried over from the Case Interpretation. Otherwise, enter a minus (-)— (-) constitutes that this was a new rule of thumb not carried over from case interpretation.

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

Rule of Thumb Type – This measure is used to characterize the type of rules of thumb students have created. Enter a number for each rule of thumb, and only enter a K, S, T, P, or O if the Rule of Thumb column contains a 2, 3, or 4. If the Rule of Thumb column contains a 1, enter a 0 for the Rule of Thumb Type.

K—Kind – Rule of Thumb Describes a Characteristic that should or shouldn't be present. Ex: "More porous rocks are more permeable" or "Harder rocks are preferred for digging"
S—Signal—Rule of Thumb Describes a Situation that signals a potential problem. Ex: "Pressure against the rock around you could be a sign of a lot of water, which is likely caused by faults or fissures."
T—Technology—Rule of Thumb Describes a Technology that can be used to address a problem
Ex: "If water somehow seeped through the permeable rock, you could use Compressed air to pump it our of the tunnel." Or "Use shields to keep back mud so it won't overflow the tunnel."
P—Process—Rule of Thumb Describes a process that can be used to address a problem
Ex: "We should always go under major cities when having to pass them in a tunnel building project. This way, the city is not disturbed.
O—Other—Rule of thumb does not describe one of the above

Causality Type – This measure is used to characterize the type of causality present in student created rules of thumb. Enter a number for each rule of thumb, and only enter a P, C, or O if the Rule of Thumb column contains a 3, or 4. If the Rule of Thumb column contains a 1 or 2, enter a 0 for the Causality Type.

> **P**—Process—The rule of thumb involves describing some process that should be used to accomplish a task. Ex: "Build a model to test a management method before building because errors can be discovered before building begins."
> **C**—Criteria or Constraint—The rule of thumb involves describing how to satisfy a criteria or constraint. Ex: "Build a model to test a management method before building because making changes during planning is less expensive and time consuming than making changes while building."
> **O**—Other—The rule of thumb does not describe one of the above

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

IX. Judges Applicability of Rule of Thumb (Case Application Tool Artifacts)

The criterion addressed by rule of thumb is incorrect and the predictions made are incorrect, but the rule of thumb is judged as being applicable.	Notices that rule of thumb satisfies a previously mentioned criterion (states how it satisfies the criteria), but provides an incorrect prediction based on that criterion OR Criterion addressed by rule of thumb is incomplete or incorrect, but predictions made are correct	The criterion addressed by rule of thumb is not previously mentioned, but group notices that rule of thumb satisfies that criterion and provides a correct prediction based on that criterion	Notices that rule of thumb satisfies a previously mentioned criterion(states how it satisfies the criterion) and provides a correct prediction based on that criterion
1	2	3	4

Rule of Thumb applied directly – Enter a + if the rule of thumb is applied directly or a - if it is modified or abandoned.

Rule of Thumb modified upon application – Enter a + if the rule of thumb has been modified upon application or a - if it has not.

Rule of Thumb abandoned – Enter a + if the rule of thumb is abandoned or a - if it is used.

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

IX Solution # – Enter a number for each solution proposed. Number should be a 2 digit number—first digit matches the criterion (from V) that the proposed solution addresses and the second digit signifies the order in which the solution was encountered chronologically.

IX. Judges Applicability of Plan (Performance Assessments Part 2) – Code for each solution proposed.

Applicability of plan is not judged or no plan or proposed solution exists.	Proposed solution is considered, but the usefulness of the proposed solution is not considered.	Proposed solution is considered and found to be useful, useful with modifications, or not useful at all.	Proposed solution is considered and found to be useful, useful with modifications, or not useful at all. Justification is provided for its use, modification, or abandonment
1	2	3	4

X. Quality of Application of Rule of Thumb

Ways that rule of thumb can be applied are not explored.	Rule of thumb is applied as a prediction or a justification for applying rule of thumb, but rule of thumb is not incorporated into a solution or a suggestion for a solution.	Suggestion for implementation of rule of thumb is given that follows from the criterion rule of thumb addresses and the predictions rule of thumb makes.	Suggestion for implementation of rule of thumb is given (that follows from the criterion rule of thumb addresses and the predictions rule of thumb makes), and justification is given for implementation.
1	2	3	4

Vocabulary Identified – Enter a + if vocabulary has been identified. Enter a ++ if vocabulary has been identified and defined. Otherwise, enter a -.

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

XI. Understands the Challenge

No description of the challenge provided	Incorrect description of the challenge provided	General, but correct description of the challenge is provided	Specific description of the challenge is provided including specific details (i.e. route to take, predator to be saved, etc.) and design goals.
1	2	3	4

XII. Finds a match between criteria and problem rule of thumb addresses (generally found in Criteria addressed by rule of thumb and Predictions the rule of thumb makes column)

No match between criteria and problem rule of thumb addresses is made	A match between criteria and problem rule of thumb addresses is made, but predictions about rule of thumb are not present.	A match between criteria and problem rule of thumb addresses is made, and prediction about rule of thumb is present BUT it is incorrect (i.e. prediction does not directly follow from the rule of thumb)	A match between criteria and problem rule of thumb addresses is made, and predictions about rule of thumb are present and correct.
1	2	3	4

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

XIII Prediction # – Enter a number for each prediction that matches a criterion. Number should be a 2 digit number—first digit matches the criterion (from V) that the prediction addresses and the second digit signifies the order in which the prediction was encountered chronologically.

XIII. Predicts which criteria are addressed – Rate for each occurrence of a prediction that addresses a criteria

No predictions about which criteria are addressed are made in challenge solution	Prediction of possible problems that could arise that address a particular criteria are given, but no solution is proposed	Prediction of possible problems that address a particular criteria are given and a solution is proposed	Prediction of possible problems that address a particular criteria are given, a solution is proposed, and justification is given for that solution
1	2	3	4

XIV Prediction # – Enter a number for each prediction that matches a constraint. Number should be a 2 digit number—first digit matches the criterion (from VI) that the prediction addresses and the second digit signifies the order in which the prediction was encountered chronologically.

XIV. Predicts which constraints are met – Rate for each occurrence of a prediction that addresses a constraint

No predictions about which constraints are addressed in challenge solution are made	Constraints that are addressed are explicitly stated	Constraints that are addressed are explicitly stated and justification is given	Constraints that are addressed are explicitly stated, justification is given, and predicted outcomes are given
1	2	3	4

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

XV Prediction # – Enter a number for each prediction that matches a criterion that was mentioned but not addressed by the proposed solution(s). Number should be a 2 digit number—first digit matches the criterion (from V) that the prediction refers to and the second digit signifies the order in which the prediction was encountered chronologically.

XV. Predicts which criteria are overlooked – Rate for each occurrence of a prediction that describes a criterion that was not addressed

No predictions about which criteria are overlooked in challenge solution are made	Criteria that are overlooked are explicitly stated, but no means of addressing overlooked criteria is proposed	Criteria that are overlooked are explicitly stated, valid justification for overlooking criteria is given, but a means of addressing overlooked criteria is not proposed	Criteria that are overlooked are explicitly stated, justification for overlooking criteria is given, and a means of addressing overlook criteria is given
1	2	3	4

APPENDIX G

CURRENT CODING SCHEME (CONTINUED)

XVI Prediction # – Enter a number for each prediction that matches a constraint that was mentioned but not addressed by the proposed solution(s). Number should be a 2 digit number—first digit matches the constraint (from VI) that the prediction refers to and the second digit signifies the order in which the prediction was encountered chronologically.

XVI. Predicts which constraints are not met

No predictions about which constraints have not been addressed in challenge solution are made	Describes which constraints that may not have been met by challenge solution	Describes which constraints may not have been met by challenge solution and gives justification for why those constraints were not met in challenge solution	Describes which constraint may not have been met by challenge solution, gives justification for why those constraints were not met in challenge solutions, and predicts specific outcomes that may result
1	2	3	4

APPENDIX H

FALL 2003 STUDY STUDENT INTERVIEW QUESTIONS

1. General Questions
    a. Tell me about what you did this semester in science class.
    b. Tell me about the software you used.
    c. If you could rate your LBD experience this year on a scale from 1-5 with 1 being “It was the worst experience ever” and with 5 being “It was the best experience ever”, how would you rate it? Why?

2. More Specific Questions
    a. LBD in general
        i. What particular thing about this semester in science do you remember most?
        ii. What makes this particular thing stick out?
        iii. What did you learn from this experience?
        iv. Tell me your feelings on being able to collaborate to solve problems.
    b. Software
        i. If you could rate the importance of learning about the experiences of others when solving problems similar to theirs on a scale from 1-5 with 1 being “Learning about the experiences of others is not helpful at all” and with 5 being “Learning about the experiences of others is extremely helpful,” how would you rate it?
        ii. Why?
        iii. (If 1 or 2) Tell me about a time in your life when someone gave you some advice and you took it.
            1. What happened?
            2. Was the result good or bad?
        iv. (If 1 or 2) Tell me about a time in your life when someone gave you some advice and you didn’t take it.
            1. What happened?
            2. Was the result good or bad?
        v. (If 1 or 2) So how do you feel about using the advice of others?
        vi. We’re trying to decide whether or not to keep the software as a part of LBD, especially the case tools you used. If you could rate your feelings about the software on a scale from 1-5 with 1 being “The software didn’t help me in solving the challenge at all” and with 5 being “I found the software very helpful in solving the challenge,” how would you rate it?
        vii. Why?
        viii. Tell me something you really liked about the software?
            1. Why does that stick out in your mind?

APPENDIX H

FALL 2003 STUDY STUDENT INTERVIEW QUESTIONS

(CONTINUED)

        2. What role did that play in your group's solution to the challenge?
- ix. Tell me something you did not like about the software.
- x. Did you notice the hints and examples in the software?
    1. Did you use either?
        a. (If yes) Which did you use?
        b. (If yes) Were they helpful to you?
            i. (If yes) In what way(s) were they helpful to you?
- xi. (Hand student a copy of their artifact(s) and for each artifact, ask the following:
    1. What were you trying to do with this tool?
    2. What did you do first?
    3. And then what?
- xii. What about this case sticks out in your mind?
- xiii. Tell me what you think rules of thumb are.
- xiv. If you were in another class (it doesn't have to be science) and the teacher gave you a problem to solve, and she also gave you an example or case to help you solve the problem, how would you use that example or case to help you figure out how to solve the problem?
- xv. Tell me about the amount of time it took to answer the questions/prompts in the software tools you used.
- xvi. How would you feel if you had the opportunity to use these tools in science classes in the future?

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STATEMENT OF PROFESSIONAL INTERESTS

My research interests include investigating how complex skill sets are developed over time and describing the developmental trajectory of those skills. Of specific interest to me is understanding the impact of educational software in cognitive-apprenticeship learning environments on students' ability to acquire and develop skills over time. In addition, I enjoy teaching in many areas of Computer Science including introductory programming, theoretical foundations of Computer Science, programming languages, data structures, and theory. I am committed to the development of computer scientists, both in their understanding of the field and in their ability to conduct and present research that can serve to advance the field.

EDUCATION

1999-Present 5th year Ph.D. Candidate in College of Computing, Georgia Institute of Technology

1995-1999 B.S. Computer Science/ Minor - Mathematics, Spelman College

EMPLOYMENT

1999-Present *Graduate Research Assistant, Georgia Institute of Technology*
Conducted research on educational units for middle school students called Learning By Design™ that teach middle school students science concepts and practices through design projects

2004-2004 *Instructor, Howard Hughes Summer Science Program, Spelman College*
Taught CIS 100: Introduction to Computer Literacy

2003-2003 *Adjunct Professor, Spelman College, CIS Department*
Taught CIS 213: Foundations of Computer Science, Fall 2003

2003-2003 *Assistant Director, Spelman College Summer Science & Engineering Program*
Organized student activities, trips, and served as a liaison between students, tutors, and Director.

2003-2003 *Adjunct Professor, Spelman College, Post Freshman Summer Science Program*
Taught CIS 102: Research Using the Internet for non-CIS majors.

2003-2003 *Assistant Director, Wings of Knowledge Tutoring, Inc.*
Managed tutors, handled payroll, registered new clients, and managed the day-to-day affairs of the office

2002-2002 *Tutor/Math Teacher, Educational Talent Search Program - Morris Brown College*
Taught SAT Math Prep class for 6 weeks for 9th and 10th graders, Summer 2002.

2000-2000 *Intern, Department of Defense*
Conducted research on Wireless ATM.

1999-1999 *Department of Defense (Intern)*

Used querying system to gather information about various components of DoD network.

1998-1998 *Technology Analyst, Andersen Consulting (Intern)*
Created and designed process plans for client company, BellSouth. Included analyzing process books, designing flow charts, and gathering and understanding network requirements to complete design process for client company.

1997-1998 *Teaching Assistant, Computer Science Department, Spelman College*
Teaching Assistant for *CS122 Intro to Programming Class* fall semester and *CS343 Intro to Programming Languages* spring semester. My responsibilities included grading papers, helping students with class work, creating keys for homework assignments and tests.

1997-1997 *Multimedia Specialist, SunTrust Banks, Inc. (Intern)*
Designed and created an interactive online kiosk for SunTrust Banks, Inc. that allowed employees and visitors to find information about the bank's services.

1996-1997 *Teaching Assistant, Computer Science Department, Spelman College*
Teaching Assistant for *CS121 Intro to Programming Class* both fall and spring semesters. My responsibilities included grading papers, helping students with class work, creating keys for homework assignments and tests, and assisting with labs.

MEMBERSHIP IN PROFESSIONAL ORGANIZATIONS

Cognitive Science Society (Student Member)
International Society of the Learning Sciences (Student Member)
Association of Computing Machinery (Student Member)

PUBLICATIONS

Kolodner, J.L., Owensby, J.N. and Guzdial, M. (2004). Case-Based Learning Aids, In D.H. Jonassen (Ed.), *Handbook of Research for Education Communications and Technology, 2nd Ed. Mahwah, NJ: Lawrence Erlbaum Associates*. (Book chapter)

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