Case Interpretation and Application In Support of Scientific Reasoning

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Abstract

Scientific reasoning involves the use of scientific skills, practices, and domain knowledge to solve science problems. A little emphasized tool that experts use to help them reason is to refer back to previous problem solving experiences, interpreting and applying those experiences as they solve problems. Results from a pilot study conducted Fall Semester 2002 suggest that improvement in interpreting and applying expert cases to solve a problem may also lead to improvement in certain scientific reasoning skills. In this paper, we seek to explore the connection between case application and scientific reasoning skills, namely, using evidence to justify a claim, generating hypotheses, making predictions, and explaining scientific phenomena.

Introduction

Scientific reasoning involves the use of scientific skills, practices and domain knowledge to solve science problems. Much research has been done to understand how students can develop more expert-like scientific reasoning skills (e.g. Kuhn, 1993; Schauble et. al., 1995), and much research has been done to promote more expert use of scientific reasoning skills in educational settings (e.g. Bell & Davis, 2000; Reiser, et. al., 2000). However, little attention has been given to the role case interpretation and application might play in learning to reason scientifically. There is evidence that scientists use cases extensively in their reasoning. For example, when trying to analyze a series of unexpected results, scientists will refer to cases that may seem unrelated but that have similar in order to explain why those unexpected results may have occurred (Blanchette & Dunbar, 2001).

In educational settings, it is often difficult to support students as they attempt to acquire and carry out expert-reasoning processes. In many cases, the expert-reasoning process may be too complex to pare down in such a way that students can engage in it without getting lost in all of the complexity (Reiser, 2000). In other cases, because the expert-reasoning process is not fully understood, it becomes difficult to assess where students may experience difficulty, and when they do, it is difficult to know what kind of help to provide.

We have sought to address these difficulties for one complex skill: case application. Fall semester 2002, we conducted a study to understand the effectiveness of the Case Application Suite (CAS) (Owensby & Kolodner, 2004), a set of tools designed to support middle-school students in project-based inquiry classrooms as they interpret and apply the experiences of experts to solve design problems. In particular, we were interested in understanding how effective our system of scaffolds was at supporting students as they interpreted and applied expert cases, whether the distribution of scaffolding responsibilities across teacher and software was effective, how well students were able to use case application skills in the absence of the scaffolding, and whether the distribution of scaffolding responsibilities could be articulated in a cognitive apprenticeship (Collins, Brown & Newman, 1989) framework.

Analysis of the data showed that CAS was effective at supporting students in case application, showing significant differences for interpretation and trends for application. In addition, the trends in the data suggested an unexpected finding—that case application supports the learning of scientific reasoning skills. Our analysis of this phenomenon suggests that this is because case application and scientific reasoning share foundational skills, namely using evidence to support a claim, generating hypotheses, making predictions, and explaining phenomena scientifically. This paper seeks to explore the connection between case application and scientific reasoning skills to suggest that improvement of certain case application skills will promote improvement in these aspects of scientific reasoning. As part of our exploration, we will show how we've used software-realized scaffolding (Guzdial, 1994) to support the acquisition of case application skills among middle-school students in project-based inquiry science (Blumenfeld, et al., 1991).

Case Application and Scientific Reasoning

Case application is the process of interpreting, analyzing, and applying experiences to address challenges or solve problems (Owensby & Kolodner, 2003; the CBR literature, e.g., Kolodner, 1993). It involves three high-level steps: interpretation, application, and assessment. Interpretation involves, at the time of encountering the case, it, focusing on extracting the connections between its criteria and constraints and the solution chosen to address its challenge, making connections between the solution chosen and the outcomes that happened, and identifying what can be learned from the experience, and at the time of working toward applying it, making connections between the case (acting as a source case) and the new situation (target). Application involves applying those lessons to the new situation or target case, either directly or via adaptation. Assessment involves analyzing the applicability and quality of the proposed solution either by making predictions about the target case's solution or by testing the target case's solution and analyzing the outcomes that result.

Case application is integral to the practices of experts. Medical experts use cases to diagnose as well as to refine treatments for patients. Architects keep file cabinets of cases to go back to when working on new projects. Lawyers refer to previous cases and decisions when constructing a strategy to prosecute someone or to defend a client.

Analogical reasoning has long been recognized as an important aspect of scientific reasoning (e.g. Gentner, 1999; Anderson, 2000, Blanchette & Dunbar, 2001). Case application extends standard analogical reasoning. In addition to mapping the solution for one problem onto the solution for another problem, we include in case application the analysis and interpretation of a case at the time it is encountered that allows its application. We also include in case application the identification of those nuggets of an encountered case that might apply in a new situation. When the cases being used are those of others, this interpretation process involves significant reading for understanding. While reading is taught in schools, rarely does science class focus on helping learners read. Yet real science practice is impossible without the skills involved in reading a scientific case for understanding and reasoning through its application.

Understanding requires identifying claims, the evidence used to support its claims, and the quality of explanations put forth, while applying what is in a science case requires making predictions based on those claims and finding particularly useful information in a big document.

In order to use evidence to support a claim, one must interpret the experience from which the claim arose in such a way that he/she recognizes that the evidence applies. Then, one must interpret the evidence in such a way that the aspects that apply to the claim can be identified. Next, one must be able to articulate how the relevant aspects of the evidence support the claim and make predictions for future use of the concept, skill, or claim. Understanding the experience from which the claim and evidence put forth involves interpreting the experience and drawing out the lessons that can be learned from the experience. Articulating how the evidence supports the claim involves articulating the lessons learned from the evidence and the experience that the claim rises from and then applying those lessons to explain how the evidence supports the claim and then making predictions about how the claim might be useful in the future. It does make sense, then, that supporting students as they learn how to interpret and apply cases illustrating the evidence of scientific phenomena and the application of scientific principles could help those same students become better scientific reasoners.

Our approach to supporting the development of case application skills

To help middle schoolers interpret cases and apply them in new situations, we have designed a suite of software tools called the Case Application Suite (CAS) to play the role of coach within a cognitive apprenticeship framework (Collins, Newman & Brown, 1989). In a cognitive apprenticeship approach to learning complex skills, the teacher models the skills and explains his/her reasoning to the students and then coaches and hints as students begin to carry out parts of that reasoning. As students become more capable, they, in turn, model for their peers and coach them to their next levels of capability. But when students work in small groups, there may not always be a group member expert enough to be able to apply that coaching to the rest of the group. CAS supports students as they work in small groups by asking the kinds of questions and making the kinds of suggestions that a teacher or more able student might make if he/she were available.

The design of CAS was informed by suggestions made by the skills acquisition, case-based reasoning, transfer, and cognitive apprenticeship literatures (Anderson, et. al, 1981; Anderson, 2000; Kolodner 1993; Branford, Brown & Cocking, 1999; Collins, Brown & Newman, 1989, respectively). CAS contains three tools. The Case Interpretation Tool helps students identify problems the experts encountered in achieving their goals, solutions they attempted and why they chose those, criteria and constraints that informed those solutions, results they accomplished and explanations of those, and any lessons learned, or rules of thumb, that can be extracted from the experience. The Case Application Tool guides students through attempting to apply the rules of thumb gleaned from the case, prompting them to consider whether a rule of thumb is applicable and then helping them explore ways they can apply it to their solution. The Solution Assessment Tool helps students make predictions about the success of their solution, analyzing the impacts they expect their solution to make as well as where they expect their solution to fall short.

The system of scaffolds in CAS includes five different types of scaffolds: (1) the structure of the suite serves as a scaffold as each tool corresponds to a major step in the case application process; (2) the prompts in each tool's center frame focus students' attention on important aspects of the case; (3) hints are provided with each prompt to give more specific help; (4) examples are provided with each prompt to help students see what they need to be accomplishing; and (5) charts and templates serve as organizers to help students with creating an analyzing the applicability of the rules of thumb they have gleaned.

Each tool is divided into three frames (Owensby & Kolodner, 2003; Owensby & Kolodner, 2004). In the left frame is the expert case and interpretations that have already been done of it. The middle-frame shows the prompts for the tool the group is currently working on. The right frame shows hints and examples (Figure 1).

Use of CAS in the Classroom

We've tried CAS out in classrooms engaging in the Learning by Design (LBD; Kolodner et al., 2003) project-based inquiry unit called *Tunneling Through Georgia*. In this challenge, student teams serve as consultants for the design of several tunnels needed for a transportation system that will run across the state of Georgia. Four tunnels need to be designed, each for a different geological area of the state—mountainous, sandy, and so on. Students need to address several issues—at what depth to dig the tunnel, what methods to use for the digging, and what support systems are needed in the tunnel's infrastructure. Cases are used extensively in the unit to suggest which geological characteristics of the tunnel location they need to learn more about to address the challenge, to introduce students to different kinds of tunneling technologies, and to give them an appreciation of the complexity of tunnel design. For example, the story about the design and construction of the Lotchberg Tunnel in Switzerland, shows

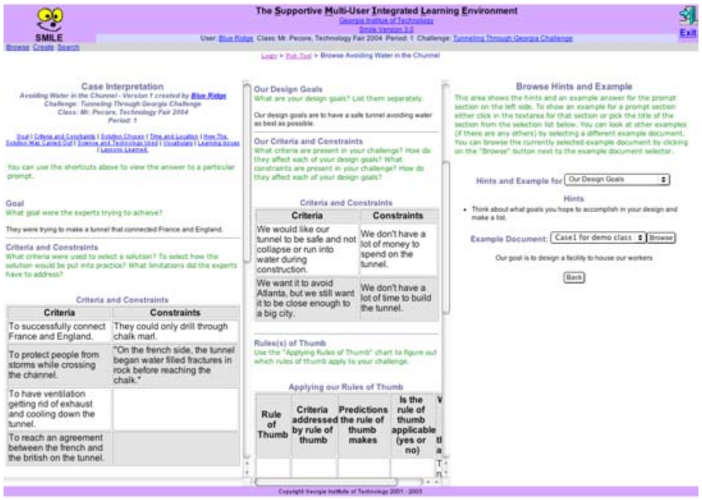

Figure 1: Case Application Tool

some of the problems the experts faced trying to tunnel through the summit of a mountain that has two peaks separated by a river and suggests understanding the composition of a mountain by using test shafts and core sampling can help to identify and possibly avoid problems like crumbling rock, flooding, and cave-ins.

The Tunneling unit is preceded by another unit that requires case application. In that unit, students learn about earth's surface processes as they engage in the challenge of designing and constructing (in a stream table) a way of managing erosion around a basketball court. They read two cases during this unit, one about the dustbowl and another about landslides on the U.S.'s West Coast. The teacher helps them read and understand the cases together as a class and moves around the room coaching them as they work in small groups to apply what they've learned to their challenge. In addition, students use a template to keep track of important aspects of the cases they are reading about. The template, created by the teacher and based on the My Case Summary Design Diary page (Puntambekar & Kolodner, 1998), organizes a page into columns representing *Case Summary, Problems, Ideas, Learning Issues, and Questions*.

As they get started with the Tunneling unit, the teacher again models case application for students as they analyze the Lotschberg Case together as a class. After analyzing the Lotschberg Case, student groups are assigned one of four tunnel cases to interpret and present to the rest of the class. They are introduced to CAS's Case Interpretation Tool to support them as they interpret the case on their own in small groups. This is followed by presentation of their interpretations of their cases to the class and discussion of the lessons that can be pulled from them. When it is time to apply what's been learned from the cases to their own tunnel challenge, students use the Case Application Tool to create a solution. This sequence is repeated a second time as groups read another set of four cases. Later, they sometimes use the Solution Assessment Tool to make predictions about how well their proposed designs might work, what they might have overlooked, and what they would do differently if given another chance

Our Study

We were interested in learning how to help students learn to interpret and apply cases to project challenges and in understanding the effects of adding software designed to augment the teacher's modeling and coaching to a cognitive apprenticeship. Our study collected data to answer three questions: (1) How are students' abilities to interpret and apply cases to their project challenge affected by such scaffolding? (2) To what extent would students' ability to apply cases in the absence of the suite be influenced by its use during a project? (3) To what extent does the suite enable students to articulate the processes involved in case application? When we noticed that some students' scientific reasoning capabilities were improved, we also analyzed to answer a fourth question: To what extent does case application capability predict scientific reasoning capability?

Methods

Procedures

We report here on a study where we used CAS in the classrooms of an 8th grade teacher (Mrs. K) (Owensby & Kolodner, 2003) who had only 4 computers available for her class. Because of this, only a subset of the students were able to use the software; the rest engaged in all of the same activities but had available only the template as scaffolding as they were interpreting and applying cases. All students in the study engaged together in solving the erosion challenge and in doing *Tunneling Through Georgia* activities, and all were exposed to the same teacher modeling. Overall, students engaged in case interpretation and application activities five times – twice during the erosion challenge, once with the teacher at the beginning of the Tunneling unit (the Lotchberg Case), and twice more in small groups. Each time, groups work together to interpret a case and draw out the lessons it teaches; they present their case interpretations to the class, and they lead discussion about their case. Comparison students (n=33 students; 9 groups) used the template to scaffold their case interpretation and application as they interpreted and applied cases after the Lotschberg Case, while experimental students used CAS (n=14 students; 4 groups). We compared the capabilities of students who had the software available to those who did not as students engaged in the unit and after its completion.

Software groups were videotaped as they used the software, and software and non-software groups were videotaped as they presented their interpretations to the class. In addition, templates and logs of CAS use were collected for analysis.

At the end of the unit, a performance assessment was given. Called the Bald Head Island Challenge, students worked in their *Tunneling Through Georgia* groups to make recommendations about the design of two subdivisions on an island off the coast of Georgia. They read a case about Bald

Head Island and used it to give advice. They were asked to identify the risks involved with the project, identify possible management methods, create rules of thumb (Part 1), design a plan for designing and constructing the subdivisions, and make final recommendations about whether the project should move forward with the given time and budget constraints (Part 2). Groups were videotaped as they discussed their ideas. All groups had only template scaffolding available as they engaged in this activity, organized into columns representing *Risk, Why Is This A Risk, Ways To Manage The Risk, Pros, and Cons*.

Analysis

Video data was analyzed using a coding scheme that described the data for specific interpretation and application dimensions. Two coders analyzed video-recorded group performance for interpretation on dimensions shown in Table 1 and for application and assessment on dimensions shown in Table 2, treating each of the two parts of the performance assessment as an episode. A five-point Likert scale was used for each, with one representing no evidence of presence of the quality being rated and 5 representing that the group fully displayed the quality being rated. Differences in ratings were negotiated by discussion, and inter-rater reliability was calculated.

Results

The results that follow provide evidence that case application can be supported in educational settings despite its difficulties, that distribution of scaffolding responsibilities across teacher and software in a cognitive apprenticeship framework seems to be a viable approach for promoting case application, and that particular scientific reasoning skills among students who used the software tools seem to be more sophisticated. We first discuss the differences between students who used the software and those who did not as they were engaging in classroom activities of the Tunneling challenge. We then discuss student capabilities while engaging in the performance assessment, completed by all students after the Tunneling unit was completed and without software scaffolding. The results are discussed with respect to using evidence to justify a claim, generating hypotheses, making predictions, and explaining scientific phenomena.

Case Application During Class Activities

Examination of student artifacts and presentations of case interpretations for groups using CAS vs. the case study template showed three major differences. First, the software groups better identified the reasons for positive and negative outcomes. For example, in learning about the Queens Midtown Tunnel, one software group told us: "They wanted to build [the tunnel] straight [through the city] but couldn't, so they continued it further underground in an S-shape under First Avenue and they took different core samples". This group was specific about the goals of the experts, the constraints that kept them from achieving those goals if they tried the obvious solution, what they did instead, and the activities they had to engage in to do that successfully. The typical non-software group, on the other hand, provided general descriptions about the experts' goals, neither mentioning the constraints' impact on the outcomes nor alternatives. For example, one non-software group told us: "The Manhattan side [was] on a large bluff higher than Queens[, so they] continued tunnels underground in a slope under First [Avenue]."

Second, the groups who used the software included more sophisticated causality in their rules of thumb. For example, the non-software groups' rules of thumb are in the form of simple imperative statements (e.g., "Control water problem", "Take core samples"), while the software groups' rules of thumb explain why (e.g., "Take core samples—they can save your life because if you hit the wrong kind of rock, you can get hurt", "You should always have an oxygen pass so the toxic fumes can get out."

Case Application at Completion of the Unit

In the performance assessment, groups discussed their answers in preparation for writing individual recommendations. We analyzed the video for interpretation and application capabilities.

Table 1 shows results for case interpretation (reliability 89%). Software groups tended to be better at all case interpretation capabilities and significantly better at specifying expert problems, identifying relevant aspects of the case to apply, and using the case to understand the context in which the risks/problems arose.

Table 1. Performance Assessment Results for Part 1 - Interpretation

Coding Characteristic (**bold** denotes significant difference, $p<0.05$)	Software group	Standard Dev. (software group	Non-Software group	Standard Dev. (non-software group)
Recognizes that the case should be used to solve the challenge	**3.88**	**0.25**	**2.66**	**0.71**
Makes direct reference to the case to justify an argument or position	3.135	0.25	2.33	0.82
Able to identify expert problems	**3.00**	**0.00**	**2.42**	**0.61**
Able to identify expert "mistakes"	2.63	0.75	2.00	1.17
Able to identify relevant aspects of the case that can be applied to the challenge	**3.88**	**0.25**	**1.83**	**0.98**
Identifies risks based on prior experience with another LBD/software case	1.88	1.44	1.33	0.41
Able to identify criteria and constraints	3.38	1.11	1.58	0.66
Uses the case to understand the context of the risks	**2.88**	**0.25**	**1.67**	**0.61**
Identifies rules of thumb	1.00	0.00	1.00	0.00

Software groups tended to describe expert problems on a finer-grained level than non-software groups

(3.00 vs. 2.42, p<0.05). For example, non-software groups identified "sand" as a risk, while software groups identified the "incompatibility of the old sand and the beach with the new sand dug when the channel was deepened" as a risk, or expert problem. In the case, there are a number of risks or problems that involve sand, so being able to distinguish between those problems is important.

Software groups tended to discuss whether a management method made sense for their challenge, analyzing how the management method would play out in their challenge and questioning each other about the feasibility of a proposed management method (3.88 vs. 1.83). Non-software groups tended to discuss management methods only if they were different from what they expected.

Software groups tended to use the case not only to identify the problems the experts encountered, but also to understand the context in which those problems arose (2.88 vs. 1.67, p<0.05). They sought to understand what was happening in the environment that caused the problems to occur or to grow worse. Non-software groups tended to look for keywords that they were familiar with when identifying problems and management methods. For example, while flipping through the case, one non-software student declared , "Oh!! I see erosion here—erosion is a problem." In a similar incident in which one software group member stated that erosion was a problem, another member of that group declared, "but it says here that the problem is the shoreline eroding." This discussion resulted in the software group providing more detail about the erosion problem. In addition, for interpretation, we looked specifically at how well software students used evidence (the case) to justify a claim, and found that software students tended to do a better job than non-software students.

Table 2. Performance Assessment Results for Part 2 – Application and Assessment

Coding Characteristic (**bold** denotes significant difference, p<0.05)	Software group	Stadard Dev. (software group)	Non-Software group	Standard Dev. (non-software group)
Identifies issues or problems not explicitly stated in the case	2.88	0.25	2.00	1.02
Able to identify relevant aspects that can be applied to the challenge	2.50	1.08	1.67	1.03
Suggests incorporating a solution found in the case	2.50	0.58	1.92	0.92
Notices that a management method used by the experts cannot be applied as is but must be adapted	1.63	0.58	2.08	0.88
Notices that a solution used by the experts cannot be applied as is but must be adapted	2.38	0.95	2.33	0.68
Justifies use, modification, or abandonment of an expert solution based on criteria and constraints of group's challenge	2.75	0.25	2.25	0.76
Applies a solution used by the experts directly to their challenge	1.75	1.03	1.33	0.82
Suggests that an expert solution should be abandoned	1.25	0.50	1.25	0.61
Applies the case to the challenge using rules of thumb	1.00	0.00	1.00	0.00

For the video-recorded data for Part 2, application and assessment, reliability was 86% and results show trends toward better performance by software groups on several dimensions. First, software groups tended to suggest that a solution from the case would be good to incorporate into their challenge solution (2.50 vs. 1.92). This seems to result from the fact that software groups tended to refer back to the risks and solutions they identified in the expert case in Part 1. They would discuss those solutions to figure out whether they made sense to use in their challenge solution.

Second, software groups tended to justify the use, modification, or abandonment of an expert solution based on the criteria and constraints of the group's challenge (2.75 vs. 2.25). For example, one software group member suggested that the group build a sea wall out of an expensive material. His fellow group member pointed out that that particular material would be very expensive and given that they only had 2 million dollars to work with, they should consider another material. Few non-software groups even mentioned criteria and constraints when deciding whether an expert solution or management method should be used. Again, justification of a claim using evidence was analyzed directly and software groups showed better performance than non-software groups.

Discussion

The goals of this paper are two-fold: (1) to show that through repeated use of scaffolding that supports case interpretation and application students do indeed become better users of cases and (2) to point out the connection between interpretation and application of expert cases and scientific reasoning. The first is shown in the data that has been reported. The second can be seen by connecting what students did while interpreting and applying cases to scientific reasoning.

It seems that using evidence to support a claim and explaining scientific phenomena is important in both case application and scientific reasoning, while analysis of the data suggests that certain case application skills (i.e. understanding the context of problems, understanding criteria/ constraints, identifying relevant aspects of the case to apply) may be important in generating hypotheses and making predictions. For example, understanding the connection between addressing criteria/constraints and the outcomes that result seems to involve the same reasoning as generating a hypothesis and analyzing the results to determine whether the hypothesis is supported or rejected. This seems to suggest several things:

1. Understanding how to better support case application may lead to understanding how to better support certain scientific reasoning skills.
2. Students can be supported in case application despite its complexity, and students can improve case application skills. As such, support that leads to improvement in case application skills may also lead to improvement in certain scientific reasoning skills.
3. Using a cognitive apprenticeship framework and distributing scaffolding responsibilities across teacher and software seems to be effective at supporting case application skills that seem to be connected to certain scientific reasoning skills. As such, this same approach may be useful in supporting other scientific reasoning skills.

To make these suggestions stronger or to make stronger claims about the connection between case application and certain scientific reasoning skills, the data would need to be coded using dimensions to describe more specifically what is happening with students' scientific reasoning skills as their case application skills are improving. Though this was not the focus of this study, the trends that emerged and the suggestions that arose certainly suggest that this connection between case application and scientific reasoning is worthy of further exploration.

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