Articulating Lessons Learned: Scaffolding and Collaboration for Summative Reflection

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ABSTRACT

An important goal of project-based and problem-based learning is that students learn concepts and skills well enough from their experiences that they are able to transfer them to new situations as appropriate. Both the transfer and case-based reasoning literatures give us clues as to how to promote such learning. Neither literature, however, provides guidelines on how to encourage students to look back over a long-term project experience to extract what's been learned in productive ways. We report here on our attempts to do that. Several years ago, using guidelines from the case-based reasoning literature, we attempted to design a computer system that would scaffold such reflection (Shabo et al., 1997). We report here on the series of investigations and modifications to the software we've done since then to understand the sequencing of reflective activities, the scaffolding, and the role of collaboration that would encourage students to reflect back on a long-term project experience and interpret it in ways that the literature tells us will promote productive remembering and reuse.

Keywords

Scaffolding, reflection, lessons learned, Learning by Design™, case based learning, case based reasoning, problem based learning, project-based learning, middle school, science education.

INTRODUCTION

An important goal of project-based and problem-based learning is that students learn concepts and skills well enough from their problem-solving experiences that they are able to transfer them to new situations as appropriate. Both the transfer and case-based reasoning literatures give us clues as to how to promote such learning. The transfer literature (see, e.g., Bransford et al., 1999) tells us about the variety of experiences with a concept or skill learners need to have to learn it well and ways to encourage them to notice commonalities across experiences. The case-based reasoning literature (e.g., Kolodner, 1993, 1997, Schank, 1982) informs on the kinds of interpretations of personal experiences that can turn them into easily accessible and productively reusable cases in memory. A variety of project-based and problem-based approaches have taken some or all of these lessons into account, and their results show significant deep learning (e.g., Anchored Instruction (Barron et al., 1998), KIE and WISE (Bell et al., 1995), Learning by Design™ (Kolodner et al., 1998)). In general, the trend has been to interleave the right kinds of reflection and abstraction with modeling, construction, and reasoning activities so that students can extract out what they are learning from individual parts of their project work and apply what they are learning in new settings.

But an area that has not gotten much attention is the role summative reflection plays in promoting deep and transferable learning. The case-based reasoning literature (see, e.g., Kolodner, 1993, Schank, 1982) tells us that while interpretation of the pieces of a large-scale experience will promote learning of the small-scale skills and conceptions needed to carry it out, only interpretation over the entire long-term experience will result in recognizing how those skills can be used strategically in the context of each other. That literature tells us, as well, that we can expect better long-term learning to the extent that we interpret our experiences from a larger variety of perspectives. And our own intuitions and experiences tell us that revisiting our experiences after the fact and from a perspective that is a bit removed from the recent doing of a skill or using of a concept results in new insights. Thus, there is reason to believe that promoting the right kinds of summative reflection over a long-term project experience is an important complement to the reflection and interpretation that happen while the project is being carried out.

But neither literature provides guidelines on how to encourage students to look back over a long-term project experience to extract what's been learned in productive ways. We report here on our attempts to do that. Several years ago, using guidelines from the case-based reasoning literature, we made our first attempt to design a computer system that would scaffold such reflection (Shabo et al., 1997). We scaffolded students as they retold the story of their project experience. But the scaffolding we designed at that time was insufficient. We report here on the series of investigations and modifications to the software we've done since then to understand the sequencing of reflective activities, specifics of the scaffolding, and the role of collaboration that encourages students to reflect back on a long-term project experience and interpret it in ways that the literature tells us will promote remembering and reuse.

We set the stage by presenting the background and influences of our work. We then segue into an elaboration of the many design iterations and classroom evaluations of our new ***Lessons Learned*** Tool. Important to promoting productive summative reflection, we've found, are three things. (1) One cannot expect learners to be able to simply list out what they've learned. (Our memories, after all, are not set up very well for free recall.) Rather, one needs to help learners to reconstruct their experiences, and recall what they've learned in the context of that reconstruction. We've learned much about how to scaffold that reconstruction effectively (2) Affect seems to play a large role in the encoding and reconstruction of experiences. The best way to use affect as a cue seems to be to use it to help jog their memories in parallel with other scaffolding to help them reconstruct the technicalities of an episode. (3) While much project work is group activity, it is important for individuals to be able to articulate what they have learned and to be prepared to transfer what they are learning to new situations. A productive way to do that is to have the group work together to reconstruct the experience and articulate what they've learned and then to have each group member proceed from there with their own individual reflections.

We present the set of investigations that led us to these conclusions. In each, we have been concerned with providing the prompting that will allow a group of students who have been working together to summarize their experience together, identify (and argue over) the most important components of their experience, and articulate what they've learned and how it might be useful in the future. The scaffolding we've been designing is intended to, first, help a group work together to collectively reconstruct their project experience and come to a shared understanding of what they've learned, and then help individuals write up their own learning in more detail.

BACKGROUND

The Transfer and Case-Based Reasoning Literatures

Transfer means being able to extend what has been learned in one context to new contexts. We all naturally engage in transfer from day to day, transferring our common sense across situations we encounter. But achieving transfer among students in classrooms has proven to be quite a bit more difficult (Bransford, et al., 1999). Transfer requires, first, deep understanding of the domain being transferred. In addition, students need to experience a variety of contexts of use of what they are learning to allow them to transfer flexibly; they need to be encouraged to construct the kinds of representations that will allow easy recognition of similarity across contexts and application of what's been learned; they need practice with transfer, including graded hinting (scaffolding) along the way; and they need to understand the processes involved in making analogies between situations.

The computational models of cognition that come out of case-based reasoning (Kolodner, 1993, 1997; Schank, 1982) provide hypotheses consistent with the transfer literature and make suggestions about promoting deep understanding, learning, and transfer – among them the role of feedback, explanation, and iteration; the kinds of interpretations of experiences that lead to efficient access; the kinds of interpretations of experiences that lead to effective reuse and application of what has been learned; and the variety of experiences needed to learn applicability. (1) A reasoner that intentionally interprets its experiences to extract the lessons they teach and to anticipate the kinds of situations in which those lessons might be useful encodes its experiences in memory in ways that make them accessible in a variety of situations. The better the analysis of an experience, the better the interpretation and encoding, the better the later access, the better the learning. (2) Failure can serve to focus a reasoner on what it needs to learn. Failure at applying an old case in a new situation triggers a need for explanation that might result in reinterpreting old situations and/or discovering new kinds of interpretations. (3) A reasoner that is connected to the world will be able to judge the goodness of its predictions, recognize its successes and failures, and evaluate its solutions with respect to what results from them, allowing encoding that discriminates usability of what it is learning and allowing good judgments about later reuse. (4) A single experience may hold affordances for learning many different things; learners will learn those that they focus on. (5) Fluidity in carrying out the processes involved in case-based reasoning allows for more productive reasoning.

Project-Based Inquiry Learning

These suggestions are all in line with a project-based inquiry approach to learning (e.g., Barron et al., 1998; Blumenfeld et al., 1991; Edelson et al., 1999). In project-based inquiry learning, students investigate scientific content and learn science practices in the context of attempting to address challenges in the world around them. Early activities introducing them to the challenge help them to generate issues that need to be investigated, making inquiry a student-driven endeavor. Students investigate as scientists would, through observations, designing and running experiments, designing, building, and running models, reading written material, and so on. Assessments are built in as a natural part of what they are doing. Students publicly exhibit what they have learned along with their solutions. The history of project-based approaches shows that when the approach is carried out by masterful teachers who engage the students well in reflection, both science content and practices are learned (CGTV, 1997).

CBR can inform about adding specificity to project-based learning's practices (Hmelo et al., 2000), suggesting that the best challenges will be those that afford iteratively moving towards a solution and timely and easily interpretable feedback will be most conducive to learning for transfer and providing specific guidance about the kinds of reflection students should be doing in order to learn for transfer.

Learning by Design™

Learning by Design (LBD) (Kolodner et al., 1998; Hmelo et al., 2000), an approach to project-based inquiry science developed in our lab, adopts all of these suggestions. LBD's approach combines what the science education community suggests about promoting good science understanding (e.g., Mintzes et al., 1998) with what the cognitive science and learning sciences communities suggest about transfer and with what the community of practice suggests about good classroom practice (e.g., PBL, Barrows, 1985). In LBD, a design challenge serves as a context for motivating a need to learn targeted science content, for focusing inquiry and investigation, and for application of what is being learned. For example, to learn about motion and forces, students are challenged to design and construct a miniature vehicle and its propulsion system that can traverse a hilly test track. Construction of a working artifact provides students with a context not only for applying what they are learning but also for gaining timely and interpretable feedback about their conceptions. An important innovation of LBD is the focus on the iterative nature of both design and science. In the real world, designers develop and test several versions of an artifact, and scientists run pilot experiments to refine methodology. In the LBD classroom, students design, build, and test one version, then articulate what they have learned from this version, try to explain why it doesn't behave exactly as expected, identify new concepts and skills they need to learn, engage in activities that will result in that learning, and then use the acquired knowledge to construct a second, third, and sometimes fourth implementation of their design. When implemented well, as learners iteratively make their designs better in this way, they also iteratively debug and refine their scientific conceptions and their ability to participate in scientific endeavors. To facilitate learning concepts and practices in ways that promote reuse, doing is interleaved richly with a variety of opportunities for reflection and articulation within a highly-orchestrated cycle of activities.

CBR's suggestions about promoting transfer are woven into the fabric of LBD orchestration. Paper-and-pencil scaffolding (in Design Diaries (Puntambekar et al., 1998)) and on-line scaffolding (in ***SMILE***, (Kolodner & Nagel, 1999; Nagel & Kolodner, 1999)) help students interpret their experiences so as to make connections between their goals, plans, actions and results. We motivate students to do a good job of interpretation by making public presentation of their experiences, results, and ideas an integral part of the classroom culture and by orchestrating activities so that students, in general, need each others' results to succeed in their own design work. As well, students come to learn that, if they make an easily understandable presentation, then they can depend on their classmates to help them with quandaries – explaining what happened, making suggestions about how to proceed, and so on. In the discussion that follows public presentations, the teacher helps students extract commonalities from across the reports they've heard and to anticipate when those things they are noticing might be useful later.

Software Support for Collaborative Reflection

There have been several attempts at writing software for promoting reflection appropriate to transfer in project-based inquiry classrooms. The Schools for Thought project (CTGV, 1997; Barron et al., 1998), for example, uses ***CSILE*** (Scardamalia & Bereiter, 1996) to help students take part in knowledge building discussions in support of the problem-based and project-based investigations. Schools for Thought, in addition, uses broadcast media to support students across several schools in achieving transfer tasks together (SMART Challenges). KIE and WISE (Bell et al., 1995) help students interact with each other as CSILE does and, in addition, provide scaffolding to help students put logical arguments together from evidence. All of these have been shown to help students learn more deeply. SMART Challenges' broadcast approach helps to engage students in applying what they have learned, and ***CSILE***, KIE, and WISE all help students to share ideas with each other in coherent ways and to engage with each other as they try to understand the implications of what they are learning. The ***Collaboratory Notebook*** (Edelson et al., 1999) takes these things a step farther by anchoring discussions to particular issues that arise during an investigation or project. KIE's and WISE's ***SenseMaker*** helps students use what they are learning well.

Our own approach to software support focuses specifically on encouraging student groups to work together to interpret their experiences in ways that will lead to them making the kinds of connections that case-based reasoning predicts are important to promoting transfer, namely connecting goals, plans, actions, and results and extracting what is special about the situation. ***SMILE***'s three kinds of ***Design Discussions*** (Nagel & Kolodner, 1999), for example, prompt students to write up their experiences while in the midst of the design process. ***Design Discussions*** provides prompts aimed at helping students make these connections and explain their results as they prepare to report on their experimental results, project ideas, and project experiences. We've found, in that investigation, that using the tool to prepare for in-class presentations and discussions resulted in attention to more sophisticated issues than when students prepared for presentations without the tool. Students were indeed motivated to use the tool and write up detailed reports for two reasons: (1) They saw that it resulted in their being able to make better presentations and (2) they liked being able to publish their reports and to use their own and each others' reports later on in the project. ***Design Discussions*** seems to have done a nice job of reminding students to consider several things that they wouldn't have considered or might have done more shallowly without the prompting – justifying ideas, finding trends in data, explaining the behavior of devices they had built, and making predictions. To accomplish that, we found that we needed to understand each of the different contexts in which a design discussion would take place and the goals and needs of the students in each of those situations and make sure the scaffolding was specific to their reporting needs. In particular, the design discussion tools scaffold thinking about and reporting on scientific investigations, design ideas, and design-and-test experiences. We also found three kinds of scaffolding useful – structuring, prompting, and examples.

We've sought to find out if we can use the same kinds of scaffolding to get students to think back over a full project experience and to tease out and articulate what they've learned. We are interested not simply in the formulas and facts of science but rather their deep understanding behind the formulas and facts, what they've learned about carrying out the practices of scientists, and what they've learned about successful project work. Our hypothesis is that if we can get students to articulate these things at a time when they have a bit of distance from the work they've been doing (at the completion of a unit), and if we can get them to think about the import of those things they've learned and anticipate situations when they might apply those things, then we can lay the groundwork for transfer – helping them both to create the kinds of well-articulated cases in memory that make application of what they have learned from experience easy and to create the kinds of indexes that will make access productive.

EVOLUTION OF THE *LESSONS LEARNED* TOOL

We began our attempt to implement and test this hypothesis in 1996, with the design of ***JavaCAP*** (Shabo et al., 1997). In ***JavaCAP*** students began by describing their design problem and went on to describe the alternative solutions they came up with, why they choose the particular solution they chose, and what they learned overall. While students were able to articulate their design problem and describe their solutions, the scaffolding we provided for having them discuss what they had learned was quite limited. The open-ended prompting we provided led most students to write about the importance of research and the importance of the collaborative process, but our scaffolding was far too generic to support students in thinking deeply about the science they had used and its implications. ***JavaCAP*** student responses lacked technical kinds of details and specificity. In addition, the structuring we provided for students' descriptions of their various design solutions took a rather limited view of project work – it didn't give support for reporting on design iterations or their reasoning and decision-making.

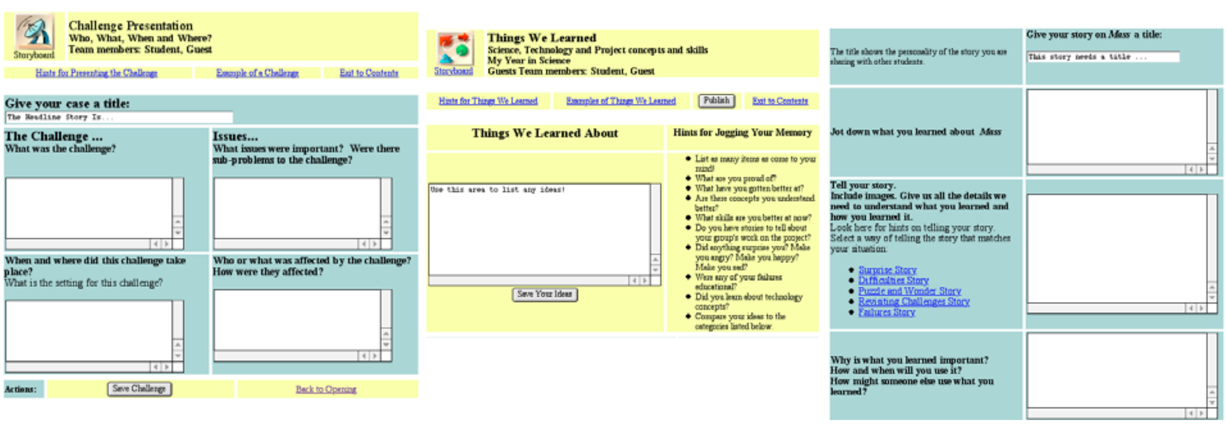
We halted the design of a lessons learned tool so that we could investigate better what it would take to get students to articulate their science understanding well. We thought we might have an easier time if we had students articulate technical details and science concepts while they were still engaged doing the project and using the science. Once we learned better how to do that, we would return to the lessons learned tool. Between 1997 and

1999, we put considerable time into the three ***Design Discussions*** tools (Kolodner & Nagel, 1999), learning the lessons discussed above.

We returned to the designing a lessons learned tool in 1999, this time calling it the ***StoryBoard Author*** (Nagel & Kolodner, 1999). There were a variety of design decisions we made in creating that version of the tool:

1. We would include it in a suite of tools that also included a library of write-ups done over the course of the project using ***Design Discussions***. Students would be able to look back at the design discussions they and their peers had authored – investigations and their results; project ideas and their justifications; and project trials, results, and explanations – and use them as resources as they were composing reconstructing their experiences and identifying what they had learned.
2. We would provide more structured and specifically-tailored prompting than we had in ***JavaCAP*** to help students put those experiences into perspective and extract out and write up what they had learned.
3. We would specifically prompt for reconstruction of their project experience in ways that would get at the details. We thought prompting according to affect would help (e.g., what were you proud of?).
4. We would provide the kinds of scaffolding found in the rest of ***SMILE*** – structuring, prompting, and examples – to help them write good stories about their project work.

Using ***Storyboard Author***, student teams were to write about (a) their challenge - their problem, important issues, the setting for the challenge, and who or what was affected by the challenge; (b) the solution - what the team decided to do, criteria for selecting the solution, alternative solutions, limitations of the solution, and favorable and unfavorable outcomes of the solution; and (c) what they learned – jotting down ideas of what they learned, then writing the specifics of what they had learned, and then writing up the story of how they had learned it, "giving us all the details we need to understand what you learned and how you learned it." The figures below show three screen shots from ***StoryBoard Author*** – the prompting for writing about their challenge, prompting for remembering what they had learned, and prompting for writing about what they had learned.



During its classroom pilot, thirty teams of LBD students used ***Storyboard Author***, but not exactly the way we had imagined. In particular, the teacher had the students go straight to its "lessons learned" section to write up what they had learned. The summarization sections, describing the challenge and design solution, remained unutilized. After jotting down notes about what they had learned (using prompting on the middle screen above), teams of students chose something to write about, articulated what they had learned, and then went on to write the story of how they had learned it (using prompting pointed to in the screen on the right).

Of the thirty pilot teams, only four jotted down notes about what they had learned before writing up what they had learned in more detail (we don't know why). The list below is typical.

> "We learned about inertia, and how it relates to the mass of an object. We also learned about friction, and the different types of friction. We also learned about buoyancy and how it relates to the volume of the water displaced by an object. We also learned about spaceships and we found that very interesting."

All teams wrote in some detail about what they had learned on the "lessons learned" pages (figure on the right above). Six teams wrote about project skills – collaboration or making decisions. Five teams wrote about science and technology strategies – controlling variables, running experiments, or presenting data. Seventeen teams wrote about science and technology concepts – energy (4), force (2), friction (2), gravity (2), inertia (1), Newton's first law (1), Newton's second law (2), Newton's third law (2), or weight (1).

All teams gave elaborated definitions of whatever they had chosen to write about, though not necessarily elaborate enough for someone else to understand. But they were confused about what it meant to write the story of how they had learned. Some teams provided a scene or set of scenes from their LBD experience. Other teams wrote stories of other times they had experienced the phenomena described. Some wrote fantasies, "Once upon a time, …" The two stories below are both about friction. The first is quite articulate and the kind of story we were looking for, but many stories were like the second.

> "When constructing our cars we had a balloon to power them. When we tested our car in the hall, it seemed to go a long distance. When we tested our car on the track, though, it stopped before going over the last hill. This is because there was more friction between the wheels and the track than with the wheels and the hard tile floor of the hall."

> "Once I was riding through the woods and I went over a hill as I was riding down the hill I notice that I was head into a creek. When I hit the brake I slid into the creek because the sand absorb the friction not letting me stop."

These were better first passes at stories than in ***JavaCAP***, but the students' writing didn't seem to convey that they understood the purpose of what they were writing – for someone else to learn from. Their accounts of their design experiences were missing context necessary for others to understand them, and none of what they wrote had particularly detailed scientific explanations.

Also quite interesting is the way the system was used. When students jotted down what they had learned, they wrote long lists, often using the word "we," as above. However, sixteen of the thirty stories they wrote were in first person singular – clearly written by an individual rather than the team.

We looked at the kinds of stories students had written. We had asked them to remember the more emotional design experiences in order to remember what they had learned and to provide scaffolding to help them. We had suggested that their stories might be about surprises, difficulties, puzzlement, and revisiting challenges, and failures. When we read their stories, however, they seemed to fall into a different set of emotionally-charged categories. Students wrote about situations when (a) their *curiosity* had been piqued, (b) they were utterly *frustrated*, (c) something about the situation caught them by *surprise*, or (d) they achieved something of which they were particularly *proud*.

Based on these results, we decided a new tool was in order. We had several goals:

1. We decided to work around use of the summary part of the tool and focus on the lessons learned portion, as this was the way teachers were having students use the tool.
2. We wanted to help students write more technically – to get the science into the articulation and to be more specific about what they had learned and how they had learned it.
3. We wanted to use affect better to help students remember and write. Emotion seemed to help them remember well, and we thought that if we used a better set of affective story-telling categories and good scaffolding to go with each, we could get them to articulate better-developed stories about their experiences.
4. We wanted to understand which writing and reflection could best be done in groups and which could best be done individually and to design the software tool with that in mind.

Lessons Learned has undergone a four major iterations between January 2000 and May 2001, aiming to achieve this set of four goals. Each of the first three iterations has been piloted with paper and pencil prototypes with middle-school science students from LBD classrooms. The data we collected was sometimes written by groups and sometimes by individuals. Our intention in designing the tools has always been that students would use it similarly to the way they use ***Design Discussions*** – they would gather around the tool in teams, using it to help them frame their thoughts, and as a team, they would compose a presentation of what they'd learned, including photos and drawings, to present orally to the class. After class discussion, they would make a second pass and perhaps even a third. Over the course of the iterations, individual students would write up their specific understandings of concepts and skills. We never had the luxury, however, of getting to a second pass. The data we've collected has been the students' first pass at articulating what they had learned. Also, the scaffolding we've been able to provide on paper has not been as complete as what we could provide on the computer. Our prototypes helped students structure their writing and provided hints (prompts) to help them know what to include, but we provided no examples. We have taken that into account in our formative evaluations.

Lessons Learned Tool: Iteration 1

The first thing we did was go back to the basics. We gave a group of students blank sheets of paper, removing almost all scaffolding, and asked them to write a story about something they had learned when they were particularly curious, frustrated, surprised, or proud. We wanted to find out how students told stories about emotional design experiences with very little interference on our part. What follows is a typical example:

> I walked into science class and the tables were dirty so I knew we were doing something fun in class. Our group gathered and Mr. Donaldson said we were going to make models of our courts. We tried lots of ideas and our differences in opinions made it frustrating. When we thought we were ready, Mr. Donaldson came and poured 2 liters of water on it. To my surprise, it worked.

Students had a difficult time drilling down into a specific situation in which they had learned something. Almost all of the students recounted a more holistic recap of the entire design challenge under the auspices of the particular emotion they felt most in tune with. We learned, primarily, that students needed help telling a *specific* story.

Lessons Learned Tool: Iteration 2

In this redesign, we began by asking teams of students to jot down ideas of things they had learned during the design process. Then, we asked each individual to select one thing they had learned to write a story about, and we provided them with prompting to help them organize their thoughts and make a good presentation.

We provided two kinds of prompting. The first kind was affective-based. We took a basic story structure of exposition, development, and conclusion, and we crafted story templates based on each of the four emotions. This was intended to help kids focus on telling an elaborated story of one specific event. For a story about surprises, for example, we prompted:

Exposition – The Story's Beginning
- Where were you?
- Who else was there?
- What had you just finished doing?
- How were you feeling before anything surprising happened?
- Were there any clues that something surprising was going to happen? Did you notice those clues at the time?

Development – The Story's Middle
- What were you doing when you were surprised?
- What was so surprising?
- Did you feel anything besides being surprised?

Conclusion – The Story's End
- How did you react to the surprise?
- How did other people react to the surprise?
- How did the surprise affect how you were working?
- How did the surprise affect what you were working on?

The second kind of scaffolding was intended to help students integrate science content into the story structure. This second dimension varied based on whether the student learned something about science concepts (e.g., Newton's third law), science methodology (e.g., controlling variables), or project practices (e.g., justifying design decisions). For a story about learning science methodology, for example, we prompted:

Exposition – The Story's Beginning
- What strategy were you using in the beginning of your work?
- Why were these strategies insufficient for what you were trying to do?
- What kinds of problems did using a poor approach cause?

Development – The Story's Middle
- What led you to try out these new science and technology skills?
- What science and technology skills did you learn?
- How did these new science and technology skills help with what you were working on?
- How were these new science and technology skills more effective than the ones you were using?

Conclusion – The Story's End
- What can you do now that you couldn't do before?
- Why is what you learned about the science skills important?
- How did learning about these science skills change the way you were working?
- How did these science skills change what you were working on?
- How and when will you use what you learned again?
- How might someone else use the skills you learned?

- What was difficult about these new science and technology skills?

We tried out two variations of this iteration in the classroom. The first had students use the sets of prompts in two passes. After jotting down things they had learned, in a first pass, they were to generate the story about how they had learned using the affective scaffolding, and then in the second pass, they were to add scientific details to the narrative. Unfortunately, the initial story generation took so long that students were not motivated to go back and rewrite their stories. Thus, in the second variation, both sets of prompts were provided at the same time. A typical student response follows:

> *Jot down things that you learned:*
>
> The tin-foil boat challenge, about how we got our boat to work and how we kept trying till it worked.
>
> *Story:*
>
> The day in science when we started the Key Relay I had a lot of fun. We read over the challenge then it was outside for us. I had a good group to work with, Beth, Mike, Joel, and me, we all worked well together. We built our boat out of tin foil and our first few boats failed. It was getting very frustrating. Then we used all our knowledge and built a boat that worked extremely well. We all had known what to do to make it work, we just had to find the best things and build them.
>
> I was very excited when my group got a boat to float successively. We had to try different ideas separately and eventually found the best ones and put them together. This helped me to see why everything happened and what caused what to happen. I learned that this way worked very well.
>
> When we finished, we were all very proud and impressed with ourselves. We all worked better and got along better once we figured out the challenge. Doing this experiment taught me to try one thing at a time because we had to test each idea individually. I might use these techniques again while doing another experiment. It was like trial and error process.

We learned how difficult it was for kids to remember what they had learned out of context. The students seemed to need to tell the big story before they could arrive at what they had learned and how they had learned it. Most students, as with the example above, were unable to jot down specifics of what they had learned. And instead of telling a specific story about the instance in which they had learned something in particular, students would tell the bigger story of their experience. In the example above, only after telling the big story was this student able to get at what her story should have been about, namely the science strategy of controlling variables. We also came to understand that affect was in many ways a false lead. Asking kids to write stories based on an emotion gave us more of the big picture than we had bargained for. The affect was generally a bit too effusive for the science content to show through. We realized that for students to remember and articulate what they had learned, they needed to have the opportunity to reconstruct their experience first, as we had aimed for in ***JavaCAP*** and ***StoryBoard Author***. We now had evidence about how important it is for students to be given a chance to reconstruct and articulate the important milestones in their project experience before moving on to articulating what they learned. We began to understand, as well, that while the idea of telling a story was a useful metaphor for us, to the children it meant something far different than what we were aiming for. We may have been misleading them with our story-based scaffolding.

Lessons Learned Tool: Iteration 3

In the third iteration, we re-immersed reflection about lessons learned back into the context of case authoring (i.e., writing a report that highlighted the milestones of the project experience), and we reconceptualized what it meant to tell a story about learning. Design experiences, which is what we want the students to reconstruct and tell their story about, don't always have the beginning, middle, and end. Sometimes, when a design is completely wrong, there is an extra beginning. Often, there are abundant iterations and a lot of middles to an experience. And in the best of experiences, the story doesn't so much end as spin off into another story. Thus, in this iteration, we moved away from the focus on storytelling, focusing instead on providing good scaffolding for helping students write technically about their design experience.

We decided to go back to the basic structure of ***StoryBoard Author***, but this time with organization and prompting more specific to their design experiences. Most importantly, we developed new scaffolding to help students articulate their most interesting design iterations – the ones that had given them the most insight into their final design. We asked them to choose their two most significant iterations and to describe the design decision they had tried out in each, what they expected to happen when the design was implemented (explained scientifically), what did happen (both positive and negative), their explanation of that (articulated scientifically), what they learned from it, and what else still needed to be done to get to success, providing hints about what to include in each section of their writeup. We also prompted them to write scientifically about the constraints and criteria of the challenge and their final design solution and how they came to decide it was the best. However, scaffolding for articulating scientifically was very weak – mostly in the form of reminders to "be scientific" in the paper-and-pencil tool we gave students. Our intention was to supplement that in the classroom with personal help.

Our intention in this iteration was that student teams would work together to reconstruct their experience and together remember what they had learned, then spend a bit of time talking together about what they had learned, and then individually (for homework), write about two things they had learned for someone else to learn from. Thus, in addition to the scaffolding we provided for groups, we gave each student a page with a list of topics they might have learned about and space to put a check mark or jot down notes to themselves as they were writing up their design experience with their team.

We also provided more specific scaffolding to help individual students write about what they had learned. We prompted them to describe what they learned (being as specific as possible and so that someone who didn't yet know could understand), then to describe the situation in which they learned it, another situation in which they had experienced this same phenomenon, why it might be important to someone else, and a situation in the future in which they might use what they had learned again. We dropped any pretense of story telling.

When we tried this out in the classroom, we found that students found it difficult to decide which of their iterations were most important. (Indeed, they had some trouble remembering their different iterations.) We noticed in this difficulty a promising niche for affective scaffolding. When we verbally prompted the groups to remember an iteration that had frustrated them, surprised them, or made them excited, they were quick to identify which iterations to write about. Using affective prompts to help students make decisions about what was important to write about also appeared to be helpful in the transition between teamwork – jotting down ideas of what was learned – and individual reflection – selecting something that was learned to write about.

Describing their experience scientifically remained the most difficult task for students. We went over with them in class what a scientific explanation is. They volunteered (in each of the six classes we worked with) that it uses science vocabulary correctly, that it refers to science laws, and that it explains. But they still had trouble making connections between the scientific principles (e.g., Newton's Second Law) and their own experiences. Several kinds of prompting helped. First, we found that if we suggested the scientific law that might be applicable, then they could make connections between it and their experience. Next, if we simulated the law with them (e.g., suppose the force increases, but the mass is the same, what will happen?), we found that they could apply it. Finally, examples of good scientific explanations to use as templates were helpful.

We were successful, in this iteration of the scaffolding, at getting students to remember their experience and to remember and articulate some of the science content and methodology they had learned. However, they were not good at separating out the science they had learned from its context of use in their project work. The two responses below were most typical. Students wrote about a scientific concept in the context of their project experience, sometimes using science to explain accurately and sometimes not, but typically not showing an ability to abstract the science concept away from the project experience.

> "I learned about mass while testing our cars. Having too much mass would make the car unable to move, but if you balance out the weight of your car, then the car would be able to move."

> "One of the things I learned was, friction can help and hinder when it comes to a car. Friction puts a grip between the wheels and ground, but it also slows your car with the wheel and axle.

A few students provided abstract descriptions of the science they had learned, sometimes accurate and sometimes not.

> "I learned about gravity. Gravity is the force that pulls down the object on the earth. This is why every object stays on the earth. If my car goes down the hill, it goes faster because of gravity."

In our next iteration, we are working on upgrading the "lessons learned" page of the tool to provide more help with abstracting out scientific concepts from experiences. But we also believe that the inability of students to write a scientific explanation cannot be solved completely with our scaffolding tool. The best explainers, we've found, are those whose teachers have consistently modeled scientific explanation, helped students recognize good scientific explanations, expected scientific explanations from the students, and helped them over and over again to turn their naïve descriptions into scientific ones. In addition to refining the scaffolding in our software, we will also be helping teachers learn these skills better.

Lessons Learned Tool: Iteration 4

Based on the analysis above, we are designing a fourth iteration, to be piloted in software during Fall, 2001. The software will be integrated into our ***SMILE*** suite of tools. As they are reconstructing their project experiences, students will have available to them the writeups of their design iterations and investigative results articulated using ***Design Discussions***. We call this new tool ***Lessons Learned***, and it includes in it all of the components of Iteration 3. We are adding to better scaffolding to help with scientific explanation, taking into account the help we gave students in the classroom and we are using affective memory cuing to help students decide which iterations to write about. To help them connect together but differentiate design experiences from science principles used, we are providing students with a more structured way of summarizing their final product – by asking them to fill in a table such as the one below, designating the component parts of their design solutions and what guided them in making decisions about how to implement each. By helping them organize their thoughts better in this way, we hope to be able to aim them towards better identifying what they had learned and to make the job of scaffolding scientific explanation and descriptions of what they had learned easier. We will be able to refer, in our scaffolding, to what they have written in particular boxes of the chart.

Part of the Car	Kind(s) You Chose	Why You Chose	Scientific Principles Guiding Choice
Propulsion system	Ramp and rubber band	The balloon system required too much extra mass. The ramp increased the potential energy without adding mass. The rubber band system could be augmented to add more force without adding much more mass.	Mass, force, potential energy
Wheel	CD	The CD had less surface area than the wooden wheel so there was less friction. Plus, the CD had a larger circumference so each rotation would make the car go farther.	Friction, surface area, circumference, distance
Etc …	Etc …	Etc …	Etc …

Table 1: Sample discussion of a final design for a challenge in which the students had to design a car using multiple propulsion systems.

We will also modify the orchestration somewhat. We will ask teams to work together to reconstruct or re-iterate their design experience and to identify, as a team, what they have learned. After they write this up on the computer, we will ask them to present to the class. Only after group work and class presentation and discussion that follows will we ask individuals to write up what they have learned.

CONCLUSIONS AND LINGERING PROBLEMS

Three guidelines fall out of our work so far. (1) To identify what they have learned, students need to first reconstruct their project experience. Structuring the scaffolding for that around the project solution and their reasoning in getting to that solution is a productive way of doing that. (2) Cueing recall using affective cues works best for helping students remember specifics of something bigger they have already been thinking about. (3) Software scaffolding aimed at groups working together can help focus their discussions while also preparing individuals for individual work. We don't know for sure, but we are hoping that providing the same scaffolding to individuals that they had while working in their groups will provide additional memory jogging.

We are closer than when we started at getting the students to become aware of what they've learned and to think ahead to when it might be useful, but we are clearly not done. Some of our more elusive design frustrations include finding ways to help students think critically but constructively about the negative aspects of a project, imagine authentic and realistic future use scenarios, describe their experiences scientifically, and get to specificity. And we still have to give more attention to helping them reflect on and write up their practices in productive ways. Our hopes are that we can indeed get middle school students to articulate what they have learned articulately and that we will see effects in their learning as a result of their engaging in that endeavor. But, we know, too, that aiming towards good transfer is not something we can do simply with a computer tool or even with a tool plus a good curriculum. We also need to engage teachers in the kinds of modeling and facilitation that engages students consistently in reasoning conducive to transfer and in attempts to transfer. We are continuing our work in both arenas – designing better software-realized scaffolding and discovering and helping teachers learn those practices.

ACKNOWLEDGMENTS

This work was supported in part by the McDonnell Foundation, the BellSouth Foundation, and the National Science Foundation.

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