

Inquiry through Design: Situating and supporting inquiry through design projects in high school science classrooms

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Abstract

This paper describes a model for supporting scientific inquiry situated within a technological design context. This model was the basis for the design of several modules intended for use in high school science classrooms. A study of the classroom use of one module examined the degree to which the module allowed students to engage in the processes of inquiry. Results based on classroom observations, videotape analyses, and interviews with students and teachers, describe how students actively engaged in inquiry processes, including defining the problem they studied, exploring multiple approaches to solving the problem, and using data to justify the effectiveness of their designs.

Introduction

Recent reports have stressed the importance of engaging students in scientific inquiry (AAAS, 1990; NRC, 1996). Inquiry—the process of generating questions for study, designing and implementing scientific investigations to pursue these questions, reflecting on the implications of the results of these investigations, and communicating these results to others—is proposed as a more authentic and more effective learning context for scientific principles (Linn, diSessa, Pea, & Songer, 1994).

However, it is difficult to cultivate inquiry with textbooks and prewritten lab exercises, which typically create the expectation of a single appropriate method and correct answer for each problem. The relative lack of inquiry-based activities, even in curricula claiming an inquiry approach, has been well documented. Particularly lacking are opportunities for students to investigate questions of their own or to develop their own method for testing a hypothesis (Pizzini, Shepardson, & Abell, 1991) and opportunities to develop scientific argumentation skills: the ability to link scientific data to conclusions (Kuhn, 1993).

Even with this recent interest in inquiry-oriented activities, there remain a number of obstacles to enacting inquiry in the classroom. First, students differ dramatically in their success in learning through inquiry. Students who come to the task with more sophisticated prior knowledge and with more effective hypothesis generation, experimentation, and data organization skills learn more from their experimentation (Klahr, Dunbar, & Fay, 1990; Schauble, Glaser, Raghavan, & Reiner, 1991a). Further, students need specific support to successfully engage in inquiry (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1992). Much of that support is dependent on instructional practice: how the teacher guides students to engage in the processes of inquiry.

Situating inquiry within a design context

One promising approach to incorporating inquiry into high school science classrooms lies in situating authentic inquiry within a design context. Engineering design tasks provide an opportunity to apply scientific understanding to produce a tangible artifact. This approach emphasizes the utility of knowledge and, in Perkins' (1986) words, "knowledge as constructed by human inquiry rather than knowledge as 'just there.'"

Design projects are a particular class of projects in which students propose, build and test an artifact to meet a specific need. A typical example is to design a scale model of a bridge that is as strong and light as possible. Design offers a rich context for inquiry and often prove very motivating to students. Design projects tend to be ill-structured and allow students to pursue any number of possible solutions. Artifacts are designed with concrete goals in mind, which focuses student inquiry and simplifies the process of evaluating how well a design performs. These tangible goals create a practical purpose for scientific understanding because students can apply what they learn to improve their designs (Perkins, 1986). And since design projects focus on solutions to real world problems, students may draw on their personal experience as well as their scientific understanding (Bucciarelli, 1994; Roth, 1996).

However, design projects have some obstacles that may interfere with student engagement in inquiry. Design projects inherently value the performance of the designed artifacts, and may bias students to focus on optimizing their design rather than investigating what affects the performance of their design (Roth, 1996; Schauble, Klopfer, & Raghavan, 1991b). Students who do focus on inquiry need guidance to be

able to explore these questions effectively; for example, to be able to thoughtfully reflect on their design and why it worked as it did.

In this paper, we describe our approach to supporting inquiry in the context of design projects, which we term *inquiry through design*. We report on a study of the use of one of these projects, the Composites Module, in two different high school classrooms. We explore how student engagement in inquiry is afforded by our approach. It is our contention that if presented with a design problem, framed in the manner we describe, students will engage in scientific inquiry. We also report on ways to encourage and help support student investigations. This support, a critical component of the curriculum as it is enacted in the classroom, derives from several sources, including the teacher, the written curriculum, and students themselves.

Inquiry through Design

Our approach to design projects has been to try to leverage the strengths of the design context—engaging students in motivating, ill-structured problems which they must figure out for themselves—while minimizing the potential conflicts between student goals of performance and explanation. Practically, this results in an approach where support for inquiry is threaded throughout the design task.

We term this approach *inquiry through design*. Students are expected to articulate and document their predictions in journals prior to constructing their designs, and to develop a method for determining the factors that contribute to the performance of their design. Time is set aside for reflection so that students spend more time thinking about why their design works, rather than focusing solely on making the design work better. A mandatory redesign cycle frees students from worrying about maximizing the performance of their first design. Instead, students can focus on understanding what affects their design's performance; they can apply this understanding to the later redesign. Finally, students are given opportunities to communicate their ideas and findings with other groups. Since groups share a common goal, but pursue it in different ways, each group may have unique information to share that others can adopt in their redesigns.

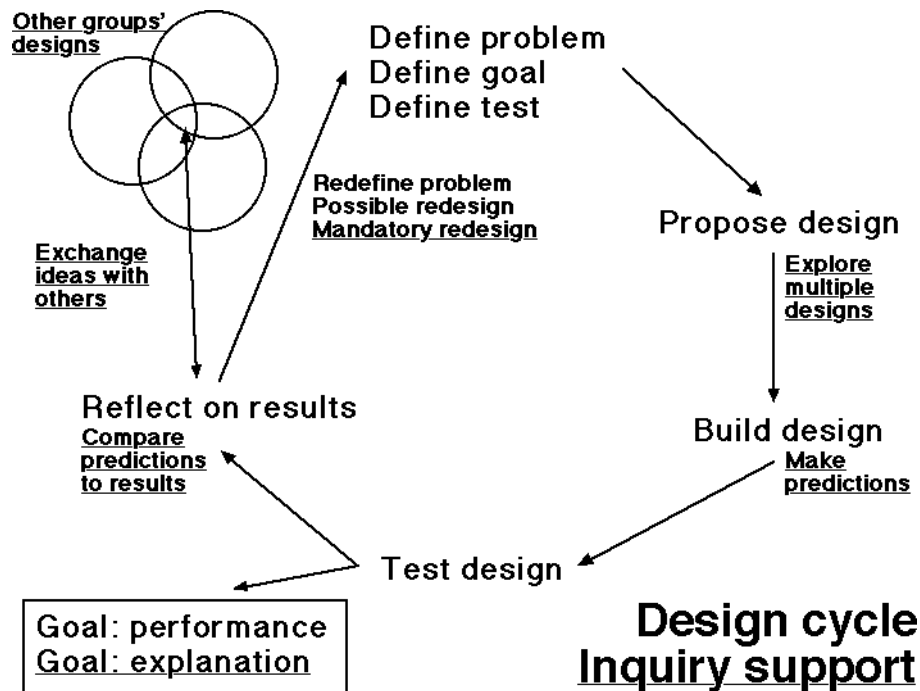


Figure 1. In Inquiry through Design, the basic design cycle has inquiry support, indicated by underlined text, threaded throughout the cycle.

The Composites Module

Several projects based on this model have been developed as part of the Materials World Modules (MWM) project¹. One module in particular, the Composites Module, has been used by more than thirty teachers in the Midwest over the past two years. Composites is a one to two week unit for use in high school science classrooms that focuses on the design implications of composite materials. The unit begins with several short activities that introduce students to composite materials and provide opportunities for students to think about how and why composite materials fulfill particular design criteria. After these initial activities, the bulk of the time in the unit is spent working on the design project. This project challenge is presented here.

¹ Materials World Modules (MWM) is a curriculum development project sponsored by the National Science Foundation. The mandate of the project is to create ten modules—one to two week supplemental curriculum units—for use in high school science classrooms. Each module focuses on a different aspect of materials science, such as composite materials, biodegradable materials, or sports materials, and consists of a series of introductory activities that culminate in a design project. More information about MWM can be found on the World Wide Web at <http://mwm.ms.nwu.edu/>.

“Catch More, a fishing supply company, is holding a contest for the design of a new fishing pole. The winning fishing pole will be made of a composite material. Enter the contest and take up the design challenge! Your group will be given a set of drinking straws to use as a base for your prototype design. With your group, you will design, construct, and test a set of prototype fishing poles; after you evaluate your design and have it critiqued by others, you will have an opportunity to redesign your fishing pole based on what you learned from working on your original design.”

Introduction to the design challenge.

The design project for composites is to build a prototype composite fishing pole based on a plastic drinking straw. By itself, the straw is fairly weak, although fairly flexible and light. Once students identify the properties they want a fishing pole to have and the means with which to test their designs, they design a set of three to five poles to test. Based on the results of these tests, students then enter the redesign phase, where they focus on the best performing design from the first round and apply what they learned about that design to make it better.

Structured journals, called design logs, highlight the inquiry support elements of the inquiry through design approach, prompting students to articulate their thinking, make predictions, and reflect on their designs’ performance.

The fishing pole project is one of two possible projects that the teacher could assign the students. The other, which neither of the teachers in this study chose, is an open-ended design project where each group of students selects their own artifact to build. (Past examples include models of dams, pole vaulting poles, sofa cushions, and baseballs.) In this project, even more emphasis is placed on the students’ ability to identify the desired properties of the artifact and determine how to test for these properties.

Design as a context for learning science

There are several characteristics of the design context that we expect can lead to scientific understanding. However, in typical design projects, these characteristics may not be present, or might require additional support if students are to be engaged in inquiry as well as the design task. The inquiry through design approach attempts to create a context in which these characteristics of design are supported, affording students the opportunity to engage in inquiry while pursuing a design task.

Here, we describe each characteristic of design which we expect can lead to scientific understanding, and the predicted aspect of inquiry that it affords.

Characteristic	Predicted affordance
Design projects connect science to the real world	Students are motivated to explore real world questions
Design projects are ill-structured	Students must define the problem and decide how to investigate the problem
Design project performance can be tested	Source of data for evidence-based reasoning
Design projects are iterative	Students must respond to emergent constraints and can apply knowledge to redesign
Design projects create shared understanding	Student groups pursue shared goal in different ways; differential expertise can be shared

Table 1. Characteristics of design and predicted inquiry elements afforded.

Design projects connect science to the real world

The products of design surround students all the time, outside of school as well as inside school. Whether they know it or not, students are aware that certain objects are built for certain purposes, and that those objects can some combination of properties that make them fit those purposes well. Design projects, which allow students to participate in the process of design, seem a natural link to students' real world knowledge and allow students to capitalize on their real world knowledge to improve their designs. Further, challenges based on real world problem can be very motivating for students, and lead them to explore questions and problems that they care about.

Design projects are ill-structured

Design projects leave many decisions up to the student. In addition to deciding what a design will look like, students must first identify what they want the design to do and how they will evaluate whether the design meets those goals. Students have the freedom to create several different designs, all of which work well; there is no single right answer upon which all designs converge.

Being able to define a problem to investigate, and then develop a method for exploring the problem, are two important aspects of scientific investigation (Beveridge, 1950; Jungck, 1991). Inquiry through design projects require students to address both of these skills: first as they operationally define the design challenge, and later as they make

design decisions and compare competing solutions. Our design challenges are intended to allow many different successful design paths.

An alternate design project, which was not used in any of the classes in this study, is an even more open-ended project in which each group of students chooses their own design challenge. We believe this “student-directed” design project provides even more opportunity for students to participate in the early stages of inquiry, as they must define for themselves the problem they will explore.

Design project performance can be tested

Many traditional design professions such as architecture have many different evaluative measures, both subjective and objective, for a given design. Often, designs will be proposed but not actually built and tested (Bucciarelli, 1994). This can make it difficult to measure the success of a design. Our approach has been to focus on design projects where students build and test their designs, producing data they can use as evidence for decisions and explanations. These evaluations, often in the form of tests that measure the design’s properties such as strength or weight, provide clear, quantifiable feedback that can be used to compare designs and determine how close the design is to meeting the specified goal.

Having clear evidence that can relate students’ current design performance to the goal may make it easier for students to monitor their own progress, traditionally a challenging part of problem-solving (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Shute, Glaser, & Raghavan, 1989). However, these tests measure performance, and do not directly evaluate student understanding. Further, students may conflate outstanding performance with conceptual understanding. We are very interested in exploring the degree to which students are successful at monitoring their progress through these tests.

Design projects are iterative

Design is by nature an iterative process. Providing time for redesign has several benefits. First, it gives students a chance to apply what they learned. This emphasizes the fact that the knowledge they are acquiring is valuable, and does not exist solely to be regurgitated on a test or a quiz. What they learn about their first design could also be of value to other groups within the classroom who are searching for proven ideas to use in their redesign.

Second, new constraints or properties may emerge as a result of the first design, which prompts changes in the way in which the design task is framed. A redesign gives students the opportunity to respond to these changes to create a design that better meets the original design challenge.

Our design projects include at least one formal redesign phase, where students get a chance to build another design that improves on their first design. In addition, students may iterate several times within the course of a single formal design phase, as they rapidly propose, evaluate, and reflect on different design approaches.

Design projects create shared understanding

Our design projects are intended to spur collaboration within student groups as well as between student groups. Because design projects allow students to productively pursue different solutions to the same problem, collaboration between groups may benefit all involved. All groups are pursuing the same challenge, and so have a shared base of knowledge and goals. But because different groups are pursuing different approaches, each group may have unique information that can inform other groups' designs. Students may know a lot about a particular approach but know very little about another. Engaging in cross-group collaboration allows students to share their expertise while gaining new ideas.

Method

This study explores the degree to which inquiry through design, as represented in the Composites Module, affords student engagement in scientific inquiry. Our analysis focuses on five dimensions of inquiry, which represent important aspects of inquiry as “problem posing, problem solving, and persuasion” (Jungck, 1991).

- Was understanding an explicit goal of students?
- Did students define the problems they investigated?
- Did students effectively explore the design space?
- Was student reasoning, including design decisions, explanations, and arguments, based on evidence?
- Did students communicate their findings to others?

Classroom setting

We observed two sophomore level chemistry classrooms that used the Composites module. Both schools were located in the metropolitan Chicago area. The classes were selected because they represented two different approaches to the use of the module, and we were interested in examining how variation in the classroom setting affected the use of the module.

One of these classrooms (EHS) was an honors level combined chemistry/physics class in a small Midwestern city. This class met every day for a double period (93 minutes) and students alternated going to physics one day and chemistry the next. The design project occurred only in the chemistry portion of the class, and took place within the first month of the academic year.

The other classroom (GHS) was a regular level chemistry class in a suburban high school outside of Chicago. Here, students met daily for 55 minutes, and the design project took place immediately prior to the holiday break in December.

None of these teachers were directly involved with the module development effort. Teacher E (of EHS) had never taught a module before, but attended a week long summer institute at Northwestern that focused on teaching approaches in the module. Teacher G (of GHS) had taught the module once before.

These teachers brought different approaches to the Composites Module. Teacher G ran the design project in roughly the manner described in the module, and used the module's design logs as journals for her students to track their progress through the project. Students submitted the design logs as their lab report, and also made presentations on the last day of class, showing their designs and explaining their performance. Student work was graded based on a rubric that another chemistry teachers in the school had developed for use with the module.

Teacher E left students free to keep their own journals, which would not be graded. Students used their results to write lab reports, which were turned in a few days after students finished their redesigns. These reports were assessed using a rubric for laboratory experiments developed by the ACT. Students also wrote a research paper that examined a composite material of the student's choosing; this activity was not directly related to the design project.

Data

A researcher observed all classes in which the module was taught. In addition to observation notes, we videotaped whole class discussions and small group work, focusing on one specific group, chosen by the teacher, in each classroom. (The teacher was requested to pick a group that was fairly representative of the class and likely to take the project seriously.) Students from the target group were interviewed following the module, and we held ongoing conversations with the teachers to document their perspective and what they saw as the benefits and obstacles of the module.

In both classrooms the researcher avoided taking a teaching role and generally offered suggestions about classroom practice only when asked by the teacher. We chose to adopt this more neutral stance because we were interested in seeing how teachers adopted the modules to fit their own practice, and how the factors of design that we felt afforded student inquiry would play out for both student and teacher.

Results

We examine student engagement in inquiry across five different aspects of inquiry, as described in the Method section. For each, we discuss the degree to which students were able to engage in inquiry.

Performance goals vs. understanding

Students participating in the Composites Module could adopt two possible goals for the design project. The first, related to design, is a goal of performance. Students who have this goal are focused on making their design perform as well as possible. In the case of the fishing pole design project, there were well-defined performance criteria students could use to evaluate their designs. Students agreed that the goal of the project was to make a strong, flexible, light model of a fishing pole, starting with a straw. Based on these criteria, a performance ratio² was used to evaluate each design for the fishing pole contest.

² Flexibility was measured by determining whether the design could flex 2 cm when subjected to a 200 gram force. If the design met this constraint, it was entered in the contest. Designs in the contest were compared by dividing the maximum load the design could hold by the mass of the design to determine the performance ratio. For example, suppose a design deflects 2.5 cm under 200 grams. It

The second goal, related to inquiry, is one of explanation or understanding. What elements of a design contribute to its success? Consider a simple design that consists of two bamboo skewers placed inside the straw and two layers of packing tape wrapped around the outside. Which elements contribute to the flexibility and strength of this design? A student engaged in this goal would be striving to improve his or her explanation of the design, rather than (or in conjunction with) improving the performance of the design.

The two goals of performance and understanding represent the fundamental tension between design and inquiry. One measure of student engagement in inquiry is therefore the degree to which students adopted the goal of trying to understand their design.

In general, students focused much more on performance goals than they did on understanding. The framing of the design project as a contest generated a great deal of competition in the classrooms, particularly among male students. Students wanted to win! Students tracked the best designs in the class, and often bragged about their designs, making comments like “We’ve got a winner here.”

Interestingly, this competition seemed to spring from the students, because students were not primarily graded on their design performance. Teacher G’s rubric, worth a total of 100 points (one test grade), devoted only 12 points to the design’s performance. Teacher E’s rubric for the lab report had no points devoted to design performance, although she did offer some extra credit to the best performing design in her three chem/phys classes.

Because students wanted to win the contest, they protected their ideas and tried to hide their designs from each other and even from the teacher. This atmosphere of competition made the pursuit of understanding difficult for two reasons. First, the pressure to produce a winning design focused students on immediate results. Second, there was no incentive to share design ideas, which might have prompted students to share explanations for why their designs worked.

Students were encouraged to generate explanations for their designs, but only after the redesign phase was complete. For example, students in Class G gave group

breaks at 1,500 grams and weighs 10 grams. Since the design deflected at least 2 cm at 200 grams, it is eligible for the contest. Its performance ratio (load over mass) is 150.

presentations following their final redesign, at which they described their designs and Teacher G prompted them to explain their designs' performance. Students in Class E explained their designs in their lab reports, in part because the rubric for these lab reports, which Teacher E handed out, emphasized understanding and explanation throughout.

It may be difficult to focus on explanations so late in the design process because students no longer have the opportunity to design experiments to test their explanations. Instead, they must try to fit their explanation to match existing data, which may not be detailed enough to allow students to distinguish between alternative explanations.

We originally had hoped that understanding would be adopted by students as an explicit goal. The evidence from these classrooms suggests even though students' grades were not dependent upon performance, the interest they had in the design challenge, and the competition the challenge engendered, led students to focus more on performance goals than understanding. When understanding was emphasized, it came at the end of the design process, too late for students to design experiments to produce data to support their explanations.

Students defined the problems they investigated

An important aspect of inquiry is being able to define, or pose, a problem that can be investigated. In the Composites module, students are presented with a problem, which is to design a strong, flexible, and light fishing pole. As stated, this problem is very abstract. To engage in design, students must frame this problem in more concrete terms.

We found that students had to redefine this problem in order to cope with new or modified constraints which arose from the design process itself. For example, strength was measured by loading a design until it failed, which was defined in any of three ways: the design could snap in two, as a piece of wood would; it could crimp, effectively compromising its strength, as a plain straw does when bent far enough; or it could permanently deform, like a coat hanger or paper clip might when bent. Several students discovered that their designs would not snap or deform, but crimped earlier than expected. This led students to focus on crimping almost as if it was a separate criteria aside from strength, and they developed particular techniques to prevent or disguise crimping, such as wrapping the straw with enough tape that the straw would not visibly crimp.

Students chose problems to pursue based on what they saw as the needs of their design. This essentially led to groups pursuing different design goals, even though the top level directive was the same: be strong, flexible, and light. For example, in Class E, one group focused their redesign efforts on reducing the weight of their design, while another chose to try to increase breaking strength, and a third group specifically redesigned their straw to prevent crimping.

While students were assigned a high level problem to investigate, each group had to redefine the problem based on what was important to them and on new constraints that emerged once students began testing different designs. The ability to cope with these changes in constraints and adapt the problem they were investigating showed that students were engaging in the inquiry process of framing questions for investigation.

Students effectively explored the design space

Design projects are by nature ill-structured, and so pose a challenge for students who engage in them. Problem-solving, in this context, consists of identifying and navigating through many possible designs, and making design decisions that eventually lead to a design that meets the target goals. One measure of how well students could participate in this problem-solving lies in how well they were able to navigate this design space.

Students in these two classes produced a wide array of designs, and did not converge on only one or two good designs by the end of the project. For example, students in Class E came up with designs that included sand, a fuel line from a car, yarn, cotton, a shoelace, chopsticks, rubber bands. Even materials which were used by several groups, such as pieces of coat hangers and duct tape, were incorporated into the designs in different ways.

Student redesigns were usually an improvement over their initial designs. This suggests that students were able to take advantage of what they learned about their design, as well as aspects of other groups' designs that they may have seen, and applied this knowledge to their redesign. Even in cases where redesigns were not superior to previous ones, students often built off what they had learned during an earlier design.

One interesting aspect of students' design exploration was that they used two distinct strategies to exploring the design space that mirrored approaches scientists use in the field. In the first design cycle, students often generated and tested several partial designs before settling on what would become their official "first" design. These early

designs were often tested qualitatively rather than taking the time for an official test. It seems like students were trying to audition several different designs to find a promising one, in which they would then invest more time.

This approach seems to correspond to a particular form of scientific investigation that Beveridge (1950) describes as “screening”, where several hypotheses are tested quickly, to confirm the plausibility of the approach before committing additional resources to the investigation. The experimenter is aware that the test are inexact and probably not reliable, but the results provide enough evidence in the experimenter’s mind to warrant expending time and effort on further investigation.

Once students settled on a particular approach, a more traditional method of scientific investigation was employed, where students explored the effects of different variations on a basic design to try to optimize its performance.

We were pleased to see students employing multiple strategies to navigate the design space, and the results indicate that students did indeed produce many varied designs, which indicated that they were capable of engaging in the level of problem solving necessary to succeed in the design task.

Students used evidence to support design decisions and explanations

A hallmark of scientific reasoning is the use of evidence. We examined the degree to which students made design decisions based on the results of past tests, and also the degree to which student explanations explicitly pointed to data.

Student design decisions were based on many factors, including their prior knowledge of how different materials behave in the world. Initial design decisions were often based on this knowledge, as students had not yet run any tests. Of greater interest is student decisions during the redesign, at which point they had not only their own results to work from, but the results of other groups as well.

Students’ decisions to adopt elements of other groups designs were mostly based on overall design performance, which is certainly a form of evidence. However, student explanations for the design’s performance tended to draw on the overall performance of the design, rather than focusing on how particular elements of the design contribute to its performance.

For example, in Class E, two groups were working on their redesign and began talking about a boy, Jim, from another class that had designed an outstanding pole. This discussion, prompted by Marla, led to speculation of what the different aspects of that design contributed to the whole. However, there was no evidence to suggest which of these aspects were causally related to the design's performance.

Marla: Do you guys know what Jim's was like?

Bill: He did something like this [refers to his design that incorporates the plastic shaft of a pen], but he threw like springboard stuff inside it so no matter how far it went down it would spring back up.

Mike: And he put so much tape on it they couldn't tell when it crimped.

Mel: They put on enough weight so that finally the spring broke.

Marla: That's a really good idea. that's really good.

Mike: That's so Jim.

Marla: But it's a good idea

[...]

Marla: OK, I need to tape. So I can't tell when it crimps.

In this case, Marla decided to adopt one aspect of Jim's design that she felt would contribute something to her own design: it would help prevent, or at least disguise, crimping. The overall performance of Jim's design seemed to convince her that the proposed explanation of why a lot of tape would prevent crimping made sense.

This example highlights a particular concern with student experimentation: that students are unwilling to design and perform experiments to confirm hypotheses they already believe to be true. In fact, it was rare to see students performing experiments to tease apart the causality behind their designs. They preferred to focus their efforts on improving their designs, and use the overall performance of the design as evidence to back up their explanation of the design. This pattern of student behavior is consistent with student adoption of performance goals over understanding.

A similar pattern of evidence use appears in student presentations and lab reports. In these settings, students are willing to offer data to support their argument for which of their designs was the best. However, their explanations for why this was the case often lacked specific evidence, and appealed to common sense. Here is an excerpt from Marla's lab report.

I learned that one straw inside of another creates four times as much strength as the straw would otherwise have. Therefore, I took five straws and put them all inside one another, as the force keeps adding itself (three straws equals 8 times as much, four straws is twelve, etc...). Then, I took a very thick, hard, plastic straw (the kind found on water bottles that athletes drink out of) and put my five straws inside that. This I felt would give it structure and strength, yet still maintain a certain amount of flexibility. Unfortunately, there was air space left, which I thought should be filled, in order to support the straw and also help it from crimping. I put some pipe cleaners in my thick straw in order to do this, while not sacrificing flexibility.

In the end, my pole was extremely heavy. It weighed 8.59g., which is huge for a fishing pole made out of a straw. However, I felt that if it could hold up a lot of weight, it could be worth it in the end. When my straw was tested, I had lots of trouble keeping the tack on, as it deflected a lot. At two Newtons, my pole deflected approximately 3 cm. It held up twenty Newtons beautifully, so I had to add another weight on. Although I'm positive that the inside straw crimped long before twenty Newtons, the outside straw held its structure and even after applying a lot of weight, it would gradually go back to its natural position. My straw was pulled all the way down to sixty Newtons, although it would probably have been disqualified early, solely on the basis of crimping. However, when left a certain amount of time, and not touched, the plastic straw will always go back to its natural, straight position.

There are at least two primary arguments Marla makes for the strength of her design: placing straws inside one another (something she said she had learned during a geometry project the year before), and the use of a thick, hard plastic straw on the outside. However, it's unclear which of these elements of her design contributed the performance. In this sense, student use of evidence could be improved; for example, by encouraging Marla to build and test two designs; one using the straws within straw argument, and another based on the thick straw design.

In addition to situations where students used evidence to improve design performance, there were also cases where students were pressed to use evidence to explain design performance. This happened when groups would challenge each other's results, based on an alternative explanation for how a design would perform. In these cases, evidence became the critical factor in resolving the arguments.

This particular argument surrounded the performance of Marla and Dave's group's best design, which was a straw, stuffed with several other straws, and surrounded by a larger, thicker straw of the sort found in sports drink containers. The design has performed very well, supporting up to 40 Newtons (roughly 4,000 grams). At this stage, the group is beginning to get some attention from other groups in the class, including Mike, Mel, and Bill.

Mike: That's cool. How many straws [inside your design]?

Marla: Six.

Mike: And tape on the outside? (Marla: Nope.) What's on the outside?

Marla: A plastic straw.

Dave: It's heavy, but she's already at 40 [Newtons], so her ratio's good.

Another student, watching: It's gotta be crimped on the inside.

Mel: It won't go up to original height. [One of the criteria for strength is that the design must return to its original shape once the weight is removed.]

Mike: Let's measure the original height. [To confirm Mel's challenge.]

Bill: The straw on the inside must have crimped. There's no way it couldn't have.

Marla: Then why is it back at its original height? [Points to data to defend her design.]

Mike: It's not. I bet you it's not. Do it again, and we'll see if it goes back to its original height.

In this exchange, Mike's group is challenging Marla's evidence in a specific way. They believe the design is in fact failing earlier than Marla and Dave have tested, and argue that their explanation, that the straws inside the design are crimping, will yield a specific kind of failure, a permanent deformation of the design.

Here, students are going beyond a simple reliance on data as justification for performance. They are beginning to propose ways of using the data to support specific explanations about designs, which is consistent with the use of evidence within the inquiry process.

One advantage to the design projects as structured was that the quantitative tests that students used provided solid data that could be used as evidence during arguments and to support explanations. However, tests of overall performance do not tease apart issues of causal function. Design projects like these may need additional support in order to prompt students to design experiments that will support explanations of causality.

Students communicated their results to others

Part of participating in a scientific community consists of communicating one's findings to peers. We hoped that because students were working toward the same goal but in different ways, they would be willing to exchange information about their designs.

In both classrooms, students had opportunity during the project to talk to other groups about design ideas. In Class G, students also made formal design presentations to each other at the end of the redesign.

The competitive nature of the project often inhibited casual communication between groups. When design findings were communicated during the design cycle, it was more the case that the findings were taken, rather than freely given. Groups made comments about “spying” on one another and, in some cases, guarded their designs from students and teachers. In this climate, design’s performance data was freely given (e.g. “this one holds 3,000 grams”) but the explanation behind the design, including the materials used, was reserved.

In spite of this, design ideas were disseminated through the classroom. Students were often actively looking for alternative designs. As we described earlier, students were willing to adopt aspects of other groups’ ideas based solely on overall performance, which was rarely concealed. And not all groups were so zealous about protecting their design. Teacher E partially addressed this issue by assigning testing witnesses to each group. The primary role of a witness was to attend and validate a group’s test results, and as a consequence, this witness often learned more about the group’s design than the group would have willingly divulged.

Students were more willing to share their explanations following the redesign phase. In Class G, students gave presentations of their designs at which they explained the decisions that led to their design and why they thought their design performed as it did. These presentations addressed one aspect of scientific inquiry in that students were sharing their results with their peers, and using evidence to support their explanations. However, by situating the presentations so late in the process, students were denied the opportunity to apply these explanations to improve their own designs.

Summary

The evidence from the two classrooms suggest that students were able to participate in aspects of scientific inquiry. Students were actively reframing the problem context and exploring varied solutions to the design challenge. Student drew on evidence from their design tests to support their explanations, although as was described, the evidence of the design’s performance often did not support students’ arguments for specific aspects of their design. Students explained their designs to their peers, although this generally

happened after the redesign, and students did not have the opportunity to apply other groups explanations for themselves.

One concern with both classrooms was the continued emphasis by the students on the performance of their designs, which was exacerbated by the competitive nature of the project. Since explanations were not valued until the end of the project (during presentations and lab reports), students did not engage in exploring causal elements of their design decisions. Questions in the design logs, which were focused on articulating explanations of how designs worked, were treated very superficially. Only when groups came into conflict, arguing about the success of a particular design, did backing up explanations with specific data become important.

Future work

Future research will address the tension between performance and understanding goals, and attempt to understand how to frame design projects in a way that emphasizes understanding and encourages more collaborative sharing between groups.

We are also interested in looking more closely at how students make decisions that affect their design, and how they view different kinds of evidence that could help them make these decisions. Understanding how students engage in this process will help us to redesign our design logs to better assist students in this task.

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