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ABSTRACT

This paper presents a set of reflective strategies for inquiry to help students in the process of learning science by conducting their own investigations. Reflective strategies are actions students can take to evaluate their progress and understanding as they conduct their investigations in order to be more systematic and effective. We also present a set of instructional supports intended to foster these strategies. These supports are embedded both in the design of learning environments and in teacher practices. We present a case example of students conducting an investigation as part of a unit on natural selection in a regular level introductory biology class at a Chicago public high school. These examples illustrate the use of these strategies by students. In particular, they demonstrate how in a collaborative context reflective strategies take the form of questions and suggestions posed between students. Analyses of strategy use and discussions reveal that more attention was focused on articulating a story about the specific episode that the students were investigating, and less attention was devoted to understanding how this episode is an instance of natural selection. Yet, extending students' understanding of natural selection is also an important learning goal. We conclude with a proposal for future designs to address this issue. (Author)

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Reflection as a Vehicle Toward Local and Global Understanding†

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ABSTRACT: This paper presents a set of reflective strategies for inquiry to help students in the process of learning science by conducting their own investigations. Reflective strategies are actions students can take to evaluate their progress and understanding as they conduct their investigations in order to be more systematic and effective. We also present a set of instructional supports intended to foster these strategies. These supports are embedded both in the design of learning environments and in teacher practices. We present a case example of students conducting an investigation as part of a unit on natural selection in a regular level introductory biology class at a Chicago public high school. These examples illustrate the use of these strategies by students. In particular, they demonstrate how in a collaborative context reflective strategies take the form of questions and suggestions posed between students. Analyses of strategy use and discussions reveal that more attention was focused on articulating a story about the specific episode that the students were investigating, and less attention was devoted to understanding how this episode is an instance of natural selection. Yet, extending students' understanding of natural selection is also an important learning goal. We conclude with a proposal for future designs to address this issue.

1. Introduction

A current area of research in science education reform centers on creating classrooms where students learn science by investigating and explaining natural phenomena. This type of learning can take many forms. One successful approach, which we refer to as guided discovery, has students work with simulation tools and other learning environments in order to derive scientific laws or theories (White, 1993). Another approach, which is the focus of this paper, engages students in the process of theory articulation (Ohlsson, 1992), where the inquiry serves as a means for extending students understanding of laws or theories by having students explain a situation in terms of a particular law or theory. In this approach students need to decide how the theory should be mapped onto the situation, and what it implies about the situation. Guided discovery and theory articulation reflect different but authentic scientific practices.

Learning through inquiry in general, and in a theory articulation approach in particular, can be challenging for students. Students need to be able to identify significant variables and the causal relations among them in order to understand and explain a natural event. Yet, there is a considerable body of research documenting students' difficulties in effectively accomplishing this process (Klahr, Dunbar, & Fay, 1990; Klayman & Ha, 1987; Schauble, Glaser, Duschl, Schulze, & John, 1995; Schauble, Glaser, Raghavan, & Reiner, 1991). For example, students often find it difficult to construct controlled comparisons, and to draw conclusions regarding hypotheses based on evidence (Schauble et al., 1995).

Encouraging and enabling students to perform reflective strategies can help overcome some of the problems and difficulties that many students encounter in conducting their own investigations (Davis, 1996, April; Loh, Radinsky, Reiser, Gomez, Edelson, & Russell, 1997). Reflective strategies (during inquiry) are a set of strategies that people employ while conducting inquiry to step back and evaluate their actions, progress and understanding in order to effectively construct causal explanations based on data (Hawkins, Mawby, & Ghitman, 1987).

We distinguish between reflective strategies and inquiry strategies. Inquiry strategies refer to any strategy that is part of, or facilitates the inquiry process, while reflective strategies are a subset of inquiry strategies that refer more specifically to strategies that involve evaluating or justifying progress or understanding. For example, documenting results is an important strategy for effective inquiry, but we do not consider this a reflective strategy. However, evaluating whether a particular result is worth noting, or articulating how particular notes can be used subsequently in the investigation would be considered reflective strategies because they involve evaluation. Reflective strategies can help students choose appropriate variables and comparisons, keep track of intermediate findings, and help them in the process of data synthesis. We are trying to identify specific actions that students can take that constitute reflective strategies, and a set of instructional supports to help students perform these actions.

In this paper we first present a set of reflective strategies for inquiry, and a set of instructional supports that are intended to foster these strategies. These instructional supports are part of a unit we designed for introductory high school biology classes in the context of the Biology Guided Inquiry Learning Environments (BGuILE) project, examining how to support students in the process of learning science through their own inquiry. Many of the instructional supports we describe are teaching practices that our collaborating teacher engaged in during this unit. Next, we illustrate these strategies in use through a case example of a group of students in the class. Finally, we examine how these students' patterns of strategy use can inform future design of instructional supports.

2. Supporting reflective strategies for inquiry

In our research in the BGuILE project we employ a theory articulation approach for supporting learning through student-directed inquiry in high school biology classes. We have designed a unit on evolution that combines a number of inquiry projects with existing classroom activities. In this section we first provide an overview of the design of the unit, and then present a list of reflective strategies that we are trying to foster in our intervention. The overview includes a description of the materials, software and curriculum we designed. We also describe the teaching practices of our collaborating teacher, which are a central and integral part of the intervention. Our strategy list describes the utility of each strategy, and the aspects of the design and teaching practices that are intended to scaffold students in the process of applying these strategies.

2.1 Overview of intervention

We designed a unit on evolution for introductory high school biology classes. In this unit we integrate a set of core investigation projects with a set of existing lab activities that illustrate particular concepts or principles of evolution. An example of an existing lab activity is a variation lab where students measure the lengths of their femurs and construct graphs showing the variation of femur lengths in the class. This activity is used to introduce the concept of existing variation in a population. In the investigation projects students are asked to investigate and explain a phenomenon relating to natural selection in the wild by generating and interpreting a set of realistic data. The final product of these investigations is a written explanation of the event with references to evidence derived from the data. Students conduct their investigation in learning environments (both paper and computer based) that include a set of supports to help students organize and manage the complexity of the available data, and the process of explanation construction.

2.1.1 Task structure

During their investigations, students work in collaborative groups of three to four students. These groups provide an opportunity for students to discuss investigation plans and data interpretations. Investigation sessions are interleaved with class discussions that are geared toward helping students reflect on their experiences, and engage in analysis and critique of investigation approaches and explanations. Through this task structure we hope to not only provide an opportunity for students to reflect on their process, but to communicate that these reflective activities are a valued and significant part of the task. This is in contrast to a task structure where students receive an assignment, complete it, and turn it in, placing the emphasis on the final product and slighting the intervening process.

The investigation activities progress from more structured to less structured environments, in which students have increasing autonomy over inquiry activities, such as defining the problem, raising hypotheses, identifying variables, planning an investigation, interpreting evidence and articulating a causal explanation. The goal is that the more structured activities scaffold students through their inquiry endeavors and provide opportunities for the teacher to model some of the skills, processes and strategies of productive inquiry.

2.1.2 The investigation projects

The Iguana Scenario

The Iguana Scenario is the first and more structured investigation project. In this problem students are asked to explain why subgroups in a population of Marine Iguanas forage at two different sites. The activity starts with the teacher leading the investigation, helping students formulate sub-questions and initial hypotheses, and begin to analyze relevant data. The activity continues with students completing the investigation in small groups. Students receive a packet of paper materials that include graphs showing morphological population data (e.g., snout length), more detailed profiles of individual iguanas, and field notes with behavioral descriptions of iguanas such as foraging behaviors.

The Finch Scenario

In this scenario students investigate microevolution in a computer-based learning environment depicting data from a Galapagos island ecosystem, based on a twenty year study of finches on the island Daphne Major (Grant, 1986). Students are asked to explain why some of the finches are surviving while others are dying during a crisis period in 1977, and the implications for future generations. The computer environment provides analytical tools that enable students to gather data, and facilities to help students interpret data and consolidate their explanations. Data requests are made through a question-based interface (see Figure 1). Students may take quantitative measurements of environmental factors (e.g., amount of rainfall), make comparisons of aggregate structural characteristics of the birds, such as differences in the beak length of live and dead birds in the dry season of 1977, and directly access profiles for individual birds through graphs generated from these comparisons. Profiles are cross-referenced to field notes showing behavioral descriptions of finches, such as descriptions of finches' foraging and mating behaviors (see Figure 2). The system includes a set of supports, we refer to as domain-specific strategic support, to help students construct informative and systematic comparisons, based on the types of conceptual approaches that biologists might take when reasoning through these types of problems. The details of the domain-specific strategic support design are described elsewhere (Tabak & Reiser, 1997; Tabak, Smith, Sandoval, & Reiser, 1996).

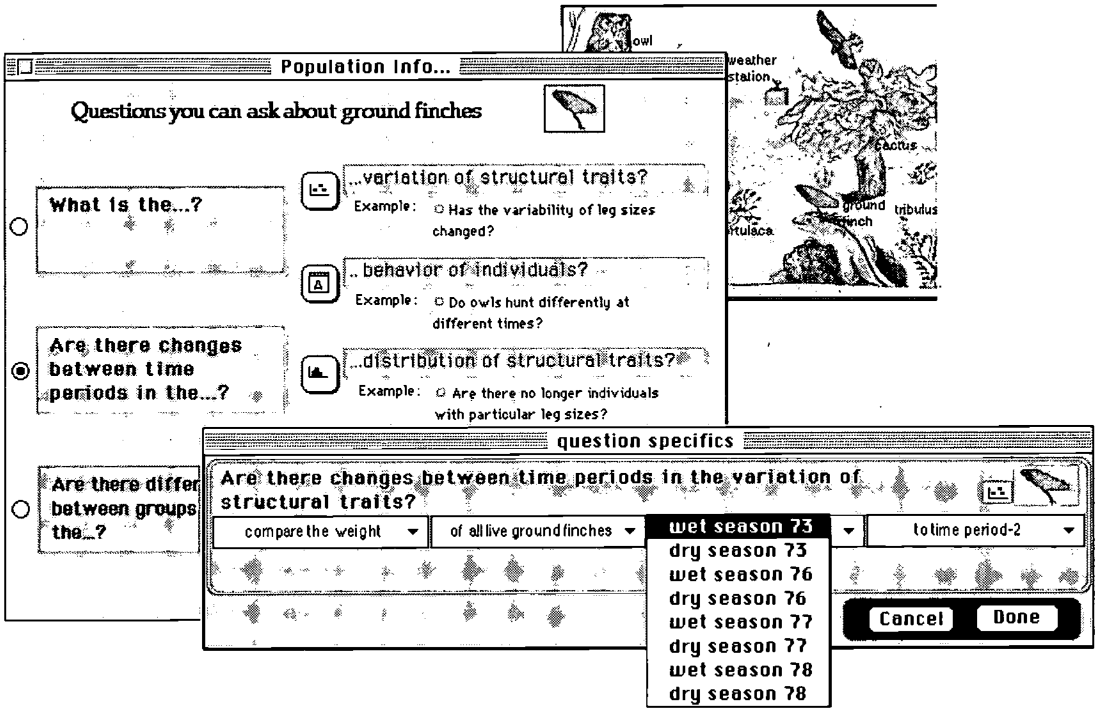

Figure 1: The questions interface and dialogue resulting from selecting "Are there changes between time periods in the..." - "...variation of structural traits?" In the dialogue students specify structure, group, and two time periods.

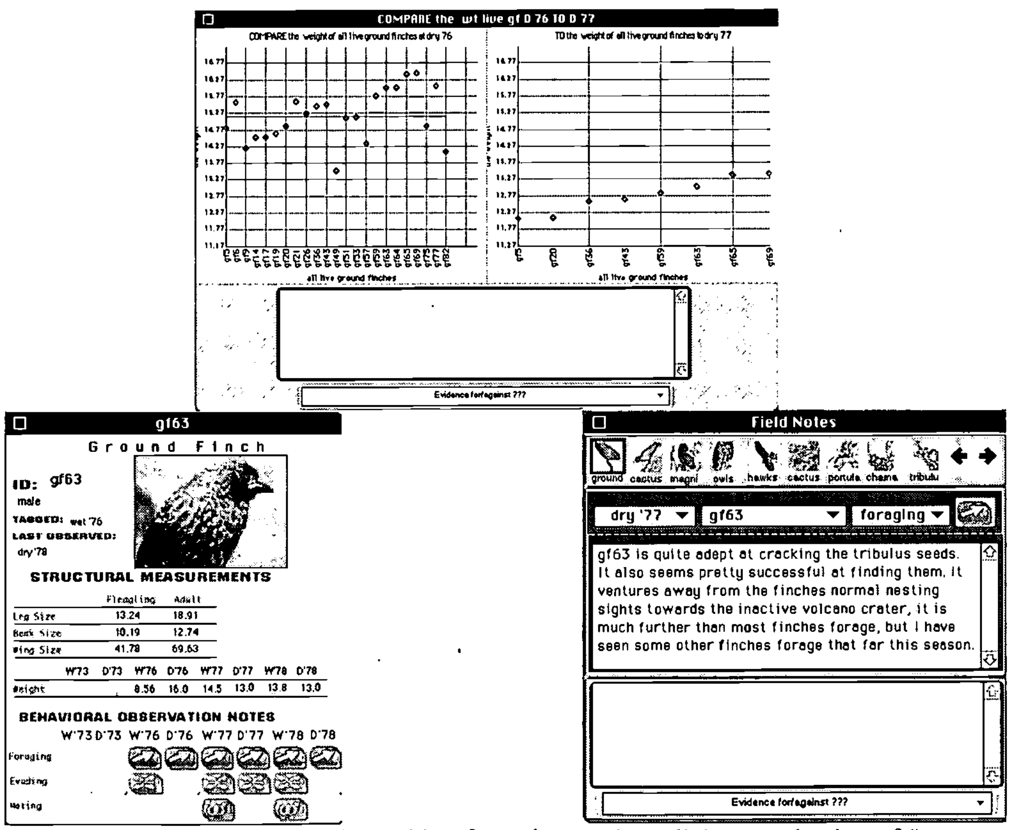

Figure 2: These screens show the graph resulting from the previous dialogue selection of "compare weight of all live ground finches between dry season '76 and dry season '77." Clicking on individual data points in the graphs brings up an individual's profile, and profiles are linked to observations of that individual in the field notes window.

The computer environment provides a data log that automatically stores each of the observations students make. Students can organize and sort their evidence according to evidence categories pre-specified by the environment. These evidence categories represent factors in the mechanism of natural selection, such as changes that introduce pressures, and differential survival (see Figure 3). Any observation that students make is automatically stored in the data log under the "unsorted" category (last row in the data log window in Figure 3). Students can categorize a piece of data either in the data log directly by dragging the thumbnail of the data into the desired slot (row), or when viewing the data using a pull down menu listing each of the categories (shown in Figure 2, it is the wide button with a pop-up arrow at the bottom of the graph window and the field notes window labeled "Evidence for/against ???").

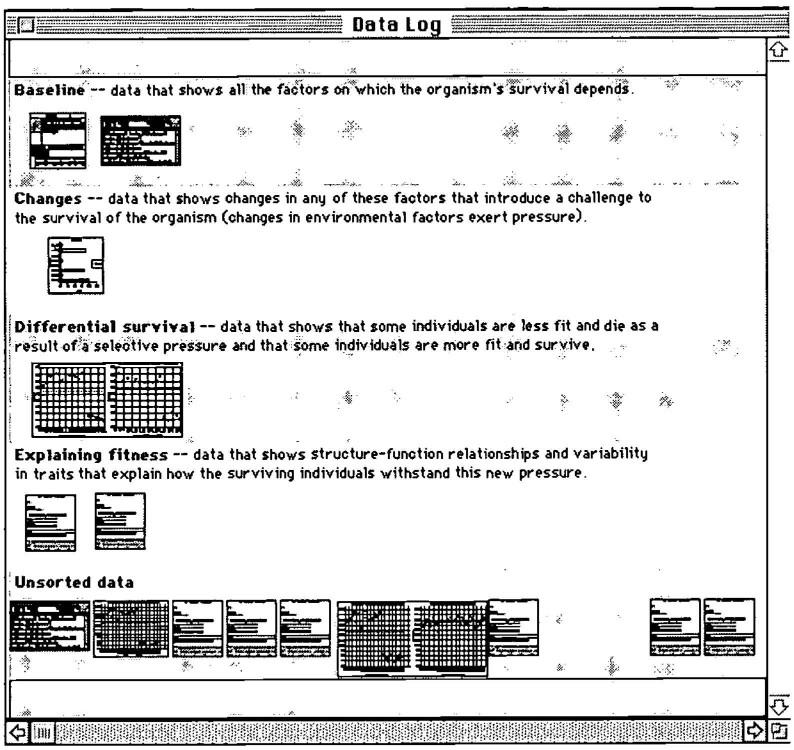

Figure 3: The data log where all student observations are stored. Students can categorize their data according to evidence categories pertinent to natural selection.

The Finch Scenario runs in conjunction with journaling software, Explanation Constructor (Sandoval & Reiser, 1997), that supports the process of articulating questions, and explanations that are supported by evidence. Students can record questions they are trying to answer as they work through an investigation, and the explanations they propose as answers to those questions (see Figure 4).

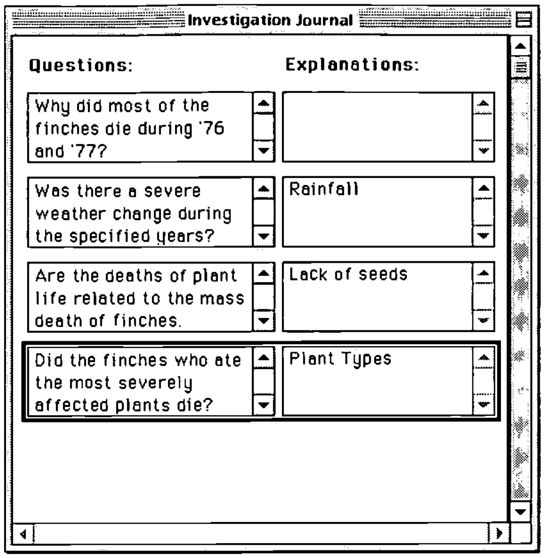

Figure 4: High level organizer of the Explanation Constructor. Students record their own questions and explanations for each question.

Students write out their explanations in *explanation templates*. Explanation templates provide causal decompositions of biological theories and mechanisms, such as natural selection. They help students frame their explanations in terms of domain principles. For example, the "selective pressure" template (see Figure 5) prompts students to explain three major aspects of a story of natural selection: identifying the factor in the environment which is exerting a pressure on some population; explaining how that factor affects particular individuals; and articulating the trait variation(s) selected for by that pressure.

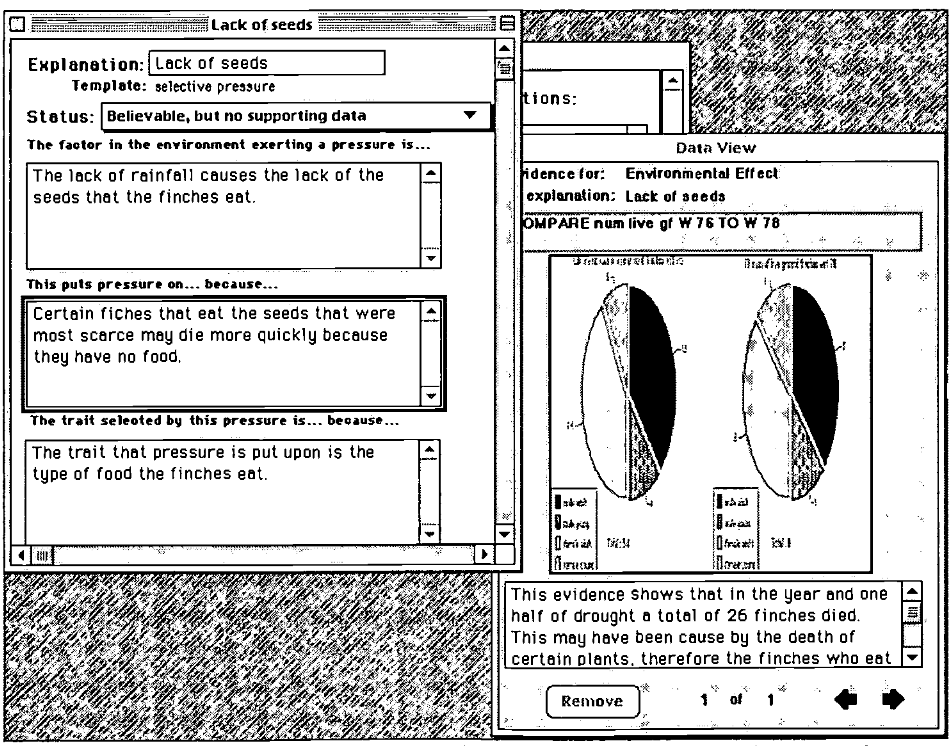

Figure 5: A "selective pressure" template, from the investigation journal shown in Figure 4. The selected component, highlighted with a black box, displays the data linked as evidence for that part of the explanation.

Students can copy individual data items, such as graphs, from the data log of an investigation environment and then paste them as evidence for a particular component in an explanation. An example of this is also shown in Figure 5.

2.1.3 Teacher practices

We ran this unit in a regular level introductory biology class at a Chicago public high school. The teacher we worked with had worked with us during the previous year, and ran a shorter pilot version of the unit and software in her class. The practices this teacher employed were central in shaping the enactment of the unit we designed. We spent some time before the unit discussing the goals for the unit, and the values that we wanted to convey to students, such as the emphasis on reflecting on process, supporting claims with evidence, and specific the biological principles that we wanted to convey. Once the unit started we would occasionally debrief after class and discuss what we thought had gone well in that class period, and brainstormed about ways to approach the next day in order to overcome any difficulties or shortcomings we identified.

Some of the practices that the teacher employed were based on ideas generated in our discussions, some were practices she engaged in regularly in that class, and some were on-demand decisions that she made during the class period. Overall, this teacher was very effective in engaging in practices that complemented and enhanced the materials and structures that are part of the unit design. For example, she would model the use of some of the tools in the computer environment, and encourage students to make use of these tools. In other cases, she provided her own set of prompts and supports that were geared at the same goals as some of the supports in the software. She also provided support for strategies that were consistent with our overall approach, but for which we did not design specific supports. The teachers' prompts were both in the form of instructions, e.g., "you want to put all the pieces together," and in the form of questions, where the sequence of question and response form the use of a strategy, e.g., "what have you found so far?"

The teacher's main role in guiding inquiry was during the whole class discussions that were interleaved with the investigation sessions, and during small group interactions when the students were conducting their investigations. In whole class discussions the teacher would usually start the discussion, or segments of the discussion by describing the goals of the discussion. She would then ask the class a series of guiding questions. The discussion style was composed mostly of joint construction (Lemke, 1990) where an idea or explanation was constructed by both the teacher and students contributing to the dialogue, with one completing or extending clauses begun by the other. There was a considerable amount of turn taking between the teacher and students, with a small amount of turn taking among students, before the teacher's next comment or question. During the group work she would circulate among the groups and engage them in discussion. She had two main styles of interaction with the groups. Some of the time she would approach a group and ask them questions about their progress, and provide feedback and suggestions. At other times, she would, in effect, become part of the group and join in their investigation, considering with them what steps to take next and how to make sense of the data.

2.2 Reflective Strategies for Inquiry

In the following sub-sections we describe reflective strategies that we tried to support in our intervention. For each strategy we describe why that strategy is useful in the context of student-directed inquiry, and what aspects of the design or teacher practices (or both) are intended to foster that strategy.

2.2.1 Drawing on earlier experiences

Engaging in a number of investigations relating to the same domain topics can provide a basis for students to reuse investigation strategies they used in earlier investigations, and to reconsider in a current problem hypothesis and principles that came into play in earlier problems. This is similar to experts who have a range of knowledge and experiences from which to draw on when they encounter a novel problem. In a learning situation, considering whether actions taken in an earlier problem apply to a subsequent problem can help students recognize that some of the actions they take are reusable strategies and not just a collection of actions that happened to be useful in one particular problem. If multiple problems depict some of the same domain principles this can also help students realize the ubiquity of particular causal relationships and principles in the domain.

Our unit includes a number of investigation problems each depicting aspects of natural selection in the wild which provides students with a collection of similar experiences. In order to facilitate the process of recalling earlier problems and noting similarities among problems we include the same structure and materials in all problems (Iguana Scenario and Finch Scenario). Although the main question and organism that students investigate is different between the two investigation problems in our unit, the sources of data and their organization is the same across both problems, despite the different medium of delivery (paper-based versus computer-based). In both scenarios data is organized according to behavioral and morphological data, and behavioral data is presented through field notes while morphological data is presented through a series of graphs. The Finch Scenario software includes the Data Log where the data that students generate is stored and can be sorted into categories. In the paper-based Iguana Scenario we include a series of three labeled folders each representing a different category of data, where students can insert sheets with data from their packet in order to sort the data they examine.

The teacher encouraged students to draw on their experiences with the Iguana problem while working on the Finch problem, and helped them recognize some of the similarities between the problems. She would explicitly tell them to try and remember how they went about solving the Iguana problem, or would precede a description of a particular process or strategy by saying "remember in the Iguana..." In the strategy discussion that came between the second and third investigation sessions of the Finch Scenario the teacher made 3 references to the Iguana Scenario. For example, during this discussion the teacher tried to help the students realize that in the Iguana problem they encountered similar factors (e.g., physical characteristics) and they tried to find relationships among the different factors. This is illustrated in the following comment (emphasis added):

> What else, **if you think back on the Iguana problem, see if you can extrapolate some of what you learned on that.** When we look at behavior, I noticed a group looked at behavior, the beak length and the leg length all that was physical characteristics, you told me a lot about the environment, so you've got those three factors. **Now, think about those three factors and think about the iguana problem**, what about some of the physical characteristics, behavioral characteristics, environment, what are you going to do with all of those?

2.2.2 Evaluating claims

Evaluating claims by asking whether they are supported or refuted by evidence is central to producing a substantiated scientific explanation. We try to create an environment in the class where working from data and supporting claims with evidence is a valued and critical part of the task. At a basic level, this is achieved by presenting the task as constructing an explanation based on the evidence gathered in the investigation environment, and providing students with environments rich in primary data. The structure of the materials is also intended to foster this view. The explanation constructor provides the means to link data from the investigation environment to each segment of the explanation templates (a block of space representing one of the general claims that are part of a particular biological explanation, such as natural selection, in which students can type in the specifics of the episode they are investigating).

The teacher complements the structure of the materials by stating that supporting claims with evidence is fundamental to scientific work in general, and a requirement for these tasks in particular. She also prompts students to describe their evidence, or acknowledge that they have evidence when they share their conclusions with the class. For example in the excerpt below the students have shared their explanations (reading from their investigation journals) with the class. The teacher then asks them whether they have evidence for their claims:

> Teacher: ok, now you read some real interesting facts to me off of the journal, where did that come from?
> Girl: field notes
> Teacher: field notes, ok, so that's part of your evidence.

2.2.3 Articulating intermediate explanations

Constructing scientific explanations involves synthesizing different sources of data in order to identify patterns and causal relationships that explain a natural phenomenon. A reflective strategy that one can employ in order to facilitate this process of synthesis is to continually articulate intermediate explanations for the phenomenon. This can serve as a prompt to try and tie pieces of a story together, and it can help identify missing pieces in the story.

Each data display in the computer environment includes a space for writing notes and annotations, this can help communicate the importance of documenting interpretations and intermediate conclusions throughout the investigation. The explanation constructor is the space that is most naturally associated with documenting explanations. The fact that the explanation constructor is integrated within the investigation environment tries to communicate to students that the task involves an ongoing process of moving back and forth between the investigation environment and the explanation constructor, noting explanations and pieces of explanations as they are generated. This is in contrast to a model that some students might have where one first gathers evidence, and writes an explanation only as a culminating step when he or she thinks they have a final explanation. The structure of the journal is also geared toward suggesting to students that there is value in noting intermediate explanations by providing the ability to associate multiple explanations with each question, rather than one definitive explanation.

The teacher tries to encourage and prompt students to articulate their intermediate findings in both small group and whole class interactions. In the small group interactions the teacher may walk up to a group and ask them to tell her their current story. For example: "Do you guys have any ideas on this, what was your story?" In the whole class discussion the teacher asks students to report on "what have you discovered so far." In these whole class discussions, she goes beyond simply asking students to report on their intermediate findings and explanations, she models the process of synthesizing findings into a causal story by repeating to students a causal account based on disparate findings that different students contributed. For example in the excerpt below the teacher first solicits different findings from the students, then in the last line she synthesizes these findings into an explanation which she shares with the class:

Teacher: a drop in almost everything?
Sandy: in like food
Teacher: why was there some kind of correlation?
Students [a number in unison]: no rain
Teacher: no rain in 77? Not much rain in 77? Not at all, sorry. You noticed the food dropped off in 77 because of no rain, that capped off from what?
Tanya: there were only 8 finches left
S [a boy]: from 76
Teacher: and
S [a boy]: it just dropped
Teacher: did you go beyond 76? You told me you had seven
S [a boy]: yeah in 73 there were 530 seeds, and in 77 Y, so it just dropped, you know
Teacher: ok, so let me see if, I can sort of tell you what you've told me so far. You've discovered that in the dry season of 77 there was virtually no

rain, you noticed that the seeds all dried up.

2.2.4 Categorizing data according to domain categories

Organizing and categorizing data can help students in the process of identifying patterns and synthesizing multiple sources of evidence. It can help students consider how any particular piece of data relates to the overall goals of the investigation. It also creates a setting where after some data has been categorized students can focus on the data within a particular category. This, in turn, can help students formulate a coherent, causal account of events rather than a list of disparate findings. Categorizing data according to categories representing domain principles can also assist students in recognizing the connection between relationships they identify in a particular setting they are examining and general relationships that are expressed in a domain theory.

In our design we try to foster the habit of categorizing data and to support students in this process through the Data Log feature of the software. The Data Log (described in section 2.1.2 and shown in Figure 3) is a space in the software where any observations that students collect are automatically stored in a section called "unsorted." The Data Log contains additional sections each representing a category of evidence pertinent to the mechanism of natural selection, such as changes that can introduce a pressure. Students can sort data into these sections.

The teacher complemented this software based support by encouraging students to sort their data when she circulated among the groups. In some cases she helped students think through which category would be most appropriate for a particular piece of data. Two examples appear below. In the first example (emphasis added) the teacher first explains some of the reasoning and data observations the students should do, and then she observes a piece of data with them (number of seeds), at the end of the excerpt (bold text) she reads off the list of options for data categorizing, thinking aloud about which category this piece of data fits. In the second example the teacher simply reminds the students to categorize their data.

Teacher: Ok look, here, of all this stuff here, during the tribulus, cactus, portulaca, which one did they eat? First of all you need to know probably were they all around during the dry season, or did the drought kill them all, and then which ones were around. Let me look at one of these. Ooooh, I clicked one too many times. All right, during the dry season amount of seeds 77, so there were some, **where are we going to put this? Evidence -- lets put it.... baselines, changing factors introducing pressure, we'll put it there.**

Teacher: you know what? you can put that into your data log
Tanya: oh yeah, that's right

2.2.5 Relating situation specific patterns to domain principles

One of the goals of investigating a particular natural phenomenon in the theory articulation approach to inquiry is to extend students' understanding of a theory by mapping it to the specifics of an actual event. If the process of investigating the particular episode includes an ongoing attempt to view patterns and relationships in terms of patterns and relationships expressed in a domain theory then students are more likely to make this mapping. This in turn can help students to better understand the domain theory, because they can think of abstract principles in terms of specific examples. In addition, investigating multiple examples can help students extend their understanding of concepts that are part of this theory. For example, investigating two episodes of natural selection that depict different types of selection pressures can extend students' concept of what constitutes a selection pressure.

In our intervention we try to encourage students to continually relate situation specific patterns to domain principles by having them write their explanations in explanation templates (described in section 2.1.2 and shown in Figure 5). The templates provide blocks into which students can write segments of their explanation. Each block is labeled with a question prompt asking about a component of the mechanism of natural selection, such as identifying the factor in the environment which is exerting a pressure on some population; explaining how that factor affects particular individuals; and articulating the trait variation(s) selected for by that pressure. Therefore, if students conclude that the finches are dying because a lack of rainfall created a shortage of food resources, then when the students want to note this in their explanation they need to decide whether this describes a pressure or one of the other components in the template.

The teacher also engaged students in the process of considering episode specifics in terms of domain principles by asking students questions about their intermediate findings using domain terminology. For example (the question in domain terms appears in bold):

Teacher: As S said you haven't quite gotten to the $64,000 question that was why the finches that are surviving why are they surviving over some of the other ones. **What is that adaptation maybe that they have that allows them to survive in especially those dry seasons. What's the stress that's being introduced here?** You all agree, I think. **What's the stress in this environment? What's the stress? What environmental condition is doing the selecting now?**
S: seasons, dry and wet
Teacher: the dry and wet season, and particularly
S: ??

2.2.6 Assessing progress

Continually evaluating whether one has answered the current question or addressed the current goal can help to ensure that these goals are met, and that findings are relevant to both hypotheses and the goal of the investigation. This in turn contributes to a more supported final explanation. It is important to not only consider whether the current question has been answered, but whether the main question has been answered as well.

In order to encourage students to continually ask themselves whether they have answered the main question the teacher would remind students of the main question at the beginning of most investigation sessions by asking students to report on the main goal and question of the investigation. During the intermediate whole class discussion she elicited students current explanations, and pointed to the fact that the explanations addressed only part of the goal, and that there was still another part of the main question to answer, and she restates the question as a next step for students:

> "oh, so there was less finches and those finches that were there you said lost weight. But what I wonder is, and the question that I might have and that you should have is why did those finches survive?"

2.2.7 Evaluating inquiry plans

Investigating a rich data set can be a complex task requiring many data observations. Having a plan, and adhering to that plan, can increase the effectiveness of an investigation, because it ensures that observations are in service of a goal, eliminating or reducing the number of haphazard, unnecessary observations. However, having a plan may not be enough. It is important that plans be relevant and have a logical connection to the main, or current question or goal. If students ask themselves whether their plan could generate information relevant to answering the question they are more likely to abandon irrelevant plans. For example, during the course of an investigation students can raise the idea of observing a particular set of data, such as the number of seeds available in each time period, because they had not observed this data previously. But if their current question is why some finches are better able to survive, these observations would not be relevant.

In the whole class discussions the teacher probed students about their rationale for making particular observations. In doing this she tried to make explicit their rationale, and communicate that having such a rationale is important. For example (emphasis added):

> Teacher: what was the extent of the data
> Students [a number in unison]: 73 to 78
> Teacher: 73 to 78, so what did you look at [to S]
> S: 77 and 78
> Teacher: **why 77 and 78**
> S: because we noticed that here was a big drop in the seeds

The teacher also models this process for the students during the small group interactions when she joins the group and takes part in their investigation. For example:

> Teacher: That's why if it were me, you know how I'm telling you to have a plan and know what you're going to look at? First I thought, well if

> there's a drought that's going to affect the foliage, it's going to affect their food supply, 'cause you told me -- competition for food, yeah. Wet seasons there's plenty of food, so now I look, cactus, sometimes absent meaty leaves, yellow flowers, blah, blah, blah, there's a tiny bit of cactus, but it looks like the most that there was tribulus, so I'm going to go back and look at that again, see what it looks like.

2.3 Summary

Our intervention combines sequences of investigation problems, software supports and teacher supports in order to facilitate students in the process of employing reflective investigation strategies. The strategies we support are summarized in Table 1 below. These strategies can help students choose appropriate variables, focus on the target questions, and synthesize data. This can help them construct a supported causal explanation and understand the event or phenomenon they are examining. Some strategies can help students map domain laws and theories to the particulars of the phenomenon, thus extending their understanding of the law or theory.

Table 1: Reflective strategies supported in the BGuILE intervention

Reflective Strategy	Description
Drawing on earlier experiences	Considering whether the current problem is similar to earlier problems, and whether some of the principles learned or strategies used in the earlier problem apply to the current problem.
Evaluating claims	Considering whether a claim is justified in light of observed data, or whether more data is needed in order to support or abandon the claim.
Articulating intermediate explanations	Expressing in speech or writing the current answer for the current or main question.
Categorizing data according to domain categories	Considering whether particular data can be used in the process of identifying states and causal relationship expressed in a domain theory, and identifying the state or causal relationship to which the data pertains.
Relating situation specific patterns to domain principles	Considering how causal relationships expressed in a domain theory can be used to guide the choice of variables and comparisons in the investigation in order to identify these relationships in the specific episode. And considering what causal relationships identified in the specific episode are instances of relationships expressed in the domain theory.
Assessing progress	Considering whether the main question or current sub-question has been answered.
Evaluating inquiry plans	Considering whether a proposed plan for choice of variables and comparisons will provide information relevant to the current question.

3. Reflective strategies at work

The reflective strategies described in the previous section can help students to be more productive in their inquiry. The instructional supports we described are intended to facilitate and encourage students in employing these reflective strategies. The question is whether students actually engage in these reflective processes, and what form do these strategies take in students' interactions. In this section we focus on a particular group in the class as a case example of students performing reflective strategies in the process of inquiry.

3.1 Tanya, Sandy and DG: a case example

The group this analysis focuses on was audio taped throughout the Finch Scenario project. This group was selected for audio taping because one of its members had been interviewed at the start of the unit (selection of students for interviews was based on volunteers from a pool of students that returned signed consent forms). The group comprised of three students, two girls and a boy, Tanya, Sandy and DG (fictitious names). Based on teacher reports the people in this group are about average in terms of their overall performance in the class. In this particular project, the Finch Scenario, this group performed slightly above average, particularly with respect to their level of engagement with the task. In their interactions this group collaborated considerably, discussing data interpretations, and consulting each other on the choice of data queries. This makes the group an interesting candidate to focus on for identifying the reflective strategies that students used in their work. The group performed fairly well, therefore, they may exhibit more strategy use than some of the less successful or less productive groups. Yet, they are not a very high end group, therefore it is likely that the strategies they exhibit are reasonable goals for a range of students.

The examples we present are drawn from the students' work on the Finch Scenario investigation project. In this problem students are asked to explain why a population of finches on a Galapagos island are suffering an extreme decline in population during a particular year, and why the finches that survive are able to survive. Students conducted their investigations in the computer-based environment described in section 2.1 (overview of the intervention). The Finch Scenario project spanned 8 class periods (one shorter than usual), a total of 5 were devoted to investigation work on the computer, and the remaining three (including the shorter period) were devoted to whole class discussions. Students conducted their investigations in groups of 3 to 4 students. The first discussion took place after two investigation sessions, and focused on the strategies and approaches students had taken in their investigations thus far. The second discussion took place at the end of the activity, and focused on students' final explanations and relating these explanations to principles of natural selection and evolution.

3.2 Tanya, Sandy and DG's reflective strategies

3.2.1 Drawing on earlier experiences

This episode takes place towards the beginning of the students' second investigation session. The group had just noted in an annotation field of a graph of the number of live finches during wet 78 (a time period following the period of stress on the finch population): "there was no rain which lead to a food lose [loss] for finches in result there was a dramatic decrease in finches, but in 78 wet there was a lot of rain, which help food grow and there was an increase the number of finches." At this point the students consider what data would be appropriate to look at next. Reading off of the options available under physical characteristics Tanya is reminded of the Iguana Scenario which preceded this problem, and wonders whether leg and weight might be significant factors, as they were in the previous problem. Although Tanya is reminded of the earlier problem, and attempts to draw on the lessons learned through that problem in order to solve the current problem she is focusing only on the surface similarities between the two problems. In contrast, Sandy recognizes the criteria that would make these variables relevant choices in the current problem. She responds by pointing out that these would only be significant factors if, just like the previous problem, the animals were in a habitat where they had to work hard to get to their food. They proceed to observe leg length of all live ground finches during dry 77 (the period of stress on the finches).

Tanya:	what is the variation of leg size, do you think it has anything to do between their leg and their weight and stuff? Like, because remember with the gripping strength?
Sandy:	but, any, it depends on where they get their food though. If they get it like in a place where they have to work hard.
Tanya:	want to try?
Sandy:	yeah
Tanya:	what is the um
Sandy:	leg length? beak length? check the leg length?
DG:	how about uh
Tanya:	wing length?
Sandy:	yeah wing
DG:	wouldn't
Tanya:	they're ground finches, remember
DG:	yeah, how about leg length?
Sandy:	they don't fly? do they fly?
Tanya:	variation of leg length of all live ground finches at dry 77, all live ground finches, their leg length

Considering the factors that were significant in the earlier problem and what criteria would make them a relevant choice in the current problem may have helped the students be more discriminating in their choice of variables. In the lines that follow Tanya and Sandy's exchange concerning the Iguana Scenario we see that the students are making some attempt to reason about what would make a good choice of variable to observe, rather than selecting the variable randomly from the list of available options.

3.2.2 Evaluating claims

In their first investigation session the group explored some field notes describing the foraging behavior of live finches during the dry season of 77 (the period of stress on the finches). They notice that different finches eat different food. DG suggests that the reason they eat different food is due to sex differences. Sandy challenges this claim, and asks whether they should first find out what finches tend to eat overall. DG agrees.

> Tanya: Ok, "gf5 picked up all the tribulus seeds..." [reads field note for gf5] [reads field note for gf69] well, they eat different things
> DG: yeah, because they are different, uh, se, uh, sapiens homo sapiens one is a male and one is a female
> Sandy: does that matter?
> Tanya: the female one is eating seeds and the male is eating spiders
> DG: did you say that the male is the one that is eating?
> [brief pause]
> Sandy: should we see what they eat first?
> DG: yeah, we're getting way ahead of ourselves
> Sandy: we should see all together what they eat

The idea that sex is correlated with the type of food that different finches eat is not well supported by the data in this system. In their final explanation, this group talks about how different finches rely on different food sources, but they do not relate this to sex. This suggests that evaluating whether they had evidence for this claim may have helped the group abandon a less supported idea. However, the group was not consistent in effectively applying this strategy, because their final explanation includes some conjectures that are not supported. For example, they describe that finches "that eat seeds need longer legs to compete for food. The longer the legs, the faster they run, the more food they eat." There is no support for this in the available data, and in fact, there is no data available on running speed.

3.2.3 Articulating intermediate explanations

The group starts their second investigation session by typing out their current explanation into the annotation field of a graph showing the number of live ground finches in wet 78 (period following the stress on the finches). In the excerpt below Tanya and Sandy are working on generating and phrasing this explanation. The excerpt ends with Tanya reading out their explanation after they had finished typing.

> Tanya: there was a lot of rain [pause, sounds of typing] which helped the food and helped the finches [short pause] increase.
> Sandy: the food grow? which produce more food?
> Tanya: wait, but in wet 78 there was a lot of rain which helped food grow and helped the finches decrease.
> Sandy: decrease?
> Tanya: no increase.
> Sandy: grow? There was an increase in finches?

Tanya: there was an increase in finches (sounds of typing) and also helped an increase in finches, delete that.
Sandy: what?
Tanya: and also helped an increase of finches, and also helped [sounds of typing] and also helped an increase of finches
Sandy: helped an increase?
Tanya: helped get an increase
Sandy: helped increase the finches
Tanya: and helped increase the number of finches, sorry. You forgot the number.
Sandy: oh, ok. increase the number of finches.
Tanya: ok. During dry 77 there was no rain which led to a food loss for the finches in a result there was a dramatic decrease of finches, but in wet 78 there was a lot of rain which helped food grow and also helped increase the number of finches.

Over the course of two investigation sessions, this and the following investigation session, the group stated or wrote and stated their intermediate explanation five times. On some occasions, the students stated their explanation in response to the teacher approaching the group. Repeating their explanations to themselves seemed to help the group keep track of what they had already found, and what questions they still needed to explore. For example [this segment of the tape had some background noise which made it difficult to discern some of the dialogue]:

Tanya: we had something about there were more birds when it was wet than when it was dry
Sandy: yeah
Tanya: we've already seen some of that stuff
Tanya: a little bit, it was something about a little bit of rain so a little bit of seeds, so there weren't that many birds
Sandy: yeah, because //, we had already figured that out
Tanya: [reading off of screen or writing] dry 77 //
?: we can't write if we've figured that out as a // some of them eat spiders

3.2.4 Relating situation specific patterns to domain principles

This episode takes place during the third investigation session. The teacher stated at the beginning of the period that the goal for that day was to get an explanation started in the explanation constructor (if they had not done so already). The group chose the selective pressure template, and the episode starts with them typing in the beginning of their story (due to less rainfall, and in some cases none at all this had led to a pressure in the environment) into the block in the template labeled "The factor in the environment exerting a pressure is..."

Tanya: there's less rainfall, and in some seasons none at all
Sandy: there is less food or whatever
Tanya: due to less rainfall, and in some seasons none at all [can hear them typing], this had led to [Tanya speaking and typing with Sandy occasionally speaking over and in unison with Tanya] to a pressure of of what the hell a pressure in the environment, this led to a pressure

in the environment

After typing this segment, the students are not sure how to proceed and they turn to another screen that has brief descriptions of each explanation template. They read the description for the selective pressure template. The description sparks an idea for them on how to continue their story, because they think it suggests a cause.

> [Tanya and Sandy reading off of the computer screen, they are reading the explanation text for the selective pressure template]
> Tanya: "these traits survive better" wow that could be a cause
> DG: there's one reason right here
> Tanya: ooh, straight, we get everybody to do this

The group tries to go back to their explanation, but experience some technical difficulties because the software is still expecting them to enter a title for their explanation, but they had not entered a title yet. The teacher and a researcher join the group and try to help them. The students are focused on trying to think about a cause for some finches surviving based on the description they just read, but the teacher and researcher are trying to get them to enter a title for their explanation. The dialogue intersperses the students attempts to express this new line of thought, and the discussion over the title of the explanation. At the end of the segment DG manages to explain to the teacher what the group is currently considering.

> Researcher: what's your theory
> Tanya: a selective pressure is causing some organisms
> Teacher: what's doing the selecting? what's the pressure?
> DG: that the less rainfall
> Teacher: all right, call it rainfall if you want to
> Tanya: no rain
> Teacher: or no rain, or anything like that
> [all three talking over each other joking about different name options with the rain motif, then they name their explanation "no rain"]
> [the group brings up the description of the selective pressure template and show it to the researcher and the teacher]
> Sandy: "the environment that causes some" [reads from the description]
> Teacher: you already did that [referring to the fact that they have already selected a template]
> Researcher: yeah, go ahead and cancel that
> Teacher: cancel that
> Sandy& DG [in unison]: but the change
> Teacher: oh, I'm sorry, what are you doing?
> DG: we're just showing you where we're going on that theme
> Teacher: ok
> DG: see we're thinking that the rainfall somehow caused the, some different finches to act different, some of these had these traits
> Teacher: ok, sounds good to me

This episode illustrates an interesting shift in the way students approach the investigation. At the beginning of the episode the students have an intermediate explanation that they express in terms of the specifics of this episode (the story about rain and seeds). They speak in terms of the local events, but choose a block in the explanation template in which to enter this part of their story by choosing among items expressed in general domain terms. They are mapping local events to general or global domain principles. After reading the template the students start speaking in global terms, e.g., "a selective pressure is causing some organisms," trying to now map domain terms to local events. In DG's final statement there is a combination of the two approaches. The part of the story that the group has "figured out" is expressed in local terms, and the pending pieces are expressed in global terms.

In subsequent sessions the students try to identify "these traits" that distinguish surviving finches. The students had already noted, prior to this episode, that there are differences in physical characteristics among the finches, and they were trying to understand what accounted for these differences. But this episode may have helped the students associate these differences with their earlier conclusions that explained why the finches were dying.

3.2.5 Assessing progress

In this episode the students recognize that although they have a partial explanation they still have not answered the main question. The group articulates an intermediate explanation, then Tanya raises the main question to the group, and then points out that that is the question they need to answer. The first few lines of the excerpt below show the students articulating their intermediate explanation, and the last line shows Tanya reminding them of the main question.

Tanya:	look at, at 73 he weighed 8.6 then he weighed 15, then he weighed 16, then he weighed 15 then he weighed 14 and then in lookit, in 77 he weighed 12.5, see their weight is dropping because there's less food, right?
Sandy:	yeah, you could write that under there
Tanya:	lookit, we could write
Sandy:	we could look up weight and then write a note under the weight
Tanya:	I think it does have to do with the rainfall and the food
DG:	it's like a causal affect, no rain, less food
Tanya:	so less // but then why are some surviving and some are not? that's the question.

3.2.6 Evaluating inquiry plans

In this episode the students formulate a plan for their next set of observations and evaluate whether this plan will help them answer the main question. The students had just observed a series of individual profiles of live ground finches, and stated an intermediate explanation that explains why the finches were dying. They realize that they now need to answer why the surviving finches are able to survive. The excerpt below opens with Sandy suggesting that they write what they currently are observing about leg sizes of live finches, and then observe a dead finch. Tanya responds by trying to understand how this investigation path will help them answer the question about the surviving finches. In this episode, the fact that the students stopped to evaluate their inquiry plan triggers some brainstorming where they raise a series of hypotheses about their current (and main) question of why the surviving finches are able to survive.

Sandy:	what is it then, maybe we can write , keep a note on their leg sizes and then we can go see one of the dead ones.
Tanya:	ok, but why, we know it has something to do with the rain and the food that they're dying, but why are some still living and some are not? maybe because some are eating different things?
Sandy:	or maybe some are stronger? and maybe they are more aggressive

3.2.7 Considering anomalous data

In this episode the students exhibit a strategy that is very critical to the process of effective inquiry, but which was not specifically targeted by the instructional supports. The students notice that some of the data is not consistent with a pattern they thought they had identified. Studies examining novices conducting experiments and investigations show that many novices will ignore data that is not consistent with their current ideas or hypotheses (Klayman & Ha, 1987). Yet, in this episode DG not only notices a discrepancy, but he tries to explain what would account for this alternative pattern, and whether it demands that they abandon their conclusion about the original pattern they discerned. Prior to the excerpt below the group had identified a pattern of weight loss, but looking at an individual profile of one of the finches DG notices that there is an increase in weight and leg size for some of the time periods. He explains that the increase in size (greater than the magnitude of decrease observed in other finches) probably indicates that during those time periods the finch was a baby that matured. He then notes that in the time periods following that finch's mature state, the finch follows the same pattern of weight loss that was observed for the other finches, and therefore their claim is still warranted.

DG:	no, wait, I don't understand, you see the leg size? [looking at individual profile] see how it's 13.3 and then it's 18.76? I'm thinking he's a kid and then he grew up, that's what I'm thinking right here, he might have been a little kid, and then when he got to 76 he might have been grown up.
Sandy:	Yeah maybe he was growing
?:	But in 1977
?:	But do we still need //
DG:	We still need our point, 76 he was grown, he starts decreasing since 76, that's when there was no rain, 76, 77

The group noticed and evaluated anomalous data two other times in this same investigation session.

3.2.8 Predicting data patterns or results

Although our design and the teacher practices did not directly ask students to make predictions about data patterns and results they expected to find, we found an example of an instance where Tanya makes a prediction spontaneously based on other sources of data. Making these types of predictions is important, because it increases the chances that students will notice unusual or anomalous data in their subsequent observations. The quote below is taken from an episode where they are observing a series of individual profiles, noting for each individual its sex, and various measurements. Tanya notices that all the individuals they had observed thus far are male, she then predicts that at least one of the finches will be a female, because she remembers that other data showed that the finches mated in a later season.

> Tanya: lookit, 77 decreased, then going up again, I think they're all males, there had to be at least one woman because they started in 78 they mate, 19, 12, ok and he decreased too?

It is important to note that Tanya made her prediction based on other data they had observed, rather than common sense or intuition. This suggests that Tanya is predisposed to engage in thinking of different sources of data in relation to each other. This is consistent with the group's overall tendency to synthesize data, arrive at intermediate explanations, and continually articulate these intermediate explanations. This is representative of the disposition and habits that we would like to foster in all the students.

3.2.9 Justifying data documentation

The supports in the computer environment and the supports provided by the teacher both try to encourage students to document their work as they go along. In this episode we see that the group not only made a habit of taking notes, but they also stop to consider and express how they will use the notes that they take. Justifying data documentation is a strategy the students engaged in spontaneously. We did not notice instances where the teacher encouraged or prompted this type of justification, and there was no support for this strategy in the computer environment.

This strategy of justifying why documenting particular results or actions can be useful to the investigation can help students to be more efficient in their investigation. It reduces the amount of superfluous notes, and consequently reduces the time it might take to go over earlier notes and use them in the process of synthesis or progress assessment. Further, justifying data documentation can raise students awareness of the utility of particular notes, making it more likely that they will actually revisit the notes and use them in the course of reasoning.

> Tanya: we're at 36, do you want to write that down, his leg length, his beak size and his wing length? and compare to some dead ones?

3.3 Summary

Tanya, Sandy and DG employed most of the strategies that the intervention intended to foster, and some strategies which we did not design for originally. In this group each student exhibited some strategies. This resulted in the expected outcome of the group employing more strategies than any one student alone due to the combined efforts of the group members. In addition, on many occasions the strategies were manifest through interactions among the students in the form of questions or suggestions posed to each other. In some cases, the strategy unfolded through a series of turn taking in their dialogue, such as the dialogue between Tanya and Sandy where they consider how they could draw on their experiences from the Iguana Scenario in order to reason through the Finch Scenario (see section 3.2.1). This suggests that collaborative groups can not only increase the degree of reflective strategy use by combining individual efforts, but that they also play a significant role in triggering and sustaining these strategies.

Although these are promising results, this analysis also suggests the need for changes or additions in the instructional supports. One issue is how to facilitate more pervasive strategy use. Only a subset of the strategies were used on a regular basis by this group, some strategies were observed only as isolated instances. Given that this group was highly engaged and performed better than other groups we can expect that other groups did not exhibit reflective strategy use to the same extent as this group. As a first step toward addressing this issue we raise the question: is strategy use (and lack of use) related to particular learning goals that would point to areas that warrant more immediate attention? We address this question and the implications of its answer in the next section.

4. Implications: reflective strategies to support global understanding

Our group of focus spent the majority of their time trying to understand why the finches were dying and what enabled the surviving finches to survive. Their discussions were in the language of the specific case, they talked about rainfall, seed types and physical characteristics of the finches. In contrast, a discussion in the language of the domain, or the language of natural selection would discuss selective pressures, advantageous traits and changing proportions of individuals. Only a small fraction of their discussion included this language. Consistent with this characterization of their discussions is the fact that reflective strategies that facilitate relating the causal relationships of the specific event to domain principles, such as categorizing data according to domain categories, were used less often or less successfully than other strategies.

In the introduction to this paper we described our approach to inquiry learning as theory articulation. Theory articulation is the process where scientists are not formulating novel theories, instead they use an existing theory in order to explain a novel situation (Ohlsson, 1992). Using a theory articulation approach to learning through inquiry can not only introduce students to this aspect of scientific practice, it can also help students gain a deeper understanding of particular theories. However, in order for this approach to be effective, students need to engage with the material at both a local and global level. At the local level, students engage with the specifics of the case, and at the global level students engage with the principles dictated by the theory. The concern is that if students only engage at the local level that they can emerge from the learning situation with clear and strong ideas about the situation, but not realize that it is an instance of a particular theory. Further, their understanding of the theory itself may not deepen.

For example, the students in our class may be able to provide a detailed causal explanation of what caused the finches to die, and what enabled the surviving finches to survive, without realizing that this episode is an example of natural selection in the wild, and without knowing how to relate the steps in the mechanism of natural selection to the chain of events they observed in the Finch Scenario. If students do make this mapping they can think of abstract principles in terms of specific examples. They can also gain a better understanding of different principles. For example, some students only think of variation as differences between species. In biology variation refers to differences within a species as well, and this variation within a population is key to the process of natural selection. Observing the individual profiles in the Finch Scenario might help students who view variation as differences between species to recognize that individuals in a population can be different from each other. But, they will only associate this with the concept of variation and begin to consider the implications of these differences to the process of natural selection if they make the mapping between the concept of variation and the observation that individual finches have different physical and behavioral characteristics.

Although the students engaged in this mapping process to a certain extent, the majority of attention in students investigations and in whole class discussions was on elucidating the finches' story in situation specific terms. The process of constructing an explanation for a particular problem may be so challenging that students are engrossed in the local details and neglect to relate their explanations to domain principles. For experts, the distinction between local and global analysis and understanding may be very subtle or non-existent, because experts may automatically perceive events in terms of domain principles. For example, studies comparing novices' and experts' solutions to physics problems show that experts immediately focus on deep features of the problem (Larkin, McDermott, Simon, & Simon, 1980). Students, however, are less likely to consider domain principles when examining a novel phenomenon. Our goal is to identify and support reflective strategies that would make students more likely and able to consider domain principles while working through their investigation, and continually map between the situation specifics and the domain principles. In the next sections we discuss why aspects of our design intended to support this process were not as effective as we had hoped, and propose changes and additions for future designs that could be more effective.

4.1 The Data Log: improving current supports for global understanding

The Data Log and the Explanation Templates are the two features of our design that are directed toward facilitating students in the process of mapping between local interpretations and global, or domain principles. The analyses conducted in the process of writing this paper do not provide enough information to discuss students use and understanding of the explanation templates and its relationship to their understanding of the domain, therefore our discussion will focus on the use of the Data Log. Students did not use the Data Log to the extent and in the way we had anticipated. When students did use the Data Log to try and sort their data they did not seem to think deeply about the different categories, and at times their final choice seemed arbitrary. What is promising, however, is that although the group of focus did not use the Data Log extensively or effectively, they displayed an ongoing inclination to use the Data Log and sort their data. Statements such as "where does this go" and "oh we got a lot of stuff... we gotta sort all our stuff" were found in their protocols. This might be due in part to the fact that the teacher encouraged students to sort their data as she worked with the different groups during their investigation sessions.

In summary, the intervention was effective in triggering the strategy of categorizing data, but the Data Log was not effective in helping students sort data according to domain principles, and thus facilitate the process of mapping between local and global understanding. We suspect that there are three main reasons why the Data Log was not used effectively. One reason is that students did not have a clear understanding of what each of the categories meant. The second reason is that there are additional categories that were not represented that reflect some of the data that was collected. Third, the connection between categories in the Data Log and causal explanation segments in the Explanation Template (blocks to enter text labeled with prompts, such as "The factor in the environment exerting a pressure") are not immediately obvious. Since the explanations that students write in their templates is viewed as the final product for the project, seeing a connection between the template and the Data Log will help students recognize the utility of the Data Log for achieving the project goals. We propose the following changes in order to address some of the problems we found in the current implementation of the Data Log:

- Coached experiences with the categories – The Iguana Scenario provides an opportunity for students to experience multiple investigations in similar contexts, but it also provides an opportunity for students to experience their first investigation in a more structured and coached setting. Although a paper version of the Data Log is part of the Iguana Scenario, and students are encouraged to engage in the process of sorting and categorizing data in both problems, the categories themselves are not the same between problems. One goal for the next design iteration is to include more shared categories between the Iguana and Finch scenarios. It is not possible for the categories to be identical, because the Iguana Scenario does not depict an actual episode of natural selection in the wild. The Iguana Scenario does depict some of the principles that come into play in natural selection, and these principles are candidates for shared categories between the two scenarios. Introducing shared categories between the problems should be accompanied by increased support in class discussions on clarifying the meaning of each of the categories.

- Neglected categories – The Data Log currently includes categories that represent the main components of a natural selection explanation, however, this explanation can be broken down to a finer grain of components. Making this breakdown, and including these components will provide students with categories that are more directly relevant to some of the data they observe. For example, the Data Log currently does not include a category for collecting data that demonstrates changing proportions in the population of individuals possessing a particular trait (a central part of the mechanism of natural selection). In this category students could place graphs of comparisons between time periods of physical characteristics (a type of graph that students can and often do generate).

- Shared language between Data Log and Explanation Templates – Although the Data Log and the Explanation Template (the selective pressure template) represent essentially the same components, they do not use the same language to express these components, and therefore it can be difficult to make the connection between the two. In future implementations we intend to use more common language between the two supports. For example, the first prompt in the selective pressure template states "The factor in the environment exerting a pressure is..." this maps directly to the Data Log category of "Changes - data that shows changes in factors in the environment that introduce a challenge to the survival of the organism." The prompt in the explanation template can be modified to include some reference to changes, and the term "pressure" can be made a more salient part of the category title, making it easier to see that the two refer to the same principle. It might also be useful to break down the causal story in the template to finer grained components as we propose to do with the Data Log. This could help students write more detailed stories, and can also facilitate making the connection between the Data Log and the Template.

4.2 Framing the problem: new supports for global understanding

Analyses of the reflective strategy use of our group of focus showed that assessing progress and articulating intermediate explanations were two reflective strategies that students seemed to use well and extensively. These strategies also received a great deal of attention from the teacher during whole class and small group interactions. One way to provide more support for mapping between local and global understanding would be to leverage off of the effectiveness of these two strategies by framing the problem, or main question, in a way that reflects both local and global terms. For example, framing the problem as "what selection pressure is causing the finches to die, and what adaptive trait (if any) enables the surviving finches to survive?"

The teacher in fact spontaneously framed the problem in a similar way during one of the whole class discussions:

> Teacher: ....As S said you haven't quite gotten to the $64,000 question that was why the finches that are surviving why are they surviving over some of the other ones. What is that adaptation maybe that they have that allows them to survive in especially those dry seasons. What's the stress that's being introduced here?

However, this was an isolated incident. We expect that if the problem is framed from the start in a way that combines local and global terms that discussions will tend to combine the two more often as well. The students and the teacher both routinely assessed whether they were answering the questions stated in the problem statement, having the statement include global terms will make it more likely that these assessments will include global terms. Students and teacher also often articulated intermediate findings. These articulations, however, were almost entirely in the language of the case, speaking specifically of the finches and their environment without making reference to what aspects of natural selection are represented in different parts of the finches story. If the problem is framed in both local and global terms and discussions focus more on global terms it is more likely that the intermediate explanations will include such references to the global terms. For example, where students currently say "so there was no rain so no seeds" they might say "so there was no rain so no seeds, so that's the pressure," or where they currently say "we think it's something about their beaks," they might say "we think their beaks might be the adaptive trait."

The fact that the problem was framed entirely in local terms may have also led students to perceive the task as limited to identifying the (local) story about the finches. It is possible that they did not realize that relating these events to the process of natural selection was an important and integral part of the task. Changing this perception of the goals of the task might make it more likely that students engage in the process of mapping the theory to the situation, and thus extend their understanding of the theory of natural selection.

5. Conclusion

In this paper we presented a set of reflective strategies intended to facilitate the process of inquiry, and a set of instructional supports embedded both in learning environments and in teacher practices to help students employ these strategies. We used a case example of a group of students conducting an investigation in the context of a unit on natural selection to see whether and how these strategies manifest in student work. This analysis showed that in collaborative groups these reflective strategies often take the form of questions and suggestions posed between students. This style may be adopted from the teacher who interacts with the students in a similar way during whole class and small group interactions. Asking students questions, where the act of posing the question and responding to it constitute a particular strategy, such as asking whether a current explanation answers the main question. The students in our case example exhibited use of most of the reflective strategies we intended to foster, although in some cases we would have liked to see more extensive use of strategies. Overall, reflective strategy use seemed to be more effective in helping students formulate a causal explanation rooted entirely in the language of the specific case, and less effective in helping students extend their understanding of the theory of natural selection. Other inquiry contexts might be susceptible to a similar imbalance between achieving local and global understanding. Examining the tension between local and global understanding, and developing instructional supports that help balance these two types of understanding may be a goal for future research on supporting science learning through inquiry.

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