Supporting Collaborative Guided Inquiry in a Learning Environment for Biology

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Abstract

We describe a learning environment for high school biology called BGuILE that engages students in scientific investigations in which they can explore interesting problems in evolution and ecology. The environment supports productive inquiry by two interrelated means. First, the system structures students' investigations, encouraging them to compare competing hypotheses, articulate predictions, and record interpretations according to specific task models of biological inquiry. Second, the system provides a context for collaboration in which the biological task model is used to drive the content of students' discussions.

Keywords — microworlds, simulation, tools for inquiry learning.

1. Science Learning through Inquiry

Science education reformers argue that students should be active learners, directing their inquiry to construct and evaluate explanations, building upon their prior conceptions [1, 2]. Fostering scientific inquiry requires more support than providing opportunities for students to pose their own questions and tools for investigating them. Students differ widely in their success in learning from their own experimentation, depending on their prior domain knowledge and their use of more effective hypothesis generation, experimentation, and data organization skills [3]. There is little evidence that experience with inquiry alone improves these heuristics. Like other types of problem solving, inquiry draws upon strategies that are often implicit in expert explanations or even absent from instruction.

In this paper, we describe a computer-based learning environment for high school biology that teaches science by involving students in scientific investigations. We describe two essential aspects of support that enable more productive inquiry. The first is the collaborative context, in which students work together, serving as learning resources for each other, to pose questions, plan investigations, gather and interpret observations, and construct models. The second is the system's specific structuring of investigations through an on-line journal and an explicit strategic model for biological investigations. In the following sections, we describe this inquiry support and the role that collaboration plays in this learning activity.

2. Overview of BGuILE

BGuILE, *Biology Guided Inquiry Learning Environment*, teaches science as a process in which students construct, evaluate, iteratively refine, and then communicate explanations. BGuILE presents puzzling natural phenomena and offers a set of analytical tools and inquiry prompts to enable students to investigate and explain them. BGuILE's complex problem contexts enable students to consider a number of competing but plausible hypotheses. We structure students' investigation of these complex scenarios as a guided collaboration. The collective generation of potential hypotheses, discussion of merits and failings of competing predictions, and evaluation of evidence can be more effective than a single student attempting to perform and coordinate these processes.

BGuILE provides a range of support for the inquiry process. First, BGuILE supports general investigation strategies with its tightly-integrated inquiry journal. The journal is an on-line system that helps students articulate and reflect on their investigations as they construct questions, pose hypotheses, gather observations, and record interpretations. More specific support is also required to help students focus on relevant questions and interpretations. The system helps students structure their investigations according to a *task model* of biological investigations by focusing students on the types of observations and interpretations biologists use to explain phenomena. For instance, a behavioral ecologist is primarily concerned with making comparisons between organisms and finding costs and benefits associated with a behavior. An understanding of this task model can help students take a more planful approach in their investigations.

BGuILE provides two types of investigative activities in evolution and ecology. *Focused investigations* present a scenario in which students study a curious outcome and are asked to explain it. *Simulations* allow students to explore questions by conducting controlled experiments in a simulated ecosystem. Students use analytical tools to investigate their hypotheses by measuring characteristics of an organism, its behavior, or the environment. The first prototype for BGuILE's focused investigation and simulation scenarios will be evaluated in a classroom setting in July 1995.

The collaborative context is an important aspect of making inquiry more productive. Students can internalize the process of inquiry as one of proposing conjectures and evaluating alternatives more easily after these processes have been practiced in a group context, perhaps with different individuals proposing alternatives and providing supporting evidence or competing explanations. Our central aim is to focus students on the process of planning and conducting a coherent investigation to build an explanatory model. For this reason, we focus on computer support for face-to-face interactions as students work to understand the phenomena — observing behavior, selecting situations to test their ideas, and making sense of the results — rather than in supporting communication between students. Thus, the computer environment provides a context for shared work [4] — groups of students collaborate to construct coherent arguments, based on well-structured investigation, which they can then communicate to their audience for discussion. Fostering productive inquiry requires more than placing students in a collaborative setting. We use task models of biological investigation to drive the content of students' dialogue. Thus, the inquiry support in BGuILE that explicitly prompts students to compare and interpret data, looking for selection pressures or costs and benefits of behaviors, provides clear goals for the group's negotiations.

3. Inquiry Support

Central to BGuILE is the notion of guided inquiry. One crucial form of guidance in the system is support for students' development of effective strategies for scientific investigation. It is unlikely that such general skills can be taught directly, therefore our approach is to exemplify more general investigative strategies within the domains of evolutionary biology and ecology represented in the system. Thus, the inquiry support in BGuILE is designed to be both at the level of general scientific investigation strategies and domain-specific strategies and heuristics.

The on-line inquiry journal is designed to foster students' development of domain-independent scientific investigation strategies. The journal presents each group of students with a shared, structured space in which to explicate their reasoning during inquiry, providing opportunities for articulation of and reflection on strategies usually implicit [5, 6]. Students actively construct paths through their investigations as they carry them out, using a pre-defined vocabulary of inquiry elements and links reflective of scientific reasoning (e.g., stating hypotheses, making predictions, interpreting data). These various elements can be linked together in constrained ways to construct a structured graph of the investigation. Group discussions centered around such concrete representations of the chain of investigation are critical to students coming to understand the nature of scientific inquiry and adopting effective strategies to pursue inquiry within scientific domains.

The structure provided by the journal supports complementary aspects of collaboration: encouraging students to discuss and reach consensus on specific strategies, while allowing for multiple points of view to be expressed as multiple lines of inquiry. The journal provides students with a framework within which to articulate their reasoning steps and negotiate consensus on what those steps should be. Thus, to enter a new hypothesis, a group of students collaborating on the investigation of some question will have to agree both on what it means for some statement to be a hypothesis, and whether or not the particular hypothesis is reasonable for the current investigation. This negotiation requires group members to reflect upon and articulate their reasoning for the group. It is not desirable, however, to proceed solely through consensus [7, 8]. A second advantage of the journal is that it supports the tracking of multiple lines of inquiry, allowing expression of different opinions and perhaps preventing a single student from dominating the group.

The investigation graph itself is an object available for reflection and discussion. The journal acts as a kind of conversational prop [9] which can guide students' debate about the course of their investigation. Students may be able to discern more and less effective strategies of investigation in patterns of linking between elements in their journal. For example, students can readily see if they have a number of hypotheses which have yet to be tested, or if they have experimented across a breadth of hypotheses, but not explored any single hypothesis in depth. This structure of the journal not only supports students' investigations into particular domain questions, but on seeing science as a process of argumentation rather than a simple search for facts.

While the journal provides a global view of the progress of an investigation, local guidance integrated with particular steps in the scenarios encourages students to act more planfully during their investigations. Students are prompted to provide rationales for specific observations and analyses in terms of how they can further the current investigation. Following the performance of some test, students are prompted to interpret their results, again in terms of their overall investigations. Through these prompts, students are encouraged to reflect upon how a particular test can further their investigative goals, and to consider how data bear upon their emerging explanations. These local rationales and interpretations are then recorded in the journal, along with students' results, and students are encouraged to link these elements into their existing investigation graphs. Thus, students are encouraged to relate their local observations to their overarching investigations.

These local prompts also reflect specific task models of biological inquiry. For example, when examining the amount of rainfall within a specified time span on a Galapagos island, students are prompted to consider how that will help them identify a selection pressure on the local bird population. Upon seeing the rainfall data, students are encouraged to consider whether that in itself is sufficient to act as a pressure or whether some other environmental factor may be at work. Thus, besides encouraging students to relate their individual steps to their investigations, these prompts help reinforce investigation strategies useful in the domain.

4. Biological Inquiry in BGuILE

The inquiry journal provides one layer of inquiry support, an additional layer is embedded in the design of the investigation activities. To make student-directed investigations more productive, the system must make otherwise invisible features observable, and should focus students on the types of analyses and interpretation strategies used in the domain (such as looking for selection pressures, variation in a trait, cost-benefit analyses of a behavior, etc.). The following sections describe two types of investigative activities in evolutionary biology and behavioral ecology.

4.1. Focused investigations

The focused investigations present students with a series of scenarios, based on data from actual biological investigations, in which students see a curious outcome and are asked to investigate and explain it. The overall design of the scenarios, in which students can examine potential causes looking for possible explanations, focuses students on the type of cause-effect reasoning necessary to build causal models.

One sample scenario states that the number of finches on a Galapagos island has significantly dropped in the last year, and asks students to explain why some of the finches are surviving while others are dying. In reality, finches were starving due to a severe drought. Normally, the birds' diet consists of small, soft seeds, but these did not survive the drought. A more resilient plant that yields large, hard, thorny seeds was still available. Finches with a slightly deeper beak were better able to eat the larger seeds and survive the drought [10].

The accepted explanation for this scenario is not intuitive, and the causal relationships are not immediately obvious. Students might raise and explore a number of conjectures, before considering the relationship of weather, food availability, and structural differences among birds. The environment provides a suite of analytical tools that enable students to gather information, and synthesis tools that reify the investigation strategies used by evolutionary biologists. The analytical tools enable students to take measurements on the surviving birds, look at what they eat, observe behavior in the natural habitat, and examine characteristics of the environment. The synthesis tools consist of a compare tool and a relate tool. The compare tool allows students to recognize trends and correlations by comparing any type of data collected with the analytical tools. The relate tool encourages students to identify and articulate relationships, such as structural-behavioral relationships, among the trends they observe.

The tools are designed to scaffold the type of reasoning required in explaining evolutionary phenomena, such as recognizing variations, changes over time, and relating behavioral and structural information. For example, students can compare finches' beak size. The display of this data shows not only the mean value, but represents the distribution of values for the chosen population. Students may note that finch 5 and finch 17 lie at opposite ends of the distribution. Next, they might go to the field notes (which simulate notes taken by scientists making observations in the field). Looking at observations of finch 5 and finch 17, they see that finch 5 twists and twists the seed but is unable to crack it, but finch 17 grabs the whole seed in its beak and cracks it open. Students can also use the analytical tools to collect information from a representative set of time periods. Information from one time period can be compared with information from another time period using the compare tool.

The design of the tools and environment were informed by a number of pilot studies using a paper-based mock up of the environment. We expect that using tools that reflect a task model of evolutionary biology will help students to form causal models.

4.2. Experimentation with simulations

The simulation we are building, *Animal Landlord*, will serve as an environment in which students form causal stories about animal behavior by articulating predictions about various features affecting an animal and testing these within a simulated world. We want students to make behavioral arguments, from observation to explanation, about complicated behavioral events. The simulation is designed to investigate questions of the form: 1) If a creature displays behavior *X*, what would be the effects, and 2) What must be true of a creature in order for it to behave in manner *X*.

The simulation might depict a lion attack on a herd of zebras: students would see the lions foraging, perceiving the zebras, assuming a stalking position, and finally attacking as a group. Within this presentation are a number of interesting factors for analysis, including [11]: What is the relationship between the size of the lion pride and this success rate? How does the behavior of the zebras, once they realize that they are under siege, affect this capture rate? Are there benefits to group hunting, or could a single lion fare just as well if not better? Students can manipulate aspects of the simulated ecosystem and creatures to see how these and other factors contribute to an explanation of the causality involved in the lions' hunt.

Making sense of interactions and focusing on intermediate steps of the hunt (as opposed to final outcomes) would be difficult for students [3, 6]. We intend to scaffold learning by providing explicit focus on causally relevant features and support for experimentation through the system's task model for investigations and the integration of the inquiry journal.

First, we deliver models of the world that simplify the number of features requiring student attention, focusing on a pedagogically relevant subset. Second, we want to reduce the opacity associated with quantitative models by building a qualitative architecture emphasizing behaviors. Third, we want to provide multiple representations of world phenomena to accentuate salient properties. For example, the system generates a timeline of actions seen during the lion hunt, providing a static representation of the world dynamics, focusing attention on the animals' state changes, and providing explanatory and background information about the simulated behaviors.

The goal-directed task of exploring the lion hunt is meant to provide a stronger context for inquiry than more open-ended animal behavior simulations [12, 13]. Our first goal is to have students explore the world with specific questions in mind, such as "How big should a lion hunting group be to catch the most zebra?" The system focuses students on the domain-specific observational methods that behavioral ecologists might use to answer such a question. For instance, students might try to discover the optimal group size by looking for variations among different population sizes to discover their chances of success. Students must decide what form the investigation should take, the requisite observations, and the ultimate data interpretation.

5. Conclusions

We have described a computer environment for supporting guided collaborative inquiry. Inquiry support in BGuILE consists of both a general model of scientific inquiry as well as specific task models for biology. The structure and prompts provided by the system serve not only to engender effective biological investigations, but also to foster productive, focused discussions among students. This guided collaboration reflects in the social context the various aspects of the inquiry process that must be internalized, such as comparing competing alternatives, mustering evidence pro and con, and looking for selection pressures. Finally, the nature of the task in which the group must come to consensus to review evidence and revise models focuses students on seeing science as a process of argumentation rather than as a search for facts.

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