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Explaining Behavior Through Observational Investigation and Theory Articulation

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Conducting observational investigations of behaviors and processes is an important method for generating scientific knowledge. This article describes a methodology for assisting students in the processes of observational inquiry and theory articulation and its instantiation in a set of digital video tools. We describe a high school biology curriculum where students use these tools to investigate video clips of animal behavior and develop theories about how and why these behaviors evolved. We focus our discussion on an investigation model that scaffolds students through the processes of observing and explaining video as data and the computational and curricular supports that were designed to make these processes explicit. We conclude with a presentation of preliminary results to illustrate the types of explanations that emerged from working with the software and curriculum and a discussion of issues that emerged during the course of the research.

Recent research in science education has been concerned with bringing rigorous scientific content into classrooms as well as introducing learners to the practices of scientific inquiry (American Association for the Advancement of Science, 1990; National Research Council, 1996). Whereas "traditional" science learning can be viewed as the acquisition of concepts and terminology, inquiry reforms emphasize

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the need for students to perform tasks similar to those encountered in scientific practice: posing questions, generating and interpreting data, and developing conclusions based on their investigations (Linn, diSessa, Pea, & Songer, 1994). Developing deep understandings of science requires understanding the nature of scientific explanations, models, and theories as well as the practices used to generate these products. In other words, students should learn how to plan and conduct investigations of phenomena while also grounding these activities in specific theoretical frameworks related to particular scientific disciplines.

For instance, much of the work on learning through inquiry has focused on learners designing and executing experiments (Klahr, Dunbar, & Fay, 1990; D. Kuhn, Amsel, & O'Laughlin, 1988; D. Kuhn, Schauble, & Garcia-Mila, 1992; Schauble, Glaser, Raghavan, & Reiner, 1991; Shute, Glaser, & Raghavan, 1989). In these settings, students generate and test hypotheses by controlling and manipulating variables. Controlled experimentation is an important method for building scientific knowledge: Indeed, it is often viewed as the primary means for generating knowledge in inquiry classrooms (DeBoer, 1991; Lehrer, Schauble, & Petrosino, 2001). Some disciplines, however, must rely on other techniques for knowledge building. For instance, learners working to find patterns in large datasets (e.g., Edelson, Gordin, & Pea, 1999; Reiser, Tabak, Sandoval, Smith, Steinmuller, & Leone, 2001) rely more on forms of pattern recognition than experimental methods, yet they are still generating hypotheses about trends in the data. Modeling and simulation environments (e.g., Jackson, Stratford, Krajcik, & Soloway, 1994) ask learners to develop theories in the form of models that are validated by comparing their results against real-world behaviors.

Our research focuses on a form of inquiry that we refer to as observational investigations. In some scientific disciplines, the primary means for building and generalizing explanations and theories comes from observing and analyzing phenomena, generally because experimental methods of controlling and manipulating variables are difficult (if not impossible). For instance, astronomers observe the universe to understand how things like planetary behavior fit or deviate from existing theories and models (Brickhouse, Dagher, Shipman, & Letts, 2002). Evolutionary biologists create historical explanations about the developments of organisms over time by observing and comparing behaviors because experimentation on natural populations is not possible (Mayr, 1988; Rudolph & Stewart, 1998). Classical experiments are difficult to perform on celestial bodies and animals in the wild, but observational techniques can be used to develop scientific explanations.

Students should understand that observational investigations can be used to generate new hypotheses and articulate existing theories to develop comprehensive understandings of scientific practice. Theory articulation occurs when scientists look for additional evidence in the form of novel observations of phenomena to support or refute existing theories (T. S. Kuhn, 1970; Ohlsson, 1992). For instance, evolutionary theory states that animal populations change due to natural selection, but it does not explain which selective pressures operate on particular populations under particular conditions. Evolutionary frameworks must be articulated and elaborated by comparing known behaviors with observations of novel ones and looking for relations that account for similarities and differences (Mayr, 1988). This form of knowledge building differs from experimental methods where conditions can be controlled and manipulated by researchers.

On one hand, observation is simply a matter of "looking at things." For instance, it is easy to notice numerous "truths" in the world: It is raining at the moment, the home basketball team lost its last game, and so on. These concrete statements about the world, however, differ from scientific observations that are used to generate further explanations and theories about observed phenomena; they require skills associated with collecting and interpreting data and are influenced by observer assumptions and domain knowledge (Haury, 2002). For instance, basketball fans may only care whether their team wins or loses (looking/seeing), but a coach may inspect hours of game films to infer strengths and weaknesses that could improve future performances (explaining/inferring). Our research seeks to understand the difficulties that students may have when conducting investigations that involve scientific observation and inference. Despite the importance of observation for knowledge building, it has received less attention than experimental forms of inquiry in science education, especially around helping students learn the goals and strategies of observation in classroom science (Haslam & Gunstone, 1996; Park & Kim, 1998; Tomkins & Tunnicliffe, 2001). We articulate challenges related to observation to address our main research question: How can learning environments be designed to facilitate student-directed observation and theory articulation in science classrooms?

There are numerous issues related to observation, but this article focuses on two that we believe are most relevant for conducting classroom inquiry. First, how can we help students understand what is important to observe? Martin (1972) suggested

> that a trained observer with certain knowledge and training can observe things that a person without this knowledge and training cannot observe. Further, a person's background will influence what properties he [or she] visually attends to in a particular object, or indeed whether he [or she] attends to any properties of the object at all. Finally, the theoretical background of a scientist leads him [or her] to observe noncognitively objects which the layman, because of his [or her] lack of theoretical background does not observe at all. (p. 107)

Expert scientists rely on tacit strategies to plan their investigations, select relevant data, and synthesize their observations into hypotheses and explanations. Learners in inquiry settings often lack strategic knowledge needed to plan and conduct scientific investigations (Edelson et al., 1999; Reiser et al., 2001), and their observations are likely to be influenced by prior knowledge and beliefs that are not necessarily "scientific" (Appleton, 1990; Driver & Bell, 1986).

Without understanding the nature of and strategies for conducting observational investigations, students may only attend to features made explicit by teachers or other experts (Haslam & Gunstone, 1996), defeating the point of student-directed inquiry. If disciplinary knowledge guides perception of observed phenomena (Driver, 1983; Hodson, 1986), we need to help students understand how to detect significant features during their observations and how to compare these against other observed examples to understand similarities and differences across behaviors. Normally tacit, expert strategies should be made explicit to learners to allow the integration of observational techniques into classroom science.

Our second concern is the use of scientific observations to provide data for hypothesis generation and explanations that articulate how and why various behaviors and processes occur. Learners often ignore the causal, intermediate interactions that could be observed, focusing primarily on final outcomes (D. Kuhn, Black, Keselman, & Kaplan, 2001; D. Kuhn et al., 1992; Merrill, Reiser, Beekelaar, & Hamid, 1992; Schauble & Glaser, 1990; Schauble et al., 1991; White, 1993). For instance, students observing the patterns of iron filings around magnets may focus their attention on the final positions of the filings, but they neglect their movement due to magnetic forces (Driver, 1983). Or they may explain the combination of two chemicals in terms of the final result (e.g., a change in color) without considering other features (e.g., temperature changes, odors emitted) preceding the final reaction (Haslam & Gunstone, 1996). Tracking the various actions that lead to final outcomes is necessary to develop casual explanations, and we need to help students understand the importance of accounting for causality (and correlations) during observations.

We examine these two issues—acquiring observation strategies and generating causal explanations—through design research to construct and investigate students' use of a computer-based learning environment called Animal Landlord. The initial curriculum was designed to support observational investigations and theory articulation in high school biology classrooms, engaging students in the study of lion hunting behaviors. Students are exposed to ecological concepts such as social organization, resource competition, and optimal foraging theory during their investigations. They also investigate core questions of behavioral ecology research—how and why do animals behave—by observing and explaining behaviors depicted in a library of video examples.

Animal Landlord provides tools to investigate digital film clips of lion hunts, and students use video as data (Nardi, Kuchinsky, Whittaker, Leichner, & Schwarz, 1996; Smith & Blankinship, 1999; Whittaker & O'Conaill, 1997) to develop explanations of animal behavior. Video was chosen as the observation medium because it allows students to observe events that are outside their daily experiences (e.g., lions hunting in the Serengeti) as well as conveying otherwise abstract concepts through concrete, visual examples (Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990). Events that occur quickly in the real world can be permanently captured in video, replayed, and analyzed many times as objects for observation and theory articulation. Students can also compare video cases to understand how contextual differences (e.g., time, location) impact the ways that behaviors and processes unfold (Collins & Brown, 1988). We can also surround digital video with software supports that guide students toward systematic observations and analyses by making investigation tasks explicit in computer interfaces and by constraining the order of progression through the tasks (Jackson et al., 1994; Quintana, Eng, Carra, Wu, & Soloway, 1999).

The remainder of the article describes a methodology for conducting observational investigations and its instantiation as scaffolds in software tools and curriculum materials. We begin with an overview of the challenges facing students as they conduct observational investigations and theory articulation. We then describe an investigation model that we developed to address these challenges by articulating methods for observing, interpreting, and explaining behavioral phenomena. This investigation model suggests a set of tasks that should be performed when conducting observations of complex behaviors: decomposing behaviors into smaller events, comparing these across numerous examples, looking for causal relations that influence final outcomes, and selecting and documenting evidence to support their explanations of behavior.

A description of the video annotation software and curriculum and their use in biology classrooms follows, focusing on the ways that these make the investigation model's tasks explicit. Animal Landlord was designed to scaffold observation tasks made explicit in the investigation model, and we analyze how these software supports influence the types of analyses learners conduct during their interactions with the tools. We consider the kinds of scaffolds that students need to develop requisite content knowledge to make informed observations, plan systematic analyses of complex data, generate coherent explanations of these data, and reflect on their findings to advance their knowledge. We also examine the ways that classroom culture supports observational inquiry, focusing on the forms of discourse and argumentation that students and teachers engage in to construct knowledge while working with the software and curricular scaffolds.

We then present data collected during the interventions to illustrate how student explanations of behavior changed as a result of using Animal Landlord to explain lion hunting behavior. The purpose of the data collection and analysis was to determine strengths and weaknesses of our investigation model and scaffolds designed around it. These data also suggest the types of explanations generated by students during their investigations. We conclude by discussing the results of our classroom studies, concentrating on issues that we noticed during the interventions and outlining an approach to supporting observational inquiry that may be applicable to domains other than behavioral ecology.

CHALLENGES RELATED TO OBSERVATIONAL INVESTIGATION

Although observation is an important method for building scientific knowledge, it has received less study than its experimental counterpart in science education research (Haslam & Gunstone, 1996; Park & Kim, 1998; Tomkins & Tunnicliffe, 2001). In this section, we review some of the challenges that students may encounter when conducting observational investigations.

We mentioned earlier that students are unlikely to possess the knowledge that expert scientists rely on when performing observational investigations. Experienced biologists possess domain knowledge that helps them distinguish between relevant and irrelevant aspects of observed phenomena and the sorts of relationships and arguments that can explain an animal's behavior. Scientists also understand that the purpose of observation is to articulate theories and models that can explain observed behaviors. Students, on the other hand, may not understand the purpose of observation in scientific contexts and fail to understand that it can provide ways to generate descriptive and/or prescriptive models that explain how and why various phenomena occur.

Observation is not unique to science; it is one of many ways that people make sense of the world during all sorts of activities (Millar, 1994). Students may not see differences between the goals of observation in scientific and everyday contexts (Reif & Larkin, 1991), where scientific observations are used as evidence to support the articulation of explanatory theories and models. Similarly, because the skill seems "obvious," teachers may feel that time spent encouraging observation in classrooms is time wasted, as students may simply "look at" phenomena without developing new knowledge (Tomkins & Tunnicliffe, 2001). Helping students and teachers understand and enact differences between "looking at" and "explaining why" is important to establish a culture of knowledge building around observational investigations in classrooms.

Scientific observation is generally preceded by domain-specific questions or problems that require explanation (Popper, 1972), resulting in an iterative cycle of observing to form and investigate questions, followed by a process of interpreting results and revising initial questions for further exploration. Students may not carefully attend to or record what they observe unless they are provided with clear initial questions to guide their investigations (Driver, 1983). Scientists' observations are directed by the domain specificity of their questions. For instance, evolutionary biologists and behavioral ecologists looking at the same scene will likely focus their observations on different features because the two fields ask different (yet related) questions. Therefore, students require some familiarity with the domains that they are working in and the types of questions that drive observations in those domains. They also need to understand the iterative process of using observation results to further refine questions and initial theories.

It is also important to understand that students hold conceptions about the phenomena they are investigating that can affect learning outcomes (Appleton, 1990; Driver, 1983; Driver & Bell, 1986; Haslam & Gunstone, 1996, 1998; Tomkins & Tunnicliffe, 2001). This can lead to confirmation biases where learners seek evidence to confirm prior knowledge and dismiss contradictory evidence (Klayman & Ha, 1987; Lord, Ross, & Lepper, 1979). For instance, a belief that lions are exceptional hunters can lead students to view observations of failed hunts as anomalies rather than new, contradictory evidence that requires altering their prior conceptions. Such biases can undermine the validity of scientific observations, as they can lead to explanations that only partially explain the complexity of the observed data.

Learners may also possess epistemological beliefs about the nature of science that lead them to believe that the results of their observations should be "facts" rather than multiple, competing hypotheses (Lederman, 1992; Songer & Linn, 1991). Such beliefs may make students believe that their investigations should yield right or wrong answers and nothing in between (Fairbrother & Hackling, 1997). Textbooks and other instructional materials may also encourage beliefs about science as a collection of facts. For instance, many classroom experiences fail to provide opportunities to understand the uncertainty of science by allowing students to investigate questions on their own, develop methods for generating and testing hypotheses, or connect data to conclusions (Germann, Haskins, & Auls, 1996; Pizzini, Shepardson, & Abell, 1991). The challenge is to help learners understand that observations can have multiple interpretations and that resolving these interpretations through argumentation is a critical part of the scientific enterprise.

These issues suggest that students need guidance to perform self-directed observations. This leads to a trade-off between letting students flounder while trying to define their own questions and problems and providing so much information that they merely "follow orders." In the latter case, students may only focus on features that are explicitly mentioned by teachers and/or experts (Haslam & Gunstone, 1996, 1998). For instance, Driver (1983) described situations where students observing Brownian motion and animal specimens only attend to scientific features after being explicitly told to do so. Teachers play a role in focusing classroom observations, but students may not learn to identify relevant features on their own if too much assistance is provided. An additional issue to consider when incorporating observation into classroom science is the balance between providing support for students while also allowing them the freedom to engage in discovery learning (Merrill, Reiser, Merrill, & Landes, 1995).

This is important when considering student tendencies to focus their observations on outcomes rather than the causal, intermediate actions that lead to outcomes (D. Kuhn et al., 2001; D. Kuhn et al., 1992; Merrill et al., 1992; Schauble & Glaser, 1990; Schauble et al., 1991; White, 1993). Complex behaviors and processes often have clear beginnings and endings that are easy to detect, but the chain of events connecting the two may differ across multiple observations. For instance, there can be a variety of reasons that a lion hunt results in the successful capture of prey, and the successes can only be explained by paying close attention to the actions performed by predators and prey in different environmental contexts. It may be difficult to see the importance of intermediate actions unless learners can view and compare a number of cases where an outcome is generated in different ways (e.g., successful hunts that include ambushes, long stalks followed by chases, etc.).

These challenges suggest a number of issues related to supporting student-directed observation. First, if observation is more than simply "looking at" phenomena, we must provide students with structured tasks that facilitate complex analysis and reasoning around observed materials. These tasks should help students understand that observation is not a goal in itself: It is a method of inquiry that provides data for articulating explanatory hypotheses and models. The tasks should also guide students to look for and use intermediate actions to develop causal explanations of observed outcomes. It is also important to include activities that force students to reexamine their claims to look for potential confirmation biases that could weaken their explanations. In a sense, observation can be divided into a number of smaller, related tasks that lead students from "looking at" to "explaining why" to deal with these challenges. In the next section, we present a "task analysis" of observation that attempts to address these issues—an investigation model that defines explicit subtasks related to the larger goal of explaining behavior through observational inquiry.

AN INVESTIGATION MODEL FOR OBSERVATION

We have said that expert scientists possess domain knowledge and inquiry skills that allow them to define and use research questions to focus their observations on relevant features and analyze the resulting data to develop explanations of observed behaviors. In this section, we discuss our efforts to help students conduct observations by making these two forms of knowledge explicit. One aspect of this is defining the process of observation—helping students develop procedures for collecting and organizing observational data. The second step is helping them make sense of their data by providing them with domain heuristics for detecting and explaining observed variations. For instance, it is useful to compare individual actions and traits across species when forming general explanations of how and why animals behave. We developed an investigation model (Reiser et al., 2001; Tabak, Smith, Sandoval, & Reiser, 1996) for the domain of behavioral ecology that explicitly guides students through expert strategies (e.g., annotation, comparison, and modeling). This investigation model is the foundation for our task supports, and it articulates two types of knowledge that students need to observe and explain complex behaviors.

The first type of knowledge concerns investigation strategies—procedural steps that assist the students in making sense of filmed events. Behavioral ecologists have systematic approaches to observing and interpreting behavior, and we want our students to use similar strategies as they view and explain behaviors in nature films. The second type of knowledge concerns explanation strategies. As students investigate video data, they need to evaluate their observations and interpretations in terms of domain-specific heuristics. What are good questions to ask? Which hypotheses are best pursued in light of the data? What are the metrics for evaluating hypotheses? Such questions can be answered by considering explanatory heuristics during the investigation process.

Investigation Strategies

Assembling a causal story about complex behavior means organizing observational data into coherent structures for explanation. It means thinking about the types of actions involved in the process and understanding how they influence final outcomes. Students do not necessarily understand how to perform these tasks, so we had to develop methods to make the process of observation explicit and understandable. More so, we had to understand the nature of the task(s) ourselves. We worked with a number of behavioral ecologists and immersed ourselves in their literature to discover how they make sense of their data. Our goal was not to develop a detailed cognitive model of expert practice. Rather, we wanted to provide students with scaffolding strategies that make components of expert practice apparent and tools that embody and encourage these principles (Reiser et al., 2001). We define four strategies for observing and interpreting behaviors.

Decomposing behavior. Complex behaviors consist of many constituent, related actions. The first task is to identify these constituent actions, to unpack behaviors into “primitive acts,“ and to understand how and why they contribute to the larger picture. Decomposing behaviors also allows us to characterize variations between different instances of a behavior. For instance, a lion might stalk its prey before attempting a capture, or it might go directly to a chase. Isolating these events from the larger hunting behavior may help students consider the connection between intermediate actions and final outcomes.

Comparing. A single observation of a phenomenon is not enough for generalizing causal explanations. Therefore, we have students view multiple examples of a single behavior so that they can compare them to look for similarities and differences. Comparing several observations can expose different ways to reach outcomes—for instance, different prey animals will have different strategies for avoiding their predators. Students might also notice temporal differences: Stalking a buffalo may take less time than stalking a zebra, and this may be important in the students' explanations. Comparison may also lead them to notice holes in their own analyses. For instance, students may miss key events while decomposing actions in the films, and these missing events become obvious as they visually compare their work products side by side.

Identifying causes of variance. After variations are identified through comparison, students need to determine their causes. For instance, discovering that lions hunt in groups of varying size is only part of the picture: One must then try to understand what variables might lead to the variation (e.g., size of prey, amount of prey in the area). This is an important part of theory articulation, for the theory of evolution does not explicitly mention the variables that govern behavior (Ohlsson, 1992), and these will likely differ across organisms. The events themselves are important, but the factors that account for these are important for generating causal explanations of behavior.

Relating. Finally, an explanation must link all of these pieces together into a coherent framework. This could take the form of a textual narrative, a mathematical equation, a qualitative model, and so on. In the Animal Landlord curriculum, students build decision trees, as these allow all possible paths from the beginning to the end of a hunt to be displayed graphically. This final product should be explanatory in some way, explicitly linking actions to factors that cause them.

Explanatory Strategies

Thus far, the investigation model provides a task model to help learners make fine-grained analyses of observed behaviors. Students also need supports to understand how to construct "valid" scientific explanations from their data (Reiser et al., 2001). We need to introduce domain-specific assumptions and methods to help students understand what makes a "good" argument. The assumptions provide a foundation for student explanations; there is no need for them to "prove" natural selection, but they can use the theoretical framework to guide their data collection and hypothesis generation. The methods are applied to the data to determine general patterns of behavior requiring further explanation or investigation. Together, the assumptions and methods help students interpret their investigation data and judge the soundness of their conclusions. For instance, a simplified view of evolutionary theory might include the following assumptions:

1. The theory of natural selection suggests that organisms perform "optimal" behaviors that contribute to their survival. Therefore, students can assume that observed creatures are "doing the right thing" or something close to it.

2. Optimal behavior can be defined in terms of the creature's ability to pass on its genetic material. This suggests that many behaviors can be explained by thinking about their contributions to survival and reproduction.

Students also need methods for "testing" the observational data to see how various actions might be explained in terms of these assumptions. For instance, it is useful to apply the following methods when observing animal behaviors:

1. *Comparative method*. The importance of a particular trait can often be determined by comparing different organisms that do and do not possess it (Davies & Krebs, 1978). For instance, comparing differences between lions and other large felines may lead to hypotheses about the lion's unique social structure. Or one might notice that the physical size of different prey animals is somehow connected to the ability to avoid predators. One can understand and explain behavioral phenomena by considering variation in (a) traits within a species, (b) traits across species, (c) approaches to achieving goals, and (d) approaches to performing actions.
2. *Costs and benefits*. Theories of optimal behavior suggest that creatures will behave in ways that maximize benefits and minimize costs (Krebs & McCleery, 1984; McCleery, 1978). These costs and benefits are assessed in terms of survival and genetic fitness. For instance, we provide an example later in the article concerning the male lion and its mane. One way to develop hypotheses about the presence of the mane would be to consider potential costs and benefits of the feature.
3. *Selection pressures*. Environmental and other external pressures may lead a creature to prefer one behavior to another in certain contexts. Identifying these pressures can be useful when trying to understand influences on behavior. Much like the comparative method, the general idea is to seek similarities and differences between actions that might be influenced by factors such as time of day, amount of ground cover, and so on.
4. *Form and function*. An animal's physical characteristics often suggest reasons for its behavior. Similarly, a creature's behaviors often justify physical traits. For instance, female lions hunt more than males, and this behavior may be linked to their size differences. The general idea is to compare behaviors with physical characteristics and develop connections between these to explain evolutionary development.

The investigation procedures specify a general framework for conducting observational work, from selecting important features to creating models based on patterns of evidence. The explanatory heuristics complement these procedures by providing ways for students to construct evidence and conclusions to expand existing theories (e.g., natural selection) and engage in theory articulation. In the next section, we describe how the investigation model is embodied in software and curricular materials to scaffold observational investigations.

SCAFFOLDING INVESTIGATION WITH ANIMAL LANDLORD

Our investigation model suggests tasks and strategies needed to conduct observational investigations, but we need to return to our original research questions to make these tasks accessible to students. That is, we need to consider ways to make these tasks explicit to students as well as having teachers, software, and curricular materials scaffold the enactment of observational inquiry in classrooms. After identifying learner tasks and problems that may arise during their execution, we can design concrete artifacts and scaffolds to facilitate learning and performance around the investigation model.

Scaffolding typically refers to the process of assisting learners to perform tasks that would otherwise be outside their competence and abilities (Collins, Brown, & Newman, 1989; Wood, Bruner, & Ross, 1976). Such support can come from teachers, parents, and other knowledgeable peers, but it can also come from computer-based environments. For example, software tools can include prompts to encourage students to perform various actions (Davis & Linn, 2000), representations to help students plan and organize their problem solving (Quintana et al., 1999), or representations that track previous actions made during student problem solving (Collins & Brown, 1988; Koedinger & Anderson, 1993). In these cases, "basic" computer tools are augmented with supports based on theories of learning to help students perform tasks that would be otherwise difficult.

In our case, student observations and theory articulation take place around a video annotation environment named Animal Landlord. In its first deployments, students used the software to investigate video footage of lion hunts, observing how they (and their prey) behave during hunting episodes. Students consider behavioral factors such as resource competition, selection pressures, social organization, and variation between individuals and species to explain how and why lions succeed or fail to capture their prey.

Our video tools provide students with opportunities to use video as data (Nardi et al., 1996; Smith & Blankinship, 1999; Whittaker & O'Conaill, 1997) that inform the generation of explanatory hypotheses and models. Rather than simply providing video "lectures" that provide information, we have tried to create a video laboratory (Rubin, 1993) where learners actively investigate filmed behaviors through careful observation. That is, students could easily watch nature film documentaries in a passive manner to learn expert opinions on lion hunting. Instead, we provide tools that allow video to be reviewed, analyzed, and ultimately explained. Previous environments that have used video as data in instructional settings have focused on mathematics (Cappo & Darling, 1996; Cognition and Technology Group at Vanderbilt, 1997; Rubin, Bresnahan, & Ducas, 1996; Rubin & Win, 1994), physics (Escalada & Zollman, 1997), kinesiology (Gross, 1998), teacher professional development (Chaney-Cullen & Duffy, 1999; Lampert & Ball, 1998; Soloway, Krajcik, Blumenfeld, & Marx, 1996; Ulewicz & Beatty, 2001), and other areas that encourage self-reflection on prior performances (Cherry, Fournier, & Stevens, 2003; Goldman-Segall, 1997; Nardi et al., 1996; Stevens & Hall, 1997). We build on this existing work by developing scaffolds that provide students with tools and visualizations to assist their work around our investigation model for observation.

In this section, we describe curricular enactments that took place in three classrooms over a period of a week (see Table 1 for an overview of the week's activities) to illustrate the video analysis and interpretation tasks, focusing on the ways that students use Animal Landlord's tools to conduct their investigations of predator–prey behaviors and how the tools and classroom discussions make investigation strategies and explanatory heuristics explicit. The main goal is to demonstrate how the design of the software and curriculum make observation tasks explicit for novice learners.

Modeling Observation Strategies

We collaborated with teachers to design introductory exercises that introduced students to the primary questions in behavioral ecology—how and why do creatures behave (Davies & Krebs, 1978; Mayr, 1988; Tinbergen, 1978). On the first day of instruction, teachers showed their students a videotape of various creatures hunting, the primary clip showing chimpanzees hunting red colobus monkeys (Gunton, 1991). Teachers used this film to highlight the ways that ecologists ask and attempt to answer how and why questions. For instance, teachers focused students on how the chimps assume various roles during the hunt—one chimp leads the attack while some chase the monkey, others block escape routes, and so on. Teachers also pointed out that the film narration mentions the chimpanzee's preference for hunting in the wet season without explaining why this is so. A discussion around the assumptions of natural selection—that organisms behave in ways that have been selected to best suit their abilities to survive and reproduce—was led by teachers to get students thinking about potential explanations for the wet season hunting.

TABLE 1
Overview of Animal Landlord's Week-Long Activities

Day	*Topic*
1. Introduction	Modeling tasks with video of chimpanzees and other creatures
2. Annotation	Hunting films annotated in small groups
3. Comparison	Annotations compared to look for similarities and variations
4. Identifying causes of variance	Students revisit video to find causes of variation; create decision trees
5. Relating and model building	Whole-class discussions of decision trees

This introductory video session is designed to help students understand distinctions between how and why questions of behavior and show them how to begin their investigations. Teachers use the chimpanzee film to show how various actions lead to the capture of prey (e.g., blocking a monkey's escape path so other chimps can ambush it). Students are shown how to deconstruct hunting behaviors into smaller, constituent actions (e.g., stalking, chasing) to begin assembling answers to how and why questions.

Decompose Behaviors

The class is divided into groups of 3 to 4 students for the first computer task, decomposing and describing the actions occurring in various hunting clips. Each group works with nine digital video clips, ranging between 30 sec to two min in length, that are displayed in Animal Landlord's movie viewer (Figure 1). There is a menu on the viewer listing some of the common actions that occur during hunting episodes. As students watch the films, they select interesting video frames and label them with these actions (or create new actions if necessary). The current film frame is placed in an annotation window when it is labeled with an action (Figure 2). Students typically

FIGURE 1 Animal Landlord's movie viewer. Students use the menu at the bottom to mark video frames.

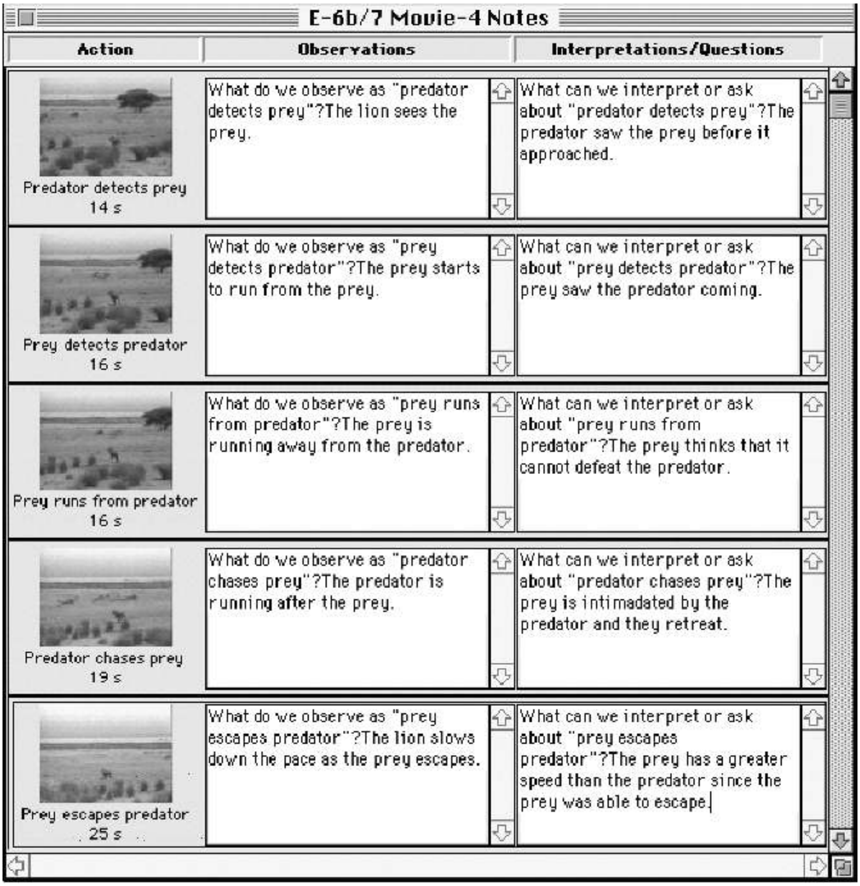

FIGURE 2 An annotation window created by students. Each row of the window contains a thumbnail of the video actions, a description of what students observed in the video frame, and interpretations and/or questions that they have from their observations.

watch the film several times before pausing it at interesting points and naming important actions with the selection menu.

Figure 2 shows an annotation window completed by a group of students. On the left is a column marked ”Action”; each action entry contains a label provided by the students, a thumbnail picture of the action’s video frame, and the time of the event’s occurrence. This collection of images and action labels show the students’ representation of the video’s “plot structure.” Elaborating this plot skeleton are students’ explanations of the events.

There are two types of annotations for each event. In the “Observations” column, students comment on aspects of the actions that led to their choice of an action label.

These observations are meant to describe the physical events occurring in the scene (e.g., "What do we observe as 'predator stalks prey'? It follows at the rear and crouches down low."). The "Interpretations/Questions" column is used to describe inferences about reasons for behaviors (e.g., "What can we interpret or ask about 'predator picks target'? The lionesses probably chose the fat one because it would provide the most meat.") and/or questions that arise about the visual events (e.g., "What can we interpret or ask about 'prey runs from predator'? Shouldn't the mother warthog warn the young ones?"). The differences between observation and interpretation in this context can be thought of as focusing students on how and why questions, respectively. The observations tell us how a creature is behaving; the interpretations tell us why it might be behaving in that manner.

This format for annotation attempts to facilitate observations and interpretations derived by decomposing complex behaviors into smaller, related actions (e.g., stalking, detection). In other words, this task is designed to facilitate the first investigation strategy—decomposing behaviors into component actions. The two-column format was designed to focus students on observable "facts" and interpretations requiring further evidence and testing (Norris, 1985).

Compare Behaviors and Identify Factors

Each event included in student annotations is a "decision point" that influences the predator's success or failure. For example, a predator may chase, ignore, or stalk after detecting its prey. Comparing multiple annotations allows students to see the range of possible interactions between predator, prey, and environment. We want students to find events occurring across all of the films and to think about why they are integral parts of the hunt. We also want them to find actions that do not appear in all of the hunting films to identify interesting variations that need to be explained. They should also be thinking about the pre- and postconditions surrounding particular events (e.g., why does prey detection occur before stalking, chasing after stalking?). Understanding what happens before and after an event is a step toward building a causal picture of the hunting behaviors, as students can begin explaining why certain events follow or precede one another. This also allows them to think about why these particular decisions have been evolutionarily determined.

We developed a tool to view and compare multiple film annotations (Figure 3). Students load their annotations into this comparison tool to inspect similarities and differences between actions. They can align actions of the same type to compare the flow of events through the films. For instance, Figure 3 shows the comparison tool with all actions labeled "Predator stalks prey" in a single row. All actions above the stalking row are labeled "Predator detects prey," whereas the actions below differ across the four films. Groups of students collaborate around the tool to look for these types of similarities and differences in events across films.

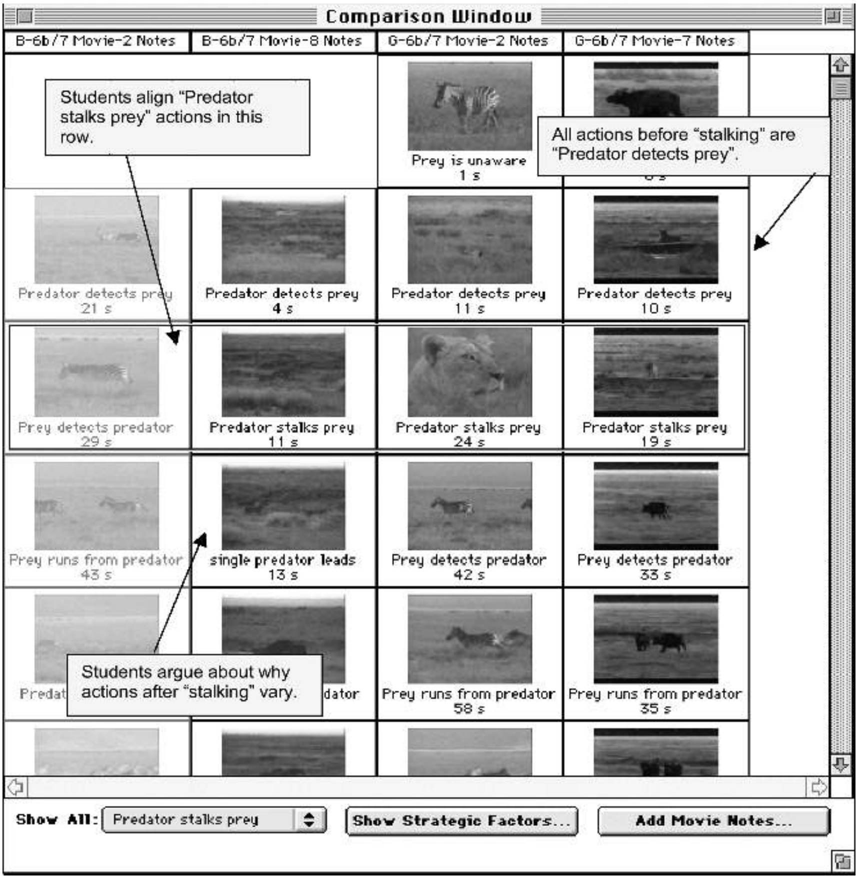

FIGURE 3 The comparison interface aligned on the action "Predator stalks prey." Students line use the tool to what happens before and after a selected action. The leftmost column is grayed out, as there is no stalking action present. The notes point to the aligned row and the actions before and after the selected action.

The thumbnail pictures access their respective video frames, allowing students to click them and quickly inspect annotated scenes. Students use this feature to return to their annotated video frames and apply them as evidence for claims during group arguments. For instance, they might argue over the different conditions that lead to successful stalking, focusing on factors like the type of prey being hunted or the amount of ground cover in the area. When looking at similar events, they use the video to understand how a particular action might differ across films, getting at the strategic factors described in the next section.

Identify Factors

The next step in the investigation model is to identify factors responsible for variation. Students use the comparison tool to argue about features and events that lead to particular behaviors. For instance, a lion might move straight to a chase if it is well camouflaged and its prey is within reach (e.g., "ambush" situations). This suggests a relation between the amount of ground cover that can conceal the lion and the distance between the predator and its prey. The comparison tool simplifies the task of visualizing the data so that students can find other relations between visual features and observed actions.

Relate

The final task is to relate findings into a qualitative explanation of behavior. The comparison tool provides facilities for explicitly comparing films, and students use it to understand variations across hunts. They use the tool's visualizations to construct decision trees representing the space of hunting interactions. Rather than building these trees with computer tools (e.g., concept mapping software), students create them on large sheets of poster paper (Figure 4). Most of the whole-class discussions revolve around the decision trees, so it is important that they be large enough for others to view and critique (as opposed to living on computer monitors where group work is difficult to display to an entire class). Students create qualitative models of predator–prey interactions resembling those found in the ecological literature (Elliott, Cowan, & Holling, 1977; Lima, 1987; Lima & Dill, 1990), specifically looking at decisions made during the hunting episode.

Decision trees are useful for describing the variations that can occur during a hunt as well as the factors that lead to these variations. For instance, a lion may

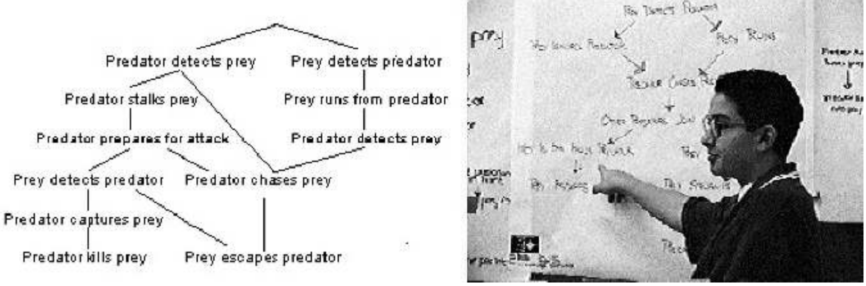

FIGURE 4 A partial decision tree generalized by students from three films. Students create these trees on large sheets of butcher block paper to model predator–prey interactions during hunting encounters. Teachers use these posters in whole-class discussions to focus students on evolutionary reasons for the various paths through the space. The image on the right shows 1 of our students presenting his group's decision tree during a whole-class discussion.

chase its prey without stalking if it is close enough to its prey. The distance between predator and prey influences the lion's decision to stalk or chase. Students were asked to look for similar factors influencing decisions made by predator and prey and write these on their decision trees. Teachers asked students about their lists of decision factors during classroom discussions of the trees.

Decision tree posters are completed and displayed around the classroom for discussion. Each group presents their tree and discusses some of the causal factors that they discovered. These whole-class discussions are used to build consensus around the models, allowing students and teacher to critique the products. Teachers typically focused on certain actions and strategic factors provided by students for extended discussions, leading students through possible evolutionary explanations for aspects of lion behavior (e.g., why do female lions do the majority of the hunting). The decision trees play the important role of linking the annotations, comparisons, and causes of variation into a unified model. The whole-class critiques exposed holes in students' models and provided opportunities to ask why questions about behavior. For example, teachers often asked students why a predator would ignore its prey or choose not to stalk and move directly into a chase.

Teachers also asked students to "test" their decision trees against other films (on videocassettes) as a whole-class exercise. As additional videos were shown (not limited to lions, but limited to hunting), students saw if their decision models could account for the behaviors seen in the new visual data. For instance, students watched a film clip about sharks to see if their actions "fit" the decision trees that they created for lion hunting. Students refined their trees if new findings were discovered from the shark film. In this way, students gain an understanding of how scientific models can be used to make predictions about behavior, pushing them from beliefs about models as simple replicas of the world toward an awareness of their predictive power (Grosslight, Unger, Jay, & Smith, 1991; Schauble, Glaser, Duschl, Schulze, & John, 1995).

By the end of the week, students observe video to isolate important actions that influence hunting, compare these actions to understand similarities and differences, attempt to find the causes of the variations, and create models to explain the overall behavior. These activities help reinforce the investigation model's strategies, and teachers work with students to help them frame their explanations in terms of domain-specific assumptions and methods. The software tools assist this by making observation tasks explicit to students and structuring student-created artifacts to reflect important scientific principles and methods (e.g., observation vs. interpretation, detecting and explaining variance).

BEHAVIORAL ANALYSIS IN CLASSROOMS

Animal Landlord's computer environment and curriculum evolved over four deployments to classrooms. One of our goals was to understand how students reasoned and argued as they conducted their investigations. In this section, we explain what occurred in classrooms, focusing on discussions, student work products, and individual student abilities to reason about behaviors as assessed in pre- and posttests. It is useful to consider our data and analyses as a type of design-based research (Brown, 1992; Collins, 1992; Design Based Research Collective, 2003)—an evaluation of the possible learning outcomes associated with our designed artifacts. We stress this, as it is important to view our results as contributing to future iterations of the software and curriculum versus being a summative evaluation.

Classroom Context

The data reported here come from pre- and posttests administered to 44 high school freshman (20 boys, 23 girls) in two Chicago-area biology classrooms, serving mostly upper- to middle-class socioeconomic communities. This particular school was linguistically diverse, with 54% of the students being language minorities (e.g., English is not their first language) at the time of data collection. The majority of the students were 14 years old, and all were enrolled in their first high school science course.

Method

We collected all student-produced artifacts, from computer annotations to paper-based decision trees. We also videotaped classroom sessions, especially whole-class discussions, to understand how teachers helped students rethink and refine their original hypotheses. These data help us to see whether the investigation tasks elicit explanatory reasoning about subtle patterns of behavior and causal forms of explanations and, in general, focus students on justifying hypotheses with domain-specific evidence associated with the investigation procedures and explanatory heuristics.

To understand how Animal Landlord influenced behavioral analyses, a pretest was given before the intervention and compared to results from a similar posttest administered 1 week after the intervention's conclusion. The tests consisted of seven open-ended essay questions drawn from university-level ecology exams (see Appendix). We wanted to see how 1st-year high school students would answer these questions and, more important, if their responses would change after the intervention. We expected students' posttest answers to include more causal explanations tied to relevant, biological concepts expressed through our investigation strategies and explanatory heuristics.

Consider this essay question that appeared on the pre- and posttests: "What limits the amount of prey consumed by a predator?" Initially, students had responses such as, "If they're not hungry, they won't eat," and "They know they have to save food for times when prey are scarce." We expected their explanations to make more use of behavioral phenomena and include more causal relations as a result of decomposing, analyzing, and linking related visual events after working through the intervention. Our teachers never explicitly talked about bounds on prey consumption with students, but they did use the investigation procedures and explanatory heuristics to impose structure on the activity, demonstrating and supporting tasks in ways that helped students attend to such issues and develop more sophisticated explanations.

In the following sections, we report pre- and posttest data from two of the three classrooms that enacted the Animal Landlord unit. The third classroom was not included in the analysis because that teacher's instructions to her class differed from the other two. Whereas the others encouraged students to be complete in answering the questions, the third teacher instructed the class to list a specified number of points for each questions. We felt these instructions introduced potential bias along the dimensions that we hoped to analyze (e.g., students' abilities to spontaneously generate multiple answers and explanations for behaviors), and, indeed, they reduced the amount of variation between students and between pre- and posttest responses found in the other two classes.

Evaluation Clarification

We aggregated the data from all questions in the remaining classrooms to compare pre- and posttest responses for each student. The first author and a rater unfamiliar with the project independently and blindly scored student responses. Interrater agreement on the various measures was 82%, and major disagreements were resolved through discussion and used in the analyses presented following.

We did not compare our test classrooms against control groups that used traditional materials to teach similar concepts. Instead, we combine our case studies of student work with analyses of the student discourse in whole-class settings and with analyses of pre- and posttests to understand the nature of the inquiry processes that students engaged in and the way that their conceptual understanding of the material grew during the intervention. Later studies provide additional evaluations to better understand student learning (Golan, Kyza, Reiser, & Edelson, 2001, 2002; Margulis, Reiser, Dombeck, Go, Kyza, & Golan, 2001). The following analyses contributed to those studies by suggesting "benchmarks" for student (and teacher) performance around the materials.

Articulating and Justifying

We asked students to answer questions that could not be satisfied by a single response. For instance, there are multiple reasons that organisms prefer to live alone or in groups. Thus, our first step in analyzing the data was to count the number of different answers given for each question. For instance, a student might say that lions hunt in groups "for safety, for hunting, and for mating"; this would count as three separate points for the question. Table 2 shows typical examples of student responses and how they were divided into unique points. An increase in the number of points raised between pre- and posttests could indicate that students understand the need to articulate multiple reasons for the execution of a behavior and/or that they have learned more relevant concepts to apply to each question.

Similarly, each point raised may contain a justification or explanation. Raising an issue such as, "A cost of predation is being out in the open," is useful, but it says nothing about why it is a cost to the creature. Justifying each point goes beyond stating what occurred in the video data, moving from simply observing to explaining behaviors. Example justifications are shown in Table 3.

TABLE 2
Student Responses to the Question, "What Kinds of Things Limit the Amount of Food That a Predator Consumes?"

Student Response	*No. of Points*
1. If a *predator cannot catch the prey,* then that would limit its food consumption.	2
2. If a *predator has offspring,* it may have to watch the offspring instead of find food.	2
His *physical characteristics* such as its teeth, claws. The *speed* that he has. *Ability to see* close and far. *His diet. Knowing what looks pleasing and healthy.*	4
1. If the *predator is hunting with a group* it may have to save food for the others.	4
2. If *another predator comes along,* the first predator may not eat all the prey and will save some for the other predator. Example—Cheetah and lions meet.	4
3. They may not be hungry because *they already ate.*	4
4. Predator *needs only enough to survive*; not to eat a lot in case something dangerous comes (another predator).	4

Note. For each answer, we look for the number of points raised (each point is italicized).

TABLE 3
Example Justifications From the Pre- and Posttest Responses

Student Response	*Type*
If it is at night. This is important *because at night I think it would be hard to catch prey.*	Explanation
Takes a lot of energy to make the catch so *by the time it catches it, it is too tired to eat it. So it wastes energy and gets nothing out of it, no energy put back in.*	Explanation
While obtaining food, the predator could die or get hurt. *For example, a hyena tries to bite and capture a bull and the bull stomps on it; the skinny hyena would be smashed by the heavy bull.*	Example
The predator could be too tired to eat. It might have wasted all its energy chasing the prey. *Example: Cheetah runs so incredibly fast that by the time it has caught the prey, it's so tired that it can't even stand up!*	Example

Note. The coded justifications are italicized.

Figure 5 shows that the mean number of points raised for each question increased from 2.43 to 3.93, $F(1, 42) = 28.63$, $p < .001$, whereas the mean number of justifications for each question also increased from 1.25 to 2.41, $F(1, 42) = 14.14$, $p < .001$. These increases suggest that students are refining their initial conceptions of behavior and/or how behavior should be explained to include more knowledge and rationales for this knowledge. During their investigations, they may have developed new understandings about the content of biological explanations. For instance, the increased responses for each question may result from observing and comparing a corpus of films, seeing alternative ways to interpret hunting behaviors. The increased justifications are likely a result of classroom discussions where there was an emphasis on explaining hypotheses with video data.

More so, the annotation work may be responsible for the increase in issues and their justifications, as it forces students to be explicit about each factor in the film leading to the success or failure of the hunt. They have to be clear about each event, and this practice may lead them to articulate more responses on the posttest. When forced to be explicit about the intermediate actions in the hunt, students gain an understanding of their importance to the overall outcome; this is reflected in the increased number of points. Working with the comparison tool could also influence these increases because discussions during that task focus on relations between actions and factors leading to predator–prey decisions.

We noticed students making careful observations of video during our classroom observations. For instance, many ecologists study herbivore vigilance—behaviors associated with prey animals scanning their surroundings for predators (Lima, 1987; Lima & Dill, 1990; Scheel, 1993). Some of the Animal Landlord films show prey animals cycling between scanning and feeding. Students may annotate these actions (“Prey looks around,” “Prey eats grass”) in a single film and not notice this

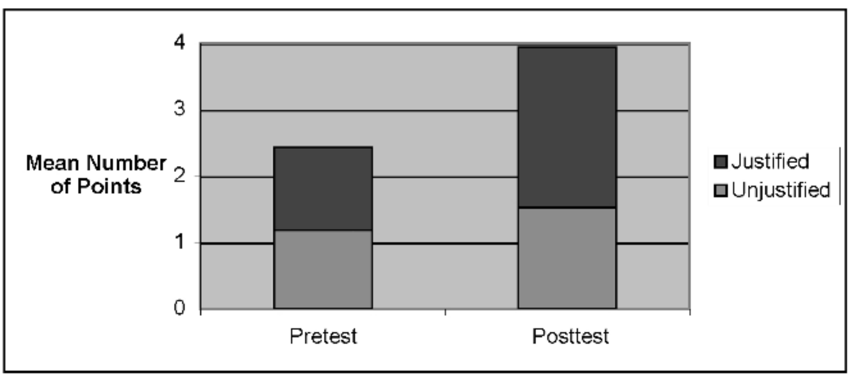

FIGURE 5 Mean number of points raised by the students in pre- and posttests. The shading within each bar shows the number of points with and without a rationale or justification.

pattern. But when multiple films were compared, some students noticed these recurring events and began forming generalizations about the behavior.

At least one group in each of the classrooms that we observed "discovered" vigilant behavior using the comparison tool. Discovering the pattern is only half of the battle, and teacher guidance was critical in helping students make the next step. In one instance that we observed, the teacher asked the students why they felt the scanning behaviors were important. More specifically, she asked them to investigate these questions to see if they could detect variations in the scanning patterns:

1. Do some prey animals scan the area longer than others?
2. Do different prey animals scan more often than others?
3. How does the number of prey affect the length and duration of the scan?

The teacher asked students to be specific about observable actions as well as stressing one of the points of the investigation model—searching for variations within and across species. The first two questions ask them to look for similarities and differences across species. The third question asks if vigilant behaviors differ within the same species: For instance, solitary zebras might scan more or less often than individual zebras in large herds. By making inter- and intraspecies comparisons, students may form richer explanations of behavior.

Interactions like these between students and teachers may play a role in the increased articulations and justifications. Teachers push students to offer multiple, possibly competing, hypotheses during class discussions. This often meant asking students to enumerate additional alternatives (e.g., "What other thoughts do people have?"). At other times, teachers posed counterexamples to students' hypotheses, forcing them to reinterpret their evidence to see alternatives (e.g., "Then why don't the *females* have manes if it would make them cooler?"). Such counterexamples help students see the value of looking for alternative explanations, but they also drive students to justify these points. Teachers may influence the increase in issues raised on the posttest by helping students recognize that no single answer is enough to consider. They may influence the increase in justifications by questioning the relevance of student explanations (e.g., "But why? It's got to have some sort of purpose, doesn't it?").

Domain-Specific Responses

We also want students to reference domain-specific problem features in their responses and justifications. Our teachers did not use terms like *altruism* and *optimal foraging* when addressing students. In fact, we steered them away from such vocabulary, as our goal was to develop conceptual understanding of patterns in the video data. Vocabulary words are useful for describing events once this understanding is acquired, but until then, we avoided scientific terminology during the intervention. Therefore, we looked for expressions of concepts on the pre- and posttests that relate to issues in behavioral ecology but might be disguised in the language of a 14 year old. We coded each justification according to the following biological concepts:

- *Behavioral*: Are students referencing behavioral features (e.g., social organization, morphological features) when justifying their responses (e.g., "If predators *are in groups*, they must share their kill.")?
- *Environment*: Are students connecting their explanations to relationships between the organism and environmental pressures (e.g., "The *time of day* affects how well the prey can see and detect the predators.")?
- *Energy*: Are they connecting behaviors to energetic requirements responsible for survival (e.g., "A predator might not chase a prey animal if it *cannot provide enough energy*.")?
- *Agent interactions*: Are they making connections between the agents involved in particular events? That is, are they drawing connections between various actors to show the directionality of causation (e.g., "If the *prey is too big*, the *predator may not want to capture* it.")?

These categories are not mutually exclusive; a single justification may be classified in multiple categories if necessary. Justifications that did not fit into these categories (e.g., " … because it isn't hungry") were considered domain general and omitted from the analysis to focus on students' use of domain-specific features.

Figure 6 shows how the presence of these four features changed from pretest to posttest. The largest change is in the use of behavioral features (from $M = 0.75$ to 2.32), $F(1, 42) = 52.53$, $p < .001$, which we would expect given our emphasis on behavior during the intervention. It seems logical that behavioral features would be

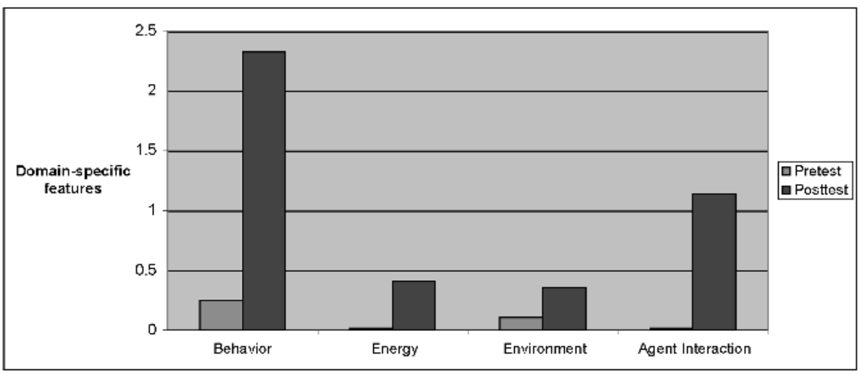

FIGURE 6 The four domain-specific measures coded for in student pre- and posttests.

the most prominent in their explanations, because students were annotating, comparing, and constructing decision trees with behavioral labels.

For instance, one group of students suggested during a whole-class discussion that female lions hunt more often than males. Their teacher instructed them to return to their computers and review the videos and their annotations to find evidence for their claim. Students used the comparison tool to look for instances of stalking and chasing and to understand when males and females succeeded or failed to capture prey. This allowed them to see that males are generally slower than the females. More so, the class observed that males are larger than females and decided that their size makes them ineffective hunters. They also have large manes that increase their chances of being detected by their prey. The teacher pushed them further.

Teacher: Having a big mane then is a *cost* to the lion. So there must be a reason for it. What's the benefit?

This is a much harder question to answer, and students explored potential explanations, most based around sexual selection ("If you have a bigger mane, you are the king of the pride," or "Bigger manes attract mates"). Such hypotheses could account for the mane, but the teacher had them revisit the video data to see if there were other observable patterns that might account for the mane. In this case, the teacher assisted students in making inferences from video to explain the presence of a mane.

Teacher: How do they kill, lions? You watched the videos.
Student 1: Fangs and bites to the upper neck.
Teacher: The upper where?
Student 1: To the jugular vein …
Teacher: (interrupting) Found where?
Student 1: Huh?
Student 2: Where's the jugular found?
Student 1: On the neck.
Teacher: Oh, so where would that be on the lion?
Student 3: Underneath his mane?
Class: Oh!
Teacher: Oh really … so anyone have another theory?
Student 4: Oh, so it's like it bites the mane and misses it.
Teacher: Yeah, the bigger the mane …
Multiple students: The harder it is to grab the neck.

In other words, males have manes to defend themselves from attack. The teacher has students articulate an alternative theory for the presence of the mane;

she pushes them to associate a morphological feature—the location of the jugular vein underneath the mane—with an adaptive trait—manes are hard to bite through. She also prompts students to recall the video data they worked with, encouraging later justification of theories with evidence.

The students were prompted to think about variation and the costs an benefits of behaviors and morphological features as the discussion continued:

Teacher:	Why do lions have this mane as opposed to other cats?
	<Much confusion and mumbling in the classroom>
Teacher:	Think, think! *Critical* thinking. Take 30 seconds and think.
Student 1:	Sun?
Teacher:	OK, the sun is a hypothesis. But why? It's gotta have some sort of purpose, doesn't it?
Student 1:	To block out the sun.
Student 2:	It makes them less hot.
Teacher:	Then why don't the females have manes if it would make them cooler?

The teacher is getting the students to think through two different types of variation—between and within species. First, she asks them to think about why the lion is the only large cat with a mane (between species). This gets students to form additional hypotheses, but then she focuses them on within-species variation, that lionesses lack manes. The teacher is doing more than just providing generic inquiry prompts; instead, she prompts students using features of the investigation model. She could have simply told them to "come up with other options" or to "explain the answer." But it may be more useful to focus students on domain-specific methods that are useful for thinking about relating features to behaviors. That is, the teacher is using comparison and cost–benefit analyses to suggest what kinds of alternatives and explanations are useful. In this case, going through a chain of possible variations gets students to reconsider their hypotheses about the lion's mane.

The students need more data to fully answer this question (e.g., they have not explained who is attacking the males such that they need a mane to defend themselves), but we are not necessarily interested in the "right" answer to the question. We are more concerned with the process of explanation that results from considering variations in the video data, trying to identify their causes, and weighing costs and benefits of behaviors and/or morphological features.

The other large leap in domain-specific features is the agent interaction category (from $M = 0.02$ to 1.14), $F(1, 42) = 24.32$, $p < .001$. We imagine the decision trees to be the biggest influence on this increase, as students had to be explicit about possible paths through the hunting space. Students had to shift viewpoints as they created their decision trees, describing behavior from the predator's perspective (e.g., "Predator chases prey") and then assuming the prey's perspective (e.g., "Prey runs from predator") to complete the interaction. This continual shift of perspective may have reinforced the outcomes we see in the agent interaction category.

There are also increases in the remaining two categories, environmental (from $M = 0.11$ to 0.36), $F(1, 42) = 4.38$, $p < .05$, and energy (from $M = 0.02$ to 0.41), $F(1, 42) = 16.76$, $p < .001$, but the magnitudes of these increases are smaller than those discussed previously. These factors were less central to the classroom discussions, and, as such, we expected fewer mentions of them. It is promising that there are increases in these areas, despite the lack of explicit focus on environmental and energy concerns. We would need to target these features in future interventions if we wish to emphasize their importance.

Anthropomorphic and Teleological Versus Causal Responses

Many studies of student beliefs about animal behavior discuss anthropomorphic and teleological explanations (Bartov, 1978; Friedler, Zohar, & Tamir, 1993; Jungwirth, 1975, 1979; Silverstein & Tamir, 1993; Tamir & Zohar, 1991; Watts & Bentley, 1994; Zohar & Ginossar, 1998). *Anthropomorphism* refers to the attribution of human reasoning to nonhumans—the assumption that organisms adapt through the use of desires, intentions, and wishes. For instance, "Zebras avoid lions because they *are scared* of them," or "Plants *like* to be in wet soil." *Teleology* refers to situations where goals are used to justify the ways that certain structures are built or certain actions are performed. For examples, people may say things like, "Plants bend towards the window so that they can get more light," or "herbivore intestines are long because they need to digest more food than carnivores."

Previous research suggests that students often use and/or accept anthropomorphic and teleological explanations (Bartov, 1978; Friedler et al., 1993; Jungwirth, 1975, 1979; Tamir & Zohar, 1991; Zohar & Ginossar, 1998) rather than explaining phenomena in terms of causal mechanisms. The use of anthropomorphic/teleological explanations can lead to misconceptions about future goals being able to generate processes in the present (e.g., because it wants to survive in the future, it needs to perform X) or organisms consciously willing outcomes to occur (Bartov, 1978). In other words, the use of these explanations may conflict with generating causal, scientific explanations. This concern has caused many biology educators to prohibit the use of anthropomorphic/teleological discourse in classrooms (Jungwirth, 1975; Zohar & Ginossar, 1998).

Anthropomorphic/teleological statements are often convenient linguistic simplifications, and students may realize that they are not strictly true. We would still like to see them extending these conventions, drawing explicit, causal connections between intermediate actions as opposed to just relying on goals or outcomes to explain behaviors. The annotation, comparison, and model-building tasks, combined with small-group and whole-class discussions, may help students think about how and why questions of behavior in ways that lead to more causal explanations. Therefore, we looked at our students' work to see if they were generating anthropomorphic/teleological explanations before observing and analyzing the hunting videos and if their explanations become more causal after the intervention.

Student justifications to the exam questions were coded into anthropomorphic, teleological, and causal categories (see Table 4 for examples of each category). A change in the proportions of the three types of justifications can be seen in Figure 7,

TABLE 4
Examples of Students' Justifications Classified as Anthropomorphic, Teleological, and Causal

Explanation	*Type*
Maybe somehow *the predator "knows" to leave some of the prey so they can reproduce so there will be more prey later.*	Anthropomorphic
Prey might be faster or bigger than predator and *predator might know it doesn't have a chance* of catching it.	Anthropomorphic
Prey might be too small; therefore, *predator conserves energy to catch a bigger prey.*	Teleological
If you eat too much, *the prey will die out and become extinct.*	Teleological
One cost of obtaining food is the loss of energy. The act of the *predator catching the prey uses up a lot of their energy, which otherwise could be used for other purposes.*	Causal
The predator could be full and can't eat anymore because it ate so much before. *This could be because the size of the prey is too big or the size of the predator is too small to consume all of the prey.*	Causal

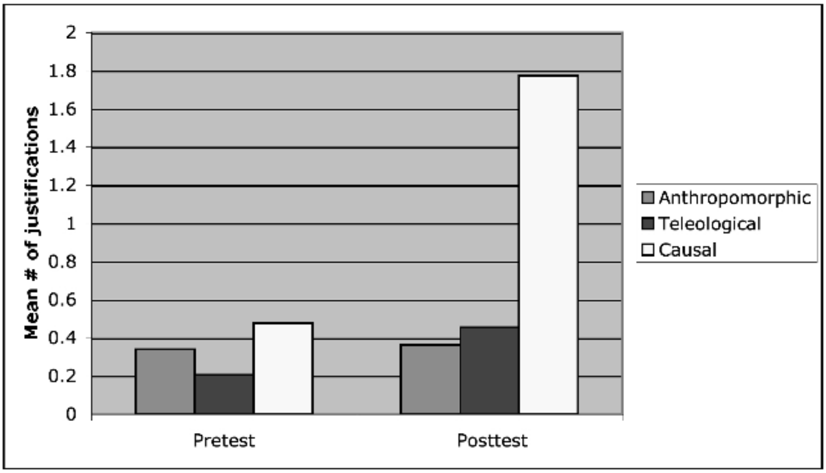

FIGURE 7 Mean number of anthropomorphic, teleological, and causal explanations found in the pretest and posttest.

$\chi^2(2, N = 136) = 14.97, p < .001$. Although anthropomorphic explanations decrease somewhat, teleological ones increase, and the causal explanations show the largest increase after the intervention.

A closer look at the data shows that some students shift their initial anthropomorphic explanations to teleological ones on the posttest. This could suggest a gradual shift from one level of reasoning to another—where anthropomorphic reasoning is the simplest level, causal reasoning is the most complex. Of interest, many of the students who initially generated anthropomorphic explanations in this study adopted causal explanations during the posttest. The behavioral tasks involving Animal Landlord may help students shift from anthropomorphic to causal explanations, although a small percentage only shift to teleological formulations.

Again, the investigation activities seem to help students see the importance of causality in behavioral explanations. Instead of listening to film narratives that might reinforce anthropomorphic and teleological explanations (Silverstein & Tamir, 1993), teachers push students to construct their own explanations according to the investigation model, and the annotations, comparisons, and decision models may account for these causal formulations. Annotating films and looking for similarities and differences with the comparison tool acquaint them with actions that make up hunting behaviors and form the basis of causal explanations. When coupled with the construction of decision trees that make interactions between organisms explicit, we see students moving from anthropomorphism to causality.

Teachers often pushed students to look for observable evidence that could be used to construct causal explanations. For example, one teacher questioned a group of students about their video annotations and their mention of a "sneaky" lion.

Teacher: What is the lion doing there [*points to video on screen*]?
Anna: It's being sneaky.
Teacher: Sneaky … I'm not sure what you mean. What do you mean by sneaky?
Anna: Sneaky, you know, it sneaks around, it's being clever.
Beth: Yeah, but that seems different than the other things. Shouldn't it be stalking?
Anna: Whatever … it's still being sneaky.
Teacher: How do you measure sneaky?
Anna: What do you mean?
Teacher: How do you describe it?
Beth: You mean how can you tell it's being sneaky? Like what's it doing?
Teacher: Yes.
Anna: It's creeping along in the grass. It's trying not to be seen. It's being sneaky!
Beth: Yeah, but that's stalking. Sneaky is more like an interpretation …
Anna: Sneaky, stalking … it's the same thing.

Beth: It's not 'cause sneaky doesn't say how the lion acts.
Anna: It's acting sneaky!
Beth: But what is it *doing*? It's crouching and going slow in the grass. So it's stalking.

The teacher is pushing the group to think about explaining the stalking behavior as a behavioral ecologist might do. "Sneaky" suggests that lions intentionally plan to quietly approach a creature—an anthropomorphic explanation. The teacher forces students to consider alternative ways to explain the observed behavior—namely, by describing the actions that occur, staying closer to what can actually be observed in the video data. She pushes them to think about "measuring sneakiness"—how to describe actions in terms of observable components. Beth begins to understand this prompting and tries to communicate this to her partner, breaking down "sneaky" (and "stalking," for that matter) into observable movements. Conversations like this one help students reflect on the nature of observation and inference and focus their attention on details to be annotated.

We also saw teachers guiding students away from anthropomorphic characterizations, such as "sneaky," "afraid," "brave," and so on. Decomposing the event into observable and, in some sense, quantifiable actions encourages a more sophisticated notion of "sneaky." Ultimately, these students begin to argue without the teacher's aid, negotiating the subtle differences between "being sneaky" and "stalking." Discussions like this help students understand the need to articulate specific actions and behaviors to create causal explanations.

Using the video tools, students noticed patterns of behavior such as prey vigilance, effects of group size (both predator and prey) on hunting success, and variations on using ground cover to conceal movement. Teachers ask students to explain these patterns using principles from the investigation model (e.g., relate features to functions, make comparisons between different prey animals performing similar actions). The posttest results suggest that students construct domain-specific explanations, providing more hypotheses for events, more justifications of these hypotheses, and grounding these justifications in terms of the investigation model's explanatory heuristics.

DISCUSSION

Our goal was to understand how observational investigation and theory articulation could be supported in science classrooms. We began with a discussion of challenges associated with performing scientific observations and described a scaffolding approach that makes the processes and products of investigation explicit to learners. Our initial efforts provided students with an explicit investigation model to structure tasks associated with observation as well as software scaffolds that staged each task with artifacts to reinforce tacit strategies used by scientists to observe and interpret data.

The video environment was designed to provide concrete support for the tasks outlined in the investigation model, but teachers and noncomputational media also play an important role in the curricular enactment. Animal Landlord is an instance of classroom-centered design (Loh, Radinsky, Russell, Gomez, Reiser, & Edelson, 1998; Smith & Reiser, 1998), a framework for instructional design that introduces new technologies and tasks into school settings while also understanding that these innovations must blend in with existing classroom norms and practices. For instance, paper artifacts are cultural norms in classrooms, and they are easier to share and critique in whole-class discussions than computational objects. On the other hand, the scaffolds that assist students in creating computer-based artifacts provide important guidance for observation and theory articulation that would be hard to replicate on paper. In a sense, classroom-centered design seeks to integrate existing and novel practices into schoolwork, merging the benefits of both to enhance student learning by distributing scaffolds in multiple forms throughout the activity (Puntambekar & Kolodner, 1998; Tabak, 2004).

Classroom-centered design also places an emphasis on classrooms rather than individual learners as the unit of analysis for research. Although we have presented data around individual students and their abilities to articulate theories, we have also tried to contextualize these results in terms of classroom activities. The scaffolds embodied in the video tools seemed to provide some structure for student observations, but there were additional support mechanisms in our classrooms that must be considered when trying to replicate our results in other settings. It is not enough to simply hand the computer software to teachers and expect them to enact the curriculum described in this article. We have identified a number of supports that also need to be conveyed for teachers to replicate the activities in their classrooms.

Support Through Modeling

Modeling activities for students is important if they are to understand the rules behind the learning activities (Collins et al., 1989). There are (at least) four methods that our teachers used to model the tasks of observation and theory articulation.

1. *Examples*. Teachers show example video clips during the introductory sessions to point out important behavioral features and to get students to begin identifying salient events for themselves. Without these initial examples, students tended to only observe and explain hunting outcomes rather than the causal, intermediate steps leading to an outcome (Smith & Reiser, 1998). Walking through the examples helps them understand what is required to create causal explanations of behavior.

2. *Analogies*. The chimpanzee film shown at the beginning of instruction plays an important role throughout the intervention, as it serves as the primary case from

which to draw analogies. Teachers use it to explain how decision trees will be constructed, how ecological and evolutionary theories can be used to explain alternative paths through the hunting space, and how different creatures have different approaches to hunting and predator evasion. An important result is that teachers and students can rely on the chimpanzee case to understand aspects of the lion problem. Perhaps more important is that teachers can use analogous cases to focus students on general features worth observing without giving away specific "solutions" to the lion problem. This assists in the trade-off between telling students exactly what to look for and having them develop their own intuitions based on the questions being investigated.

3. *Domain heuristics*. Teachers constantly remind students to think about the domain-specific, investigation heuristics that can be used to explain behaviors. For instance, in classroom dialogues, we noticed teachers focusing students on costs and benefits of particular actions. We also noticed them asking students to frame their explanations in terms of natural selection and to look for variations across the films. Each heuristic assists students in generating and explaining observations, and they form the core of the investigation model discussed earlier. By making these heuristics explicit, students can appropriate and use them during problem solving.

4. *Questions*. Guided questions and prompts can assist students in understanding the types of questions they should ask during inquiry activities (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Davis, 2003; King, 1994; Sandoval & Reiser, 1997). During the Animal Landlord intervention, we present a series of questions to students, from the top-level "how and why do lions hunt?" to strategic questions such as "what are the costs to the predator?" and "what can you interpret from that action?" Questions like these help students understand what they should be asking during the investigation process. Teachers constantly question students' assumptions during discussions, forcing them to justify their claims and rethink their hypotheses.

Early deployments of the curriculum often suffered because we tried to use only one or a few of these modeling methods. Our most successful interventions occurred when teachers integrated all of these into their coaching repertoire. By using examples, analogies, strategic hints, and questions, students begin to understand the important features of an ecological argument. These forms of modeling also assist students in overcoming the challenges related to observation—namely, developing their own domain-specific questions and knowledge to focus observations rather than relying solely on teachers to precisely explain features that need to be observed.

Support Through Artifacts

Each step in our investigation model can be linked to an artifact produced by students: The process of observation is broken down into subtasks associated with particular work products. Table 5 shows the investigation strategies supported by Animal Landlord and their related work products.

Each artifact was designed to make investigation strategies explicit to students. For instance, the structure of the annotation notes helps students understand the importance of causal, intermediate actions in theory articulation—that large behaviors need to be broken down into smaller units for analysis. The two-column layout of observations and inferences draws attention to the importance of distinguishing between the two when explaining behaviors. The comparison tool encourages students to think about multiple films as evidence and encourages argumentation about behavioral issues. That is, students collaborate to look for patterns in the video data with the comparison table, and as they do so, different groups often bring different perspectives to the classroom discussions. The conversations occur because these patterns can be detected with the software tools.

The ways that work processes and products are represented seem to influence final products and the types of reasoning that take place (Suthers & Hundhausen, 2003; Wojahn, Neuwirth, & Bullock, 1998). In the data analysis section, we suggested that various features of our work products might explain student outcomes. Our investigation model for observation was inspired by the ways that ecologists reason about complex behavior during their studies, and that model was instantiated into the tools described in the article. We hypothesized that the visual representations used in Animal Landlord would assist students' investigations, but we need to conduct further studies to compare the existing representations with others to understand how the structure of student artifacts influence the process of observation and theory articulation.

Support Through Discussion

Students engaged in discussions with their peers and teachers to argue what they learned from their observations of the nature films. The small-group and whole-class discussions were opportunities for groups to generate and explain their hypotheses about behaviors and for other groups to critique theories and

TABLE 5
Investigation Strategies Emphasized in Animal Landlord and the Artifacts Used to Help Students Use Them in Their Work

Strategy	*Artifact Support*
Observation versus inference	Annotation notes
Behavior decomposition	Annotation notes
Comparison	Comparison tool
Identifying variation	Comparison tool and decision trees
Relating concepts	Decision trees and strategic factor lists

question supporting evidence. Teachers supported these conversations, helping students understand how to justify and critique ecological arguments with explanatory heuristics. By articulating theories, students engage in a form of scientific discourse that is more aligned with that of experts, mostly through creating causal explanations and supporting these with empirical evidence.

Video became a conversational prop (Brinck & Gomez, 1992; Roschelle, 1992) for these discussions, providing data to stimulate student-directed argument and learning in classrooms. More so, each investigation stage provided opportunities for teachers to critique emerging hypotheses and lead students toward causal explanations. These critiques pushed students to overcome existing confirmation biases and epistemological beliefs about the nature of science and observation. Students reflected on their artifacts, using them as objects of their own thinking (D. Kuhn, 1993). Teachers used the same artifacts to understand students' thinking and to help them reinterpret their results in light of new information and data.

Although we would argue that the use of multiple scaffolds assists learners in various parts of the observation and theory articulation process, we also acknowledge that the distribution of these scaffolds emerged over iterations of the tools and curriculum rather than being planned ahead of time. The questions of how to (a) design distributed scaffolds in principled ways and (b) analyze the contributions of different elements on learning outcomes remain unanswered in this study (although Tabak, 2004, presents conceptual frameworks that are a first step toward rationalizing the design of distributed scaffolds). For instance, we present students with a set of tasks and artifacts to assist their observations, but we have not studied the impact of each task in isolation. Therefore, we cannot say whether annotation is more important than comparison, peer arguments are more important than whole-class discussions, and so on. Taking this step of decomposing the scaffolding system and determining the impact of its constituent parts is a future goal to further develop our understandings of ways to support observational inquiry in classrooms.

ISSUES

Although the results of our preliminary experiments with Animal Landlord and its classroom enactment suggest that students are using observations to articulate theories and hypotheses about behavior, there are issues and concerns about our use of video as data to support observational investigations that we address following.

Anthropomorphism

We reported students shifting from anthropomorphic and teleological accounts of behavior toward causal explanations that are more accepted by science educators. These results need to be considered carefully, however, as a student's talk may not reflect their actual mental models of behavior. Some students may use anthropomorphic explanations as convenient ways to express their hypotheses rather than going through the longer process of elaborating causal mechanisms—it takes more effort to explain that a lion is moving slowly through high ground cover than explaining that it is "being sneaky."

We could use students' anthropomorphic explanations to scaffold the development of causal accounts of behavior (Watts & Bentley, 1994; Zohar & Ginossar, 1998). Rather than discouraging students from anthropomorphic or animistic descriptions of behavior, it may be beneficial to build on people's inclinations to explain animal behavior in human terms to help them develop more "scientific" explanations. So we recognize that anthropomorphic explanations can be used as instructional scaffolds and that we cannot "penalize" students for using anthropomorphic explanations, as they may have richer mental models of behavior and causality than their discourse suggests. Still, we followed traditions in biology education that advocate the elimination of anthropomorphic and teleological discourse in our data analyses. We were pleased to see students shifting toward causal explanations, but we recognize that those who did not may not have completely articulated their understandings of the causal mechanisms underlying lion behavior.

Video Validity

Our video cases were pulled from existing documentary films where producers and editors carefully assemble moving images into coherent and compelling stories. Students saw highly edited clips that do not necessarily represent the full set of behaviors for lions and their prey. For instance, a lion could stalk its prey for 25–30 min before making its attack, but documentary producers remove these long periods to move viewers to the final outcome. The "grammar of film" increases the differences between documentary productions and real life. Cuts, pans, and zooms are often used in educational films to focus student attention on salient issues (Salomon, 1994). These film conventions often signaled behavior transitions in our video corpus, perhaps helping students during the annotation task by making changes in activity explicit.

Our video clips are best thought of as an idealized model of reality, much like ideal models used in physics, chemistry, and other science pedagogy. It seemed appropriate to use existing documentary films to train students on the core investigation strategies, using cinematic conventions as a type of scaffold. We selected clips that featured variables affecting the outcome of lion hunts (Table 6). The simplest variation is the outcome of the hunt—succeeding or failing to capture prey. More complex variables include the number of predators engaged in the hunt, the amount of ground cover, and the amount of visible light. Each clip varies several parameters at a time to increase the complexity of student investigations. But it

TABLE 6
Variables and Their Ranges Represented in Animal Landlord's Nine Films

Hunting Variable	*Variable Range*
Number of lions	1–12
Hunt style	Ambush, ignore, stalk, and chase
Amount of ground cover	None, low, high
Hunter gender	Male, female
Type of prey	Buffalo, gazelle, zebra, wildebeest
Number of prey	1–many
Amount of visible light	Night, day
Hunt outcome	Success, failure

could be argued that these prototypical cases display exaggerated versions of lion hunts, potentially giving too much support to students.

Future interventions could increase the complexity of the video to increase validity and introduce further strategies for data analysis. Newer instances of Animal Landlord use unedited video of zoo animals (Golan et al., 2001, 2002; Margulis et al., 2001) and lack film conventions that could lead students to associate sudden cuts or close-ups with biological significance. Students require more assistance during these investigations to understand what it important and what is "noise." Starting with ideal video segments may focus students on mastering basic observation and interpretation skills, opening the door for more complicated analyses of unedited video (and the real world).

Data Collection

Instead of working with an established video corpus, one could imagine learners posing and investigating questions around local animals (e.g., ants, dogs, squirrels) that they film themselves. That is, we could have asked our students to videotape and observe animals in their neighborhoods, much like other video environments that allow students to capture and study personal events like foot races, body movements, and so on (Cappo & Darling, 1996; Gross, 1998; Rubin et al., 1996; Rubin & Win, 1994). We excluded this type of data collection from our initial research for pedagogical reasons.

We felt that defining a novel research question and collecting data to study it should be separated from the task of receiving a high-level question and employing investigation strategies to arrive at potential hypotheses. Our students investigated how and why lions behave during hunting. Had they shot their own footage of animal behavior, they would have had to generate a similar top-level research issue. They would need to understand if their questions could be investigated through observation, and they would also need to collect data suitable for addressing their concerns. Such question posing is obviously important, but training students to do so was beyond the scope of this work. We see Animal Landlord as an interim step toward building observation skills that could later be applied to more open-ended investigations.

At the same time, we have allowed learners to collect their own visual data in recent projects. In one case, students studied history by photographing buildings in their communities and using the images to generate and investigate questions about changes in the urban landscape (Smith & Blankinship, 1999). We have also worked with adult diabetics who photographed their diet and exercise habits to pose questions to peers and medical practitioners about the connections between their behaviors and overall health (Frost & Smith, 2003). In those cases, learners create their own questions and make observations of their image collection to investigate related hypotheses. The teaching demands for these environments are considerably harder, as students (and teachers) require additional instruction around forming good questions for investigation and understanding domain concepts to help them create strong hypotheses and explanations.

Is It Better Than?

Because the studies reported in this article do not compare student performance against a control group, we cannot say if our approach is "better" or "different" than other approaches such as simply watching nature films. The purpose of this design research was to understand the potential of our approach, to see if our scaffolding techniques resulted in any changes in student knowledge after the intervention. We have reasons to believe that having students conduct their own observational investigations will yield more knowledge building than methods where students simply examine and study previous results. For instance, Park & Kim (1998) found that students conducting their own observations of electrical circuits were more likely to change existing misconceptions than those who simply listened to preexisting, expert observations. Nevertheless, we acknowledge the need for further experimental testing of our methodology to compare the knowledge gains reported in this article with other methods of learning similar content and process skills.

Teacher Adoption

We worked closely with willing and interested teachers who wanted to introduce inquiry activities into their classrooms. More so, they had already experimented with student-directed learning in their own teaching practices, so they understood our objectives and were able to codesign the supporting curriculum and materials. Because we cannot have direct contact with every teacher, we need to consider ways to disseminate our curricular materials in classrooms where we do not have direct contact with teachers.

In another study of Animal Landlord (Golan et al., 2002), students did not compare behaviors as we described earlier in this article. Teachers in those classrooms either lacked class time to engage in detailed comparisons or they did not see the need to have students draw analogies between behaviors across video clips. In contrast, the first author was present in the classrooms discussed in this article, and teachers occasionally depended on him to field unusual content and process questions. More important, we codesigned activities with the teachers involved in our studies, so there may have been a sense of ownership that led them to pursue comparison tasks, not to mention the understanding that comes from participating in design activities.

Teachers' prior knowledge, experiences, and beliefs will, of course, affect what occurs in classrooms, and the impact of educational technologies will ultimately be influenced by teachers' pedagogical practices (President's Committee of Advisors on Science and Technology, 1997). Future work must consider teachers' beliefs about scientific inquiry and how to assist them in developing practices that benefit classroom learning. Recent versions of Animal Landlord have addressed this by providing written materials, based on the preliminary results reported in this article, to help teachers navigate the curriculum and technology (Chicago Zoological Society & The Center for Learning Technologies in Urban Schools, 2000). These documents explain the inquiry process as well as domain-specific content (e.g., "animal fact sheets") that teachers can use to address student questions as well as overviews of the investigation process. Additional work around professional development "work circles" (Reiser, Spillane, Steinmuller, Sorsa, Carney, & Kyza, 2000) may also assist teachers in implementing inquiry curricula in their classrooms.

CONCLUSION

The results reported in this article suggest that our conceptual investigation model can support mindful approaches to observation and theory articulation. Students went beyond "looking at" to "explaining why" various behaviors occur in different settings. Video clips became cases for observation, teachers helped students gather evidence to support and critique claims, and the computer tools facilitated theory articulation around observed evidence. Students generated more evidence and causal explanations after working through the curricular activities, likely because of the explicit supports that assist in creating fine-grained analyses of behaviors, comparing these to look for variations, and using evidence to generate explanatory models.

Creating a classroom culture to support observational investigations required us to identify challenges that learners face and then designing and distributing scaffolds throughout all aspects of the learning experience to address them—in digital and analog artifacts and in small-group and whole-class discussions. Teachers model investigation skills for students to help them understand the purpose and goals of observational inquiry. The software tools provide scaffolds to encourage expert scientific practices defined by our investigation model (such as looking for intermediate actions to generate causal explanations). The written and graphical products created with the software provide teachers with opportunities to initiate and lead discussions and arguments around students' hypotheses. We began with a conceptual task model of observational investigations to articulate the activities that students needed to perform, but its practical enactment in classrooms required us to (a) develop concrete artifacts to make learner tasks concrete and visible for critique and (b) distribute support for learners across different media and classroom activities.

Our discussions in this article have focused on observing video in the domain of behavioral ecology, but the general approach of supporting observation with investigation models can be applied to other areas. The Animal Landlord software has been used to support studies of other animals, asking students to investigate different biological questions (Golan et al., 2001, 2002; Margulis et al., 2001). The investigation model has been used as a foundation to scaffold other software environments in history (Smith & Blankinship, 1999, 2000) and diabetes education (Frost & Smith, 2003). We suspect that the approach could be generalized to other domains where analyses of multiple cases of visible behaviors and processes are required to fully understand the causality leading to outcomes.

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The current version of Animal Landlord can be downloaded for Microsoft and Apple operating systems at http://www.letus.org/bguile/animallandlord/animallandlord.html

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APPENDIX
Animal Landlord Pretest and Posttest Questions

1. Predators do not eat all of their available prey. What kinds of things limit the amount of food that a predator consumes? Explain how each of your points limits food consumption.
2. Food provides energy for creatures, a benefit in terms of survival. What are some of the *costs* of obtaining food? Explain why each of your answers is a cost to the creature.
3. Some scientists argue that animals make "decisions" when hunting and being hunted.
   a. What kinds of decisions might a predator have to make in order to successfully capture its prey? Why does it need to make each of these decisions?
   b. What kinds of decisions might a prey animal have to make in order to avoid being captured by a predator? Why does it need to make each of these decisions?
4. Many species of animals live in groups, while many others do not.
   a. Why might an animal live in a group?
   b. Why might an animal choose to live alone?
   c. Would an animal ever choose to be in a group sometimes and not in a group at other times? Why?