How does a teacher scaffold students’ self-regulated learning
during a collaborative science inquiry investigation in GenScope?

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Abstract

The study investigated how a high-school science teacher scaffolded his students' self-regulated learning (SRL) during a collaborative CBLE-based science inquiry investigation in the classroom. Sixty-two 9th and 10th-grade honors biology students used GenScope to learn about evolution. We used instructional discourse analysis to explore our guiding research question: What aspects of students' SRL did the teacher scaffold in this context? Additionally, we distinguished between teacher utterances that were teacher-initiated instructional moves and utterances that were intended to scaffold students' SRL through guides, suggestions, and questions. The analysis revealed six main areas in which the teacher scaffolded students' SRL, listed in decreasing order of their frequency: use of cognitive strategies, planning and goal setting, metacognitive monitoring of cognition, monitoring and control of the context, behavior, and motivation. Two-thirds of the teacher's utterances were teacher-initiated instructional strategies. We argue that the teacher relied on teacher-initiated instructional strategies as a means of controlling the context of the classroom. We discuss implications for guiding the teacher's choices as he scaffolds student inquiry in a CBLE in his classroom in the future, and the use of SRL as a theoretical framework through which both pre-service and experienced teachers might explore their own teaching and better understand their students' learning.
Introduction

Advances in computer technology have led to an abundance of computer-based learning environments (CBLEs) designed to help students gain a deep conceptual understanding of complex science topics (see Jacobson & Kozma, 2000). It is not clear, however, that simply providing students with a high degree of control in such an environment can lead to measurable gains in their understanding of science content (Azevedo, Cromley, Winters, Xu, & Iny, 2003; Horwitz et al. 1998; Jacobson & Archidodou, 2000; Vye et al, 1998). Science learning with CBLEs in the classroom requires complex learning strategies and associated cognitive, metacognitive, and motivational dimensions (e.g., White & Frederiksen, 1998). These dimensions are elements of the construct known as self-regulated learning (SRL). This paper addresses the role that the science teacher plays in scaffolding students' SRL while they engage in collaborative inquiry in a CBLE.

In this study, high school science students used the GenScope (Horwitz et al. 1998) environment to investigate concepts of evolution through collaborative inquiry-based learning. Inquiry-based learning refers to an instructional model whereby students formulate their own experimental questions, generate predictions and hypotheses, design and carry out a controlled investigation, analyze data, and then draw conclusions based on the data (AAAS, 1993; White & Frederiksen, 1998). CBLEs can provide students the opportunity to ask questions and test hypotheses in a domain that would otherwise be too impractical to investigate through traditional scientific inquiry (Jacobson & Kozma, 2000). Research has shown, however, that students lack the proficiency in the cognitive, metacognitive, and motivational dimensions of SRL that are necessary to use CBLEs as a
tool for inquiry (Vye et al., 1998; White & Frederiksen, 1998; White, Shimoda, & Frederiksen, 1999). Simply providing students with the opportunity to inquire in a CBLE will not necessarily enhance learning (Singer, Marx, Krajick, & Chambers, 2000). Students must be able to regulate cognitive, metacognitive, and motivational aspects of their learning, and to engage in processes that activate and sustain these aspects as they progress toward learning goals (Schunk & Zimmerman, 1998). Due to the difficulties that students may experience in regulating their learning in an inquiry-based context that includes a CBLE, science teachers can scaffold aspects of SRL by modeling and coaching students in the use of cognitive strategies and by fostering metacognition and motivation (e.g., Azevedo, Verona, & Cromley, 2001; Singer et al, 2000)

**Theoretical Framework**

SRL is a theoretical framework that examines cognitive, behavioral, and affective aspects of learning. Learners regulate their own learning to the degree that they set goals for their learning and then attempt to monitor and control their cognition, motivation, and behavior. SRL is an active and constructive process that is guided and constrained by the learner’s goals and by contextual features of the learning environment (Pintrich, 2000). Students who are good self-regulators have generally been shown to be high achievers in a variety of learning domains (Zimmerman & Schunk, 2001). In this study, we make the assumption that students must self-regulate their own learning in order to learn complex science content in an inquiry-based CBLE context (Vye et al., 1998; White, Shimoda, & Frederiksen 2000).

There are several prominent theoretical perspectives on SRL, such as social cognitive (Schunk, 2001), information processing (Winne, 2001), and Vygotskian
These perspectives propose different constructs and mechanisms (Zimmerman, 2001; Pintrich, 2000), but most share four common assumptions about learning. First, learners are active, constructive participants in their own learning. Second, learners can monitor, control, and regulate aspects of their own cognition (e.g., goal-setting, employing and monitoring of cognitive strategies), motivation (e.g., self-efficacy beliefs, values for the task, interest), behavior (e.g., help seeking, maintenance and monitoring of effort and time use), and features of the learning environment (e.g., evaluation and monitoring of changing task conditions). Third, there is some standard against which learners can make comparisons to determine if particular processes should continue or if changes should be made. Fourth, individuals' self-regulation of their cognition, motivation, and behavior mediate the relationships between the person, the context, and achievement (Pintrich, 2000).

The assumption that SRL mediates relationships between the individual, the context, and achievement is particularly important for studying SRL in the classroom (Perry, 2002). This assumption is emphasized by several models, including social cognitive and sociocultural (Vygotskian) theories of self-regulated-learning, which recognize that individuals are situated within psychological, disciplinary, social, and cultural contexts (McCaslin & Hickey, 2001; Perry, 2002). However, this perspective has not been extensively used to examine the role of SRL in a classroom environment that includes CBLEs to learn science content, and analysis of SRL in this context is only now emerging (e.g., Azevedo, Verona, & Cromley, 2001; Azevedo, Winters, & Moos, 2004).
Scaffolding Students' Learning in CBLEs

In CBLEs, students control much of the learning context, so the students must be able to self-regulate their own learning in this context. Students may lack the ability to regulate their learning in a way that would allow them to use CBLEs as a tool for inquiry, however (e.g., White & Frederiksen, 1998). In a complex context such as a classroom that involves collaborative work in an inquiry-based CBLE, student learning must be scaffolded. Scaffolding is a critical aspect of providing individualized instruction (Hogan & Pressley, 1997, Meyer & Turner, 2002). It represents instructional support in the form of guides, strategies, and tools that can be used by students during learning to support understanding that would be impossible if they were left to learn on their own (Azevedo, Cromley, & Seibert, in press).

Teachers can scaffold students' SRL in the classroom by supporting students' monitoring, control, and regulation of their learning as they progress towards learning goals (Meyer & Turner, 2002). Meyer and Turner (2002) suggest three areas in which teachers may support students' SRL during instructional scaffolding: a.) helping students to build competence through increased understanding b.) engaging students in learning while supporting their social and emotional needs, and c.) helping students to build and exercise autonomy as learners. Ideally, this support shifts from external regulation by the teacher to greater individual regulation by students as the students internalize dimensions of SRL that are modeled by their teacher (Vygotsky, 1978).

In the context of the present study, scaffolding is critical for students' successful learning in GenScope because it can provide them with the external support that they need to employ cognitive, metacognitive, and motivational dimensions of their learning.
(Hickey & Kindfield, 1999). Within a GenScope learning context, the teacher must provide this external support, because there is little embedded scaffolding in the GenScope evolution environment. Students can run simulations repeatedly to test out their ideas, and these simulations do help scaffold students' learning by allowing them to view effects of the variables that they alter. These are not, however, sophisticated scaffolds that can help students when they are having difficulty regulating their learning.

A teacher concerned with supporting students' SRL in an inquiry-based CBLE should scaffold aspects of students' cognition (e.g., use and monitoring of cognitive strategies, planning), motivation (e.g., activation and monitoring of interest), behavior (e.g. help-seeking), and control and monitoring of the context, while they inquire in the CBLE. Azevedo and colleagues (2004), examined teachers' scaffolding behavior as students' learned about ecology and the effects of land use on water quality while collaboratively exploring the RiverWeb™ water quality simulation. They found that the teachers' scaffolding in this context consisted primarily of a few low-level cognitive strategies (e.g., following procedural tasks) and very little planning and monitoring of cognition. They observed the teachers engaging in virtually no scaffolding of students' motivation, behavior, or control and monitoring of the context (Azevedo et al, 2004). This study did observe a small gain in students' learning between a pretest and a posttest, and the authors reported that these gains were related to the self-regulatory behaviors observed among the students and within the teachers' scaffolding.

The main purpose of the current study is to describe how one teacher (the first author) scaffolded his students' SRL while they investigated concepts of evolution in the GenScope environment (Horwitz et al., 1998). In focusing on SRL, we make the
following assumptions: that students must regulate their own learning in order to learn complex science content in an inquiry-based CBLE context (Vye et al., 1998; White, Shimoda, & Frederiksen 2000), and that the teacher must play an active role in scaffolding student SRL in any classroom context (Meyer & Turner, 2002).

**Method**

*Participants:* Participants in the study were 62 honors biology students (33 girls and 29 boys) from a large (~3200 students) Mid-Atlantic, suburban high school. The students were 9th and 10th graders (between the ages of 14 and 16) from diverse racial, ethnic, and socioeconomic backgrounds. Most had never formally studied evolutionary biology in school.

*Research Design:* We gave students a pretest before instruction, and we gave a posttest (identical to the pretest) after instruction (see Appendix A). We also collected video and audio data from 10 dyads while they worked collaboratively to investigate principles of evolution in GenScope. In this study, we focused specifically on discourse analysis of the teacher's efforts to scaffold students' self-regulated learning. Quantitative analysis of the testing data is included in another paper (Winters, Azevedo, & Levin, 2004), which presents students' self-regulated learning.

*GenScope:* Students used the GenScope (http://genscope.concord.org) evolution program (Horwitz et al, 1998) to investigate principles of evolutionary biology. This program allows students to alter the environmental and population conditions for a species of dragons, with inheritance following the rules of Mendelian genetics. Analysis of the changing conditions allows students to investigate principles of Darwinian evolution. The program does not provide on-line scaffolding. As a result, it provides an opportunity
to investigate the role the teacher plays in scaffolding students’ SRL of evolutionary principles through a computer-based scientific investigation in isolation from any on-line scaffolding.

Considering the time scale involved in evolutionary processes, it is often difficult for students to appreciate the effects of particular variables on the evolution of a population. The GenScope evolution program allows students to alter variables in populations and then run simulations to identify dependent variables that change as a result.

**Procedure:** The research study took place over two 45-minute class periods and two 90-minute block class periods. During the first class period of the study, students took the paper-based pretest. Students were given 45 minutes to complete this test.

During the second class period, the students were grouped in heterogeneous dyads of high and low ability based on whether their pretest scores were above or below the class median. Students were not aware of their pretest scores or the rationale for the grouping. In their dyads, the students followed a tutorial to run the evolution program in GenScope (modified from http://genscope.concord.org). Each pair then formulated three inquiry questions, using the teacher-set guidelines shown in Appendix B. To help students identify questions that would be appropriate for investigation in the GenScope evolution environment, the teacher led a whole-class discussion about the merits of the different experimental questions.

During the third class, the students spent the entire 90 minutes working in their dyads on answering a selection of the student-generated questions by investigating these questions in GenScope. The questions that were selected for investigation were:
1. Will increasing the mutation rate cause the population to split faster than if the mutation rate is left as it is (the default setting)?
2. If we set the mutation rate to zero, will some dragons still grow legs in order to reach the food on land as the food in the water is consumed?
3. If we add a third type of terrain beyond "land" called "mountains," and set the rules to allow only four-legged dragons to enter and survive in the mountains, will a population of four-legged dragons inhabit the mountains?

While students were investigating these questions, the teacher circulated to scaffold students’ SRL. The data reported in this paper only describes the teacher's scaffolding while students worked on the first two questions. In addition to the teacher's scaffolding, each pair had a planning sheet (Appendix C) to help them identify their scientific questions, hypotheses, independent variables, data, and conclusions. The teacher visited each dyad 2-3 times during the class period, and he spent approximately 3-5 minutes with each dyad during each visit. At the beginning of the fourth class, the students completed the posttest, which they were given 45 minutes to complete.

Data Sources: We collected and transcribed 100 minutes of audio data from ten pairs of students. To identify examples of teacher scaffolding, we examined the periods during the class when the teacher visited each pair's station.

Coding: We developed a coding scheme for teacher scaffolding of SRL that is based on Azevedo and colleagues’ (in press) model. In addition to analyzing students’ regulatory behavior in a CBLE, Azevedo and colleagues extended their model to analyze a tutor’s behavior in providing tutor-initiated instructional methods and tutor-scaffolded behavior, varying the levels of scaffolding designed to enhance students’ understanding while learning in a CBLE. Our scheme differs from Azevedo and colleagues’ model primarily in terms of the cognitive strategies that the teacher attempted to scaffold. Because of the inquiry-oriented and collaborative instructional approach of this treatment, we referred to
Okada and Simon’s (1997) investigation of collaborative inquiry in a scientific domain to construct our strategy codes. We used the scheme developed from these two sources to code the teacher’s statements and questions that were intended to scaffold dyads' SRL.

The classes, descriptions, and examples of the planning, monitoring, strategy use, and task difficulty and demands variables used for coding the teacher's regulatory behavior are described in Appendix D. Teacher scaffolding of students' self-regulatory learning was coded in six main areas. These are (1) the use of cognitive strategies, especially strategies that are appropriate for scientific inquiry (e.g., hypothesizing, identifying variables, establishing experimental control); (2) planning and goal setting, activation of perceptions and knowledge of the task and context, and the self in relationship to the task and context; (3) monitoring processes that represent metacognitive awareness of different aspects of the self, task, and context; (4) efforts to control and regulate aspects of the context; (5) efforts to control and regulate aspects of behavior; (6) and efforts to control and regulate motivation.

Within these broad areas we have identified 26 codes. Eleven of these codes have been categorized as teacher scaffolding (TS) codes, and 15 have been categorized as teacher instruction (TI) codes. We have also tallied the teacher's use of positive feedback (PF) and negative feedback (NF).

The distinction between TS and TI codes is adapted from Azevedo et al (in press). We do not view the difference between teacher scaffolding and teacher instruction as a dichotomy. Rather, we consider this distinction to represent two general areas on a continuum. Our teacher scaffolding codes (scaffolded discourse) refer to instances when the teacher is guiding students with reminders: "You have to think back to what
happened when you ran the first simulation;" questions: "What's the process you're gonna use to try both of them?" or suggestions: "Why don't you try? You can try both." Teacher scaffolding generally offers students choices, while teacher instruction does not.

Teacher instruction does not simply mean direct explanation of concepts. Explanation is a type of teacher instruction, but we would place it at the most extreme end (TI) of the continuum. Teacher instruction codes generally refer to instances when the teacher is giving direction: "What you have to do is state a factor, and then call it something, and then make a rule for that factor;" stating his opinion: "I think that probably will increase variation;" or asking very specific questions: "And in the first simulation, when you run it the whole way, the no-leggeds in the water don't die off from lack of food?"

**Inter-rater Agreement:** The first author coded 100% of the transcript data, and the third author coded 30%. We found agreement on 65 out of 71 coded units, yielding an inter-rater agreement of 92%.

**Results and Analysis**

Discourse analysis of the teacher’s statements and questions revealed six main areas in which the teacher scaffolded students' SRL: use of cognitive strategies, planning and activation, metacognitive monitoring of cognition, monitoring and control of the context, behavior, and motivation.

We have tallied 238 coded units from transcripts of ten pairs of students. 181 of these units fit within the broad areas described above. Sixty-six percent of these were categorized as teacher instruction codes and 34% were categorized as teacher instruction codes. Of the remaining 57 units, 56 were recorded as general positive feedback (e.g.,
"You made a good point there"), and one was recorded as negative feedback ("Well, no"). This data is summarized in Table 1.

The predominance of teacher instruction codes suggests that the teacher's own goals for the class shaped his discourse. The teacher, who is also the first author, reports that he was paying close attention to his use of instructional time during the lesson. He was concerned with making certain that his students had an opportunity to pursue all of the assigned questions during the ninety-minute block. In many cases, rather than take the time to guide students and offer them choices, the teacher often pursued a more direct route (i.e., teacher instruction) in supporting his students' learning. Clearly, elements of the teacher's own regulation of his classroom and the learning context (particularly his monitoring of progress towards goals and his time-and-effort planning) impacted the choices that he made in the classroom.

This is most noticeable in the teacher's use of direct explanation. We have identified 9% of coded units as examples of teacher explanation. We found that the teacher often turned to direct explanation when his efforts to use indirect means to scaffold his students' self-regulated learning were not effective.

In the example shown below, the students are expressing some confusion about the experimental question. The question was, “Will increasing the mutation rate cause the population to split faster than if the mutation rate is left as it is (the default setting)?” This wording confused some students. Many were uncertain if "split" meant that a population began to inhabit a different environment, or if it only meant that new mutations would arise. (Parentheses indicate the codes assigned to each teacher utterance).
S1: Does "split faster" mean, like, more of that kind? Or like--
S2: More in a different place
S1: Separated from the water…yeah..
T: Uhh. (NC)
S1: [unintelligible] mutation-wise or split?
T: Well, if you think about it--the answer to the question…if you're just talking about more of that type it's pretty obvious, right? (TS-FOK)
S1: Yeah, yeah.
T: Um, which is what? (TS-ELAB)
S1: Which is yes.
T: Because of the mutation rate. (TI-EXPL)
S1: Right. Heh.
T: So what we're really talking about is-- (TI-ELAB)
S2: Where they go?
T: Where they go. (NC)
S1: Yeah.
T: The population splitting having to do with…this being a different population than this in terms of the distribution of the dragons. (TI-EXPL)

**Strategies.** Much of the teacher’s effort (39% of coded units) was focused on scaffolding students’ use of strategies that are appropriate for learning in an inquiry environment. Most frequently (10% of all coded units), the teacher scaffolded students' use of experimental control. The teacher also scaffolded students' description of the independent variables in their experiments (7%), their description of their experimental results (7%), and their use of data collection strategies (6%). He also asked students to elaborate when they explained their ideas to him (7%), and he asked them to make inferences based on their observations and experimental results (2%).

The teacher only asked students to generate a hypothesis in one instance. Considering the important role of hypothesizing in science inquiry, it's curious that the teacher spent so little time scaffolding this strategy. This may simply be an artifact of the instructional procedure, however. There may have been little opportunity for the teacher to scaffold this strategy. The planning sheet (Appendix C) asked the students to
formulate hypotheses before they ran their simulations. Consequently, by the time the
teacher visited most of the student pairs, students had already made their predictions and
were actively running their simulations.

Analysis of the teacher's discourse shows that he frequently moved from
scaffolded instruction to more direct instruction as he attempted to get his students to use
inquiry strategies. Again, the teacher was conscious of his own goals for his students'
learning, and he relied on direct instruction to make certain that his students "got it." He
was particularly concerned with his students' understanding of experimental control and
their use of strategies to establish control in the environment.

S1: [unintelligible] increase the mutation rate. Will it split? Will the
population split faster?
T: Okay, so faster than what? [TS-CON]
S1: Than the normal rate.
T: Okay, so how are you going to do that? (TS-CON)
S1: We increased the mutation rate.
T: Okay, and now you're running the simulation? (TI-GOAL)
S2: We're going to run it.
T: Oh, okay. And how are you going to know if it splits faster? (TS-DATA)
S2: We'll look at the increase.
S1: Um, how fast it increases and then test like, the normal.
T: Oh you're going to test it normally too? Okay, good. So that's like a
control? (TI-CON)
S2: Yeah.
S1: Yeah.

Planning. We coded 21% of the teacher's scaffolding in the area of planning and
activation. The teacher scaffolded students' setting of goals (17%), and prior knowledge
activation (4%). The teacher's decisions in scaffolding students' goals were closely tied
to his assessment of his students' particular needs. Usually, he could tell when he first
arrived at a station that the students understood the expectations for the class, and he
simply tried to scaffold their articulation of their learning goals: "Oh look at this, we see
some data! (TI-DATA) What's going on here?" (TS-GOAL). We placed questions like this on the TS end of the spectrum.

By contrast, the teacher occasionally assessed that his students did not have a clear understanding of the expectations for the task. In these cases, he tended to be much more direct in his guidance of students' learning goals, and we coded these utterances on the instruction end of the spectrum. For example:

S:   Do we write what's up there? (Referring to the experimental questions listed on the overhead projector).
T:  Those are your questions, that we've compiled from the class. So on the sheet you have a place for "What are the questions, what's the scientific questions?" Those are your questions. (TI-GOAL)

The class had used GenScope during a genetics unit that preceded this experience, so the teacher often scaffolded students' prior knowledge of the genetics of the population of dragons that inhabit the GenScope microworld. For example, when a student was curious about the changes in phenotypes that occurred between two generations, the teacher asked, "Well, do you remember what the inheritance is for legs?" (TSPKA)

The teacher also frequently scaffolded students' prior knowledge of mathematical ideas that impacted students' choices as they changed variables in the simulations. In the example shown below, the teacher has discovered that the students changed the mutation rate from 0.1 to 10 as they tested one of the questions.

T:   You went up to 10? (TS-EX)
S1:  Something like that.
T:   Okay, so, .1 to 10, what kind of increase is that? (TI-PKA)
S2:  That is really high.
S1:  It's like a big increase.
T:   Big yes, like how big? (TI-PKA)
S2:  Like 9.9 or something, but it's really big.
T:   Well if you went from .1 to 1, how many times would you be increasing the mutation rate? (TI-PKA)
S1:  Ten
Scaffolding SRL in GenScope

T:   Ten times, right?  (TI-PKA)
S1:  Ten times, so it's--
T:   If you went from .1 to 10, how many times would you be increasing it?
     (TI-PKA)
S1:  100 times
S2:  100 times!!  Whoa!!  [laughs]
T:   So you've got 100 more mutations appearing in every generation than you
     did previously.  [TI-EXPL]
S1:  Yeah, well it said increase the mutation rate.

Monitoring. We coded 19% of the teacher's scaffolding in the area of
metacognitive monitoring of cognition. Some of this discourse was coded as scaffolding
of monitoring progress toward goals (7%). This code was frequently assigned to the
teacher's statements when he first arrived at the students' table. The majority of these
statements were coded on the TS end of the continuum. The teacher did not often
directly ask students to monitor their progress towards their goals. Instead, he provided
them with the opportunity to do this monitoring themselves, by asking questions like,
"How are you guys doing here?"

The teacher frequently scaffolded students' feelings of knowing (FOK) by asking
them to recall what they had learned earlier in the task, and how they would apply it to
the existing condition (12%). The excerpt below shows how the teacher used TS-FOK
and TI-FOK strategies. Again, the data shows a progression from scaffolded discourse to
more direct instruction.

S1:   What does it mean for the population to split faster?
T:   Well, what. You have to think back to what happened in the first, um--
     (TS-FOK)
S1:  Does it mean, like it grows faster?
T:   Well like when you ran the um, the first simulation.  (TS-FOK)
S1:  Like, [unintelligible] they split off the land and stuff?
T:   Ok, so that's what you saw when you ran the first simulation?  (TI-FOK).
     So then the question would be, how is it different now as we change this
     factor?  (TI-CON)
**Control of Context.** We coded 6% of the teacher's scaffolding in the area of control of context (6%). The teacher's scaffolding of students' control of the context suggests, again, that the teacher was primarily concerned that the students establish appropriate controls for their simulations. In the excerpt shown below, for example, the students have reported (to the teacher's surprise) that dragons adapt to a new environment even when the mutation rate has been set to zero.

T: But did you change the mutation rate to zero before you started running the um?--(TI-COC)
S1: Um, we ran the original one and then we set it to zero.
T: And then ran it again from the start? (TI-COC)
S1: No we didn't run it again from the start.
T: Oh, because the question has to do with are you gonna see this looks like you are creating new dragons with legs, right? (TI-G). And are you creating new dragons with legs there? (TI-RES)
S2: No
T: Those are from the original simulation, right? (TI-FOK)
S2: Yes
T: Yes, you see what I mean like in terms of comparison, you started halfway through the simulation. (TI-EXPL)
S1: I see what you mean.
T: So you might want to run it without the changed mutation rate and then just run it with the changed mutation rate. (TI-CON)

**Behavior.** 3% of coded units showed the teacher scaffolding students' behavior. Within this category we identified two codes: scaffolding of help-seeking behavior (2%), and scaffolding of peer collaboration (1%). We assigned the code TS-HSB to situations in which the teacher demonstrated a positive response in reaction to students' request for help. We believe that these responses encouraged students to seek help. The teacher never ignored students' requests for help, nor did he respond with negative statements like, "What do you want?" We also did not see any examples in which he responded with a neutral, "What?" Instead, when the students asked the teacher for help, he responded with statements like, "Yes sir?" or "Yes, ma'am?"
**Motivation.** The discourse analysis also suggests that the teacher was concerned with scaffolding motivational variables. We identified a number of instances in which the teacher expressed interest in the task (3%). All of these responses were coded on the TI end of the continuum, because they were all direct statements of interest by the teacher. For example: "That's interesting. I'll be interested to see that data."

**Discussion**

This study investigated how a high-school science teacher scaffolded his students' self-regulated learning (SRL) during a collaborative CBLE-based science inquiry investigation in the classroom. The results revealed six main areas in which the teacher scaffolded students' SRL: use of cognitive strategies (particularly inquiry-process strategies), planning and goal setting, metacognitive monitoring of cognition, monitoring and control of the context, behavior, and motivation. Two-thirds of the teacher's utterances were teacher-initiated instructional strategies, while one-third were teacher scaffolding utterances.

**Scaffolding of Inquiry Strategies, Planning, and Monitoring**

The teacher's attention to scaffolding of inquiry strategies and metacognition was consistent with prior research that emphasizes the importance of these variables for learning with an inquiry-based CBLE (White & Frederiksen, 1998; White, Shimoda, & Frederiksen, 1999). Additionally, the teacher's scaffolding of students' planning and goal setting is consistent with Singer and colleagues' (2000) contention that students need support in making decisions concerning how to proceed in an inquiry context. Our results add additional support to these research findings and apply them to high school honors students.
The teacher's scaffolding of students' inquiry-process strategies is also consistent with Meyer and Turner's (2002) argument that teachers support students' SRL by helping them to build competence for understanding in a particular learning domain. In science, an understanding of the processes of inquiry improves students' understanding of scientific concepts and laws (White & Frederiksen, 1998). Therefore, by scaffolding students' use of inquiry-process strategies, this teacher was supporting students' competence for learning about evolution through inquiry in GenScope.

Our finding that much of the teacher’s scaffolding was in the areas of inquiry strategies, planning, and metacognition, differs from the findings of Azevedo and colleagues (2004), who examined teachers' scaffolding behavior in a CBLE and found that the teachers scaffolding consisted primarily of a few low-level strategies (e.g., following procedural tasks) and very little planning and monitoring. While it is possible that the inquiry-oriented nature of this study required greater planning and monitoring by the students, it is equally likely that the difference between our findings and those of Azevedo and colleagues (2004) reflects the difference between the two populations of students and the instructional goals used for these studies. Both sets of students attended the same school. However, the students in our study were 9th and 10th grade honors biology students, and the students in the other study were in an environmental science class that they had been placed in after failing several required classes such as biology (Azevedo et al., 2004). The high achieving honors students in our study may have needed fewer of the low-level strategies than the struggling environmental science students did. As a result, the teacher may have had greater time and flexibility to scaffold planning and monitoring.
Teacher Scaffolding and Teacher Instruction

The finding that the teacher in the current study spent more time instructing students than he did scaffolding their learning is consistent with the findings of Azevedo and colleagues (2004). We argue that in the current study, the teacher's need to control the context of his classroom influenced his choice of using instructional strategies more frequently than scaffolding student learning.

In contrast to the finding that the teacher used scaffolded discourse less frequently than he used instructional discourse in the areas of strategies and planning, we found that the teacher used scaffolded discourse more frequently than instructional discourse in the monitoring sub-category. When the teacher wanted students to recall knowledge that they gained earlier in their investigations (feelings of knowing--FOK), or monitor their progress toward their goals (MPTG), he took an indirect approach more often than he used instructional moves. Previous work (e.g., Azevedo et al., 2004) found that the teacher neither scaffolded nor instructed students' feelings of knowing at all, and that the teacher scaffolded and instructed students' monitoring of progress toward goals with equal frequency (2% each for TI-MPTG and TS-MPTG). Again, the difference between our findings and those of Azevedo and colleagues (2004) may reflect differences between honors high school science students and high school students who struggle in science.

We hypothesize that the honors students involved in the current study were accustomed to an academically rigorous curriculum in which they were frequently expected to monitor their learning (both in science class and in their other classes). As a result, the teacher may have simply needed to guide them by using scaffolded discourse to monitor their progress toward their goals and to recall knowledge that they had gained
earlier in their investigations. By contrast, since students were unlikely to have experience using particular science inquiry-process strategies in other classes, the teacher may have needed to be more direct in helping them to use these strategies.

Limitations

This paper reports the results of an exploratory study in an area that has not been widely researched. The findings are based on an analysis of a sample of students from one teacher's classes, and the instruction occurred during a short period of time. Additionally, it is difficult to generalize from this study because it is highly contextualized.

Future Directions

We plan to further refine our coding scheme and extend it to other learning situations in which students conduct scientific inquiry in a CBLE. What elements of teacher scaffolding of students’ SRL are similar or different in other inquiry-based CBLEs? For example, would we expect to see the same predominance of instruction of inquiry-process strategies, or would this be unnecessary with another CBLE? What elements of teacher scaffolding would be similar or different with different students? For example, if this same study were conducted with the students in Azevedo and colleagues' (2004) study, would we expect to see a predominance of teacher instruction of low-level procedural strategies and very little scaffolding of planning and monitoring?

Elucidation of these types of questions will lead to a more complete and flexible model that can be adapted to particular learning situations. Additionally, we plan to examine the effectiveness of the teacher’s scaffolding of students’ SRL in greater depth. What scaffolding is particularly important for students’ learning in this context?
Continued observation and analysis of the teacher’s scaffolding will enable us to design experimental treatments that can promote SRL in this context.

**Implications for Action Research**

The value of this investigation in informing the teacher’s own instructional practice should not be overlooked. We believe that self-regulated learning is an important lens through which teachers may view their classrooms, and it provides a useful theoretical basis for conducting action research. By viewing and analyzing their own instructional behavior through this lens, teachers may gain a greater understanding of the impact that their own instructional behavior may have on the various areas and phases of students’ self-regulated learning.

For example, the finding that the teacher’s own focus on time and task completion guided his instructional behavior is revealing. Many science teachers who are interested in promoting student inquiry feel a great tension between their inquiry goals (e.g., scaffolding students' questioning, hypothesizing, and experimenting) and the more traditional goals of "covering the content" (Hammer, 1997). This teacher clearly was concerned that his students complete the task and cover the content in the time he had planned for this inquiry. Frequently, however, when given the opportunity to inquire, students may not reach the learning goals that the teacher had intended (Hammer, 1997). When this happens, the teacher must choose to either explicitly refocus students on their learning goals, or to guide them through scaffolded discourse.

Scaffolded discourse may require significantly more time than giving explicit directions. An example of the choice that the teacher must make is presented in the results section, when the teacher found an error that led the students to an incorrect
conclusion. In this exchange, the students had incorrectly concluded that setting the mutation rate to zero would still allow a new population to evolve on land. The teacher discovered that their error was in their control of the context, and he gave them specific and direct instruction to correct it. This instance was consistent with the teacher's general approach of using instructional discourse when he sensed that his students were not progressing toward learning goals, in order to make certain that they reached their goals in the time allotted. Alternatively, if he were not so preoccupied with time constraints, the teacher could have taken a less direct approach, using more scaffolded (TS) discourse, and allowing the students to struggle until they possibly discovered the mistake on their own.

For this teacher, it was important to discover that his discourse was partially dependent on his goals of task completion and coverage of content. This finding will certainly guide his choices as he scaffolds student inquiry in his classroom in the future. Using self-regulated learning as a basis for action research could reveal similar insights for other teachers. Following Paris and Winograd (2001), we suggest that a focus on SRL would provide a theoretical framework through which both pre-service and experienced teachers might explore their own teaching and understand their students' learning.
Appendix A: Pre-Test/Posttest

1. If two organisms are members of the same species, then they can breed in the wild to produce fertile offspring. If two organisms are members of different species, they either cannot successfully mate or their offspring will be infertile. For example, although a horse and a donkey can be bred to produce a mule, the mule itself cannot reproduce. Additionally, horses and donkeys will not breed with each other in the wild.

Speciation is the term used to describe the production of two new species from a single ancestral species. Horses and donkeys, although they are different species, probably arose from a common ancestor.

Quaggas, a species similar to zebras, lived in Africa before they were exterminated by hunting in the 1870’s. Quaggas were physically very similar to zebras, and they fed on similar plants. Instead of being entirely striped like zebras, however, quaggas were yellow-brown from the abdomen to the rear. Also, quaggas were able to retain water like camels.

a) Describe how you think the quaggas’ trait of retaining water first arose.
b) What might have caused the quaggas and zebras to eventually separate into two different species?
c) Describe the process that led the quaggas and zebras to become 2 separate species over many thousands of years.

2. Bacteria reproduce approximately every 20 minutes. Bacteria are therefore ideal for studying evolutionary processes in the laboratory, since a large number of generations can be observed in a relatively short period of time. Given the right conditions, one species of bacteria can separate into two distinct populations in a matter of days or weeks. A colleague suggests to you that changes in environmental factors (such as temperature) and changes in the mutation rate of bacteria may both lead to the evolution of new characteristics. As a scientist, you are interested in determining whether differences in temperature or differences in mutation rate will lead to the separation of two species more quickly. You have the following tools in your laboratory:

- All of the materials necessary for growing bacteria in culture: the bacteria, a food source, petri dishes, and incubators to control the temperature of the environments.
- A machine that will bombard the bacteria with ultraviolet radiation. Ultraviolet radiation causes changes to bacterial DNA. Changing the amount of ultraviolet radiation that the bacteria are exposed to will allow you to alter the rate of mutation in the bacteria.
- Materials necessary for isolating and separating the DNA of bacteria. These include chemicals used in DNA extraction, restriction enzymes for cutting DNA, and electrophoresis tools for separating DNA fragments.
- Microscopes, microscope slides, and cover slips

In the space below, describe the scientific processes that you will follow to answer the bold-lettered question above. Use the back of the page if you need more space. Provide as much detail as possible
Appendix B: Questioning Worksheet

1. Explore the options (population and environmental options) to help you to decide what questions you might ask. To answer your questions you will be changing some of these variables. In the space below list the possible variables that you might change (as many as you can). Be specific. **Do not begin to run any simulations yet.**

2. With your partner, construct a list of three questions that you would like to investigate in GenScope. Also provide a hypothesis (a testable prediction) for each of your questions. Your questions should have the following characteristics:

   - The questions should be testable and measurable within the GenScope environment.
   - **Counter-example:** Are dragons friendly?
   - The questions should lead you to a greater understanding of evolutionary processes.
   - **Counter-example:** What are some of the mutations that are formed in the simulation?
   - You should be able to set the parameters and run the simulations for three questions within a 60-minute time period.
   - **Counter-example:** If I completely restructure the environment so that the water is on the outside of the land, and I reverse the sex of all of my dragons, will the simulation turn out different?
   - The questions should not be too simple.
   - **Counter-example:** How will the situation be different if I run the simulation for four generations instead of five?
Appendix C: Question Template

Use this worksheet to investigate the questions that the class has chosen

Question #1

1. Question: What is the scientific question?

2. Hypothesis: What is your hypothesis? Why do you believe this is the case?

3. Independent variable(s): What independent variable(s) will you change to test your hypothesis?

4. Data: What were your results? How did they compare to the original tour simulation?

5. Conclusion: Does your data support your hypothesis? If not, why do you think this was the case?

Question #2

1. Question: What is the scientific question?

2. Hypothesis: What is your hypothesis? Why do you believe this is the case?

3. Independent variable(s): What independent variable(s) will you change to test your hypothesis?

4. Data: What were your results? How did they compare to the original tour simulation?

5. Conclusion: Does your data support your hypothesis? If not, why do you think this was the case?

Question #3

1. Question: What is the scientific question?

2. Hypothesis: What is your hypothesis? Why do you believe this is the case?

3. Independent variable(s): What independent variable(s) will you change to test your hypothesis?

4. Data: What were your results? How did they compare to the original tour simulation?

5. Conclusion: Does your data support your hypothesis? If not, why do you think this was the case?
## Appendix D: GenScope Evolution Program Teacher Scaffolding Coding Scheme

**Classes, Descriptions, and Examples of the Variables Used to Code Teacher’s Scaffolding of Students Self-Regulatory Behavior.**  
*(based on Azevedo, Cromley, & Siebert (in press)*

<table>
<thead>
<tr>
<th>Area Variable</th>
<th>Phase Variable</th>
<th>Description</th>
<th>Example—Teacher Scaffolding</th>
<th>Example—Teacher Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planning and Activation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Prior knowledge activation (PKA)</td>
<td>Cognition</td>
<td>Teacher guides or directs students' search of their memories for relevant prior knowledge from a previous class or experience.</td>
<td>Do you remember what the inheritance is for legs?</td>
<td>What was it [the original mutation rate], 0.1?</td>
</tr>
<tr>
<td>2. Goals (G)</td>
<td>Cognition</td>
<td>Teacher guides or directs students to plan or describe operations that are possible, postponed, or intended, or states that are expected to be obtained. Goals can be identified because they have no reference to already-existing states</td>
<td>What's going on here?</td>
<td>So you're running it with the changed mutation rate?</td>
</tr>
<tr>
<td><strong>Monitoring</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Monitoring progress toward goals (MPTG)</td>
<td>Cognition</td>
<td>Teacher guides or directs students to assess their progress towards overarching goals for their learning.</td>
<td>How are you guys doing over here?</td>
<td>You're on the third one already?</td>
</tr>
<tr>
<td>4. Feelings of knowing (FOK)</td>
<td>Cognition</td>
<td>Teacher guides or directs students to become aware of having learned something in the past and having some understanding of it, but not being able to recall it on demand. Or, teacher guides or directs students to remember something from earlier in the current class. (related to PKA)</td>
<td>You have to think back to what happened when you ran the first simulation.</td>
<td>And in the first simulation, when you run it the whole way, the no-leggeds in the water don't die off from lack of food?</td>
</tr>
<tr>
<td>Strategy Use</td>
<td>Cognition</td>
<td>Teacher guides or directs students to make a hypothesis or to state their hypotheses. This may include elements of the CBLE.</td>
<td>Your hypothesis is--?</td>
<td></td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------</td>
<td></td>
</tr>
<tr>
<td>5. Hypothesis (HYP)</td>
<td>Cognition</td>
<td>Teacher guides or directs students to describe the choices that they have made in testing the questions (often a description of independent variables), which may include manipulation of the CBLE.</td>
<td>So what did you do?</td>
<td></td>
</tr>
<tr>
<td>6. Experimental test (EX)</td>
<td>Cognition</td>
<td>Teacher guides or directs students to describe the results of an experimental test.</td>
<td>What did you change the mutation rate to? What did you increase it to?</td>
<td></td>
</tr>
<tr>
<td>7. Results (RES)</td>
<td>Cognition</td>
<td>Teacher guides or directs students to use a data collecting strategy, or asks them to describe their data collecting strategy.</td>
<td>So you're saying four-legged dragons appeared more quickly on land when the mutation rate was set higher?</td>
<td></td>
</tr>
<tr>
<td>8. Data collection (DATA)</td>
<td>Cognition</td>
<td>Teacher guides or directs students to use experimental control to test scientific questions, or asks them to describe their use of experimental control.</td>
<td>What were you watching, here, as you counted your numbers?</td>
<td></td>
</tr>
<tr>
<td>9. Control (CON)</td>
<td>Cognition</td>
<td>Teacher explains concepts of evolution or processes of inquiry. This may include features of the CBLE.</td>
<td>The question is, what's the process you're gonna use to try both of them?</td>
<td></td>
</tr>
<tr>
<td>10. Teacher Explanation (EXPL)</td>
<td>Cognition</td>
<td>Teacher guides or directs students to make inferences based on observations.</td>
<td>Oh, you're going to test it normally too? So that's like a control?</td>
<td></td>
</tr>
<tr>
<td>11. Inference (INF)</td>
<td>Cognition</td>
<td>Teacher guides or directs students to explain their responses to his questions in greater detail, or with greater clarity.</td>
<td>Why are they all dying?</td>
<td></td>
</tr>
<tr>
<td>12. Elaboration (ELAB)</td>
<td>Cognition</td>
<td>Teacher explains concepts of evolution or processes of inquiry. This may include features of the CBLE.</td>
<td>What do you mean by &quot;survive&quot;?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Is that the rule? Really?</td>
<td></td>
</tr>
<tr>
<td>13. Control of context (COC)</td>
<td>Context</td>
<td>Teacher guides or directs students to alter the CBLE environment.</td>
<td>Did you want to change the food consumption rate only in the water?</td>
<td>If you go back to population options, there is an option that allows you to change the mutation rate itself.</td>
</tr>
<tr>
<td>----------------------------</td>
<td>---------</td>
<td>---------------------------------------------------------------</td>
<td>---------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>

**Task Difficulty and Demands**

<table>
<thead>
<tr>
<th>14. Help-seeking behavior (HSB)</th>
<th>Behavior</th>
<th>Teacher guides or directs students to request assistance.</th>
<th>Yes sir?</th>
<th></th>
</tr>
</thead>
</table>

**Other**

<table>
<thead>
<tr>
<th>15. Peer Collaboration (PC)</th>
<th>Behavior</th>
<th>Teacher guides or directs students to work with their partners constructively.</th>
<th>So if you do something, you're not just grabbing the mouse and going, right? You're helping her to understand what you're doing?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>16. Interest (I)</td>
<td>Motivation/Affect</td>
<td>Teacher encourages interest in the task, context, or domain.</td>
<td>I'll be interested to see that data.</td>
<td></td>
</tr>
<tr>
<td>17. Positive feedback (PF)</td>
<td>Teacher gives encouragement or affirmation for students' ideas or decisions.</td>
<td>You made a good point there. All right, that sounds good.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Negative feedback (NF)</td>
<td>Teacher discourages or disagrees with students' ideas or decisions.</td>
<td>Well, no…</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1: Frequencies of Teacher-Scaffolding (TS) and Teacher-Instruction (TI) Codes

<table>
<thead>
<tr>
<th>Code</th>
<th>Teacher Scaffolding</th>
<th>Teacher Instruction</th>
<th>Total (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher Explanation Subtotal</td>
<td>0</td>
<td>17</td>
<td>17 (9)</td>
</tr>
<tr>
<td>Strategies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>7</td>
<td>11</td>
<td>18 (10)</td>
</tr>
<tr>
<td>Results</td>
<td>7</td>
<td>7</td>
<td>14 (8)</td>
</tr>
<tr>
<td>Experiment</td>
<td>2</td>
<td>11</td>
<td>13 (7)</td>
</tr>
<tr>
<td>Elaboration</td>
<td>7</td>
<td>5</td>
<td>12 (7)</td>
</tr>
<tr>
<td>Data</td>
<td>3</td>
<td>7</td>
<td>10 (6)</td>
</tr>
<tr>
<td>Inference</td>
<td>0</td>
<td>3</td>
<td>3 (2)</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>0</td>
<td>1</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Strategies Subtotal</td>
<td>26</td>
<td>45</td>
<td>71 (39)</td>
</tr>
<tr>
<td>Planning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goals</td>
<td>7</td>
<td>23</td>
<td>30 (17)</td>
</tr>
<tr>
<td>PKA</td>
<td>1</td>
<td>7</td>
<td>8 (4)</td>
</tr>
<tr>
<td>Planning Subtotal</td>
<td>8</td>
<td>30</td>
<td>38 (21)</td>
</tr>
<tr>
<td>Monitoring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOK</td>
<td>13</td>
<td>8</td>
<td>21 (12)</td>
</tr>
<tr>
<td>MPTG</td>
<td>8</td>
<td>4</td>
<td>12 (7)</td>
</tr>
<tr>
<td>Monitoring Subtotal</td>
<td>21</td>
<td>12</td>
<td>33 (18)</td>
</tr>
<tr>
<td>Control of Context Subtotal</td>
<td>3</td>
<td>7</td>
<td>10 (6)</td>
</tr>
<tr>
<td>Behavior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSB</td>
<td>4</td>
<td>0</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Peer Collaboration</td>
<td>0</td>
<td>2</td>
<td>2 (1)</td>
</tr>
<tr>
<td>Behavior Subtotal</td>
<td>4</td>
<td>2</td>
<td>6 (3)</td>
</tr>
<tr>
<td>Motivation/Affect</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest</td>
<td>0</td>
<td>6</td>
<td>6 (3)</td>
</tr>
<tr>
<td>Motivation/Affect Subtotal</td>
<td>0</td>
<td>6</td>
<td>6 (3)</td>
</tr>
<tr>
<td>Total SRL Codes</td>
<td>62 (34%)</td>
<td>119 (66%)</td>
<td>181 (100)</td>
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<tr>
<td>Positive Feedback</td>
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<td>56</td>
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<tr>
<td>Negative Feedback</td>
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<tr>
<td>Grand Total</td>
<td></td>
<td></td>
<td>238</td>
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</table>
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Azevedo, R., Winters, F.I., & Moos, D.C. (June, 2004). Can students collaboratively use hypermedia to learn about science? The dynamics of self- and other-regulatory processes in the classroom. Paper to be presented at the 6th International Conference of the Learning Sciences, Santa Monica, LA.


