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RESEARCH

Enhancing science teachers' understanding of ecosystem interactions with qualitative conceptual models

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ABSTRACT

The project described in this article explores how a series of conceptual ecological models can be used to portray the improvement in ecological understanding over the span of a short course. The course involved high school teachers working collaboratively on ecological research projects. Teachers were asked to construct qualitative conceptual models (a diagram of important ecosystem components and the linkages between these components) and write explanatory essays at three points during their research experience.
spanned initial intuitive explanation, with misconceptions, to the post-test elaboration of a more complex and accurate understanding of ecological

understanding. The models essentially provided them with a means to visualize their conceptions of ecosystem processes. Their understanding was further enhanced through collegial discussions. We present a series of

and their students need the opportunity to engage in real world research, coupled with reflective use of qualitative modeling and ongoing collegial discussions, to be able to develop more appropriate reasoning about ecological concepts.

KEYWORDS

Research experiences, qualitative conceptual modeling, reflective learning, professional development, high school ecology.

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INTRODUCTION

It is generally accepted that pre-college science education should emphasize the process of inquiry, i.e., develop an understanding about natural phenomenon through experimentation, especially bringing experimentation

and thoughtful consideration of the meaning/significance of that data (NRC 1996a). The National Science Education Standards describe how inquiry is effective in developing scientific reasoning skills. Besides an overall inquiry emphasis, high school science teaching should provide students with an opportunity to do more first-hand creative work as is done by scientists (e.g., see Trautmann & Krasney 2006, Harhisch *et al*. 2003). However, most science teacher in-service courses typically do not expose teachers to science in a real, creative setting (Raphael *et al*. 1999). Without experience and training in alternative strategies, high school teachers are likely to teach science the same way that they were taught; most will rely on memorization and lecture (Darling-Hammond 1996; NRC 1996b).

Professional development that requires high school teachers to participate in

knowledge is open ended and based upon making observations, and it can encourage teachers to become more inquiry-based and student centered (Melear *et al*. 2000; Westerlund *et al*. 2002). Authentic research is an active approach to learning and uses the five key features of science research as a mode of inquiry: forming and testing hypotheses, developing an experimental design, obtaining evidence by observation and measurement, using logic and insight to analyze data, and developing an explanation based on valid observations using logic and application of conceptual knowledge (AAAS 1989). Especially important is the ability to interpret the data that has been collected. Here, the researcher needs to bring their understanding of theory into coordination with their experimental evidence.

Following the steps of science inquiry does not necessarily lead to greater understanding. Newer insights into learning suggest specific pedagogical approaches to ensure that scientific phenomena are really understood. These include: engaging prior understanding, providing a rich, meaningful conceptual framework, and providing opportunities for self-monitoring or metacognition (NRC 2005). Prior understandings are intuitive understandings that everyone has about phenomena, typically unexamined or not well articulated. If these intuitive understandings are not engaged, a person will only superficially learn a new concept (Butler *et al*. 2001). Metacognition is

(Hennessey 1999). Engaging metacognition can help strengthen scientific understanding because it helps build connections between science experiences and ideas (Blank 2000). Constructivism, which maintains that

including beliefs

and knowledge about science (Coburn 2000), underscores the need for reflection on what is being learned. By providing opportunities to reflect on what a learner comprehends at a point in time, through written and verbal means, a learner can become aware of their prior conceptions. This awareness is a first step to help better understand more accurate or new concepts, and even learn how to monitor their own learning process.

The professional development program described in this paper used qualitative conceptual modeling. Qualitative conceptual models, a term we have coined for the synthesis of two approaches-- concept mapping and qualitative ecological modeling-- are depictions of the main components of an ecological system, the links between them, plus an explanation of what is
The use of
qualitative conceptual modeling, in combination with science inquiry, is a powerful combination leading to potentially deeper understanding of the science concepts behind the experiments.

In this program teachers engaged in field research and used qualitative conceptual models at intervals to record their understanding at key points during the research process. It was conducted with minimal lecture and with a
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instruction, an approach developed over the past 10 years in programs called

programs associated the Long-Term Ecological Research (LTER (http//www.lternet.edu) programs. Exercises using conceptual qualitative

the content of their models provided them with opportunities for self-monitoring or metacognition. Thus this research course, overall, was structured to provide a rich, meaningful conceptual framework for the teachers

Qualitative conceptual modeling
A conceptual model is a visual summary with an accompanying explanation of the basic features of the system under study
thinking about a phenomenon. It is thus drawn from the perspective of the participant. It is both a simplification of a complex system and an expression
g. Since it emphasizes what the participant knows at a point in time, and is not necessarily right or wrong, it is a representation of the p thinking about how the ecosystem functions. Conceptual modeling is an adaptation of concept mapping; concept maps are diagrams showing the relationships among concepts. Concepts are connected with labeled arrows, in a downward-branching structure. The technique of concept mapping was developed by Joseph Novak (1990) as a means of representing the emerging science knowledge of students. Novak's work is based on Ausubel (1968), who stressed the importance of prior knowledge in being able to learn new concepts.

Qualitative models are typically drawn as diagrams that describe the relationships between components in an ecological community. A component is any variable such as a given species, or the temperature of the water in a stream. Components are connected with links that represent the type of ecological interaction, the flow of material, or a causal effect of one component on another, such as predation. Any combination of two or more components that have direct and indirect effects on one another is termed a

Several other important studies using either qualitative or conceptual modeling include Hogan and Thomas, (2001), who found that having a concrete representation of knowledge structure in the form of this kind of model
and foster understanding of nature of science. White and Frederiksen (1990) argue that qualitative models provide novices with the means to learn alternative and more accurate conceptualizations for changes that occur in

helped students acquire the skills to recognize aspects of complex ecosystem functioning, e.g., understanding multiple levels of organization. However, other concepts, such as non-linear and non-deterministic conceptions were found to be difficult to acquire. In our program for science teachers, described below, we developed a series of teaching tools that we believed might help to help overcome the limitation found in the above study.

In our application of qualitative conceptual models, specific aspects of ecosystem functioning were highlighted. The overall effect of any input from one component on another (direct and indirect) gets incorporated into the diagram. Appropriate conceptual models can be used to illustrate otherwise incomprehensible ideas about ecosystems; such as, how some actions in ecosystems result in otherwise unexpected
consequences. W to
illustrate several important aspects of ecosystem functioning: feedback, indirect effects, and subcomponents. Teachers were subsequently asked to illustrate these aspects of ecosystems in their own models.

This paper describes a study we conducted to investigate how qualitative conceptual modeling enhanced what and how science teachers learned about ecological interactions. Through the course of a new NSF-funded science teacher education project, Teaching Ecological Complexity (ESIE #0554379), two teams of LTER educators and scientists used qualitative conceptual models in combination with participation in ecology research projects. All aspects of informed consent were followed according to guidelines of the Human Subjects Research Review Committee at Portland State University.

through their models, was obtained through teacher interviews and analysis understanding of aspects of ecosystem patterns were portrayed in their conceptual models and their essays. We analyzed the data looking for

functioning including interactions, feedbacks, subsystems, inputs, and outputs.

METHODS

Two parallel summer courses were held in 2007 for this study. One course was at Arizona State University in association with the Central Arizona-Phoenix Long-Term Ecological Research (CAP LTER) project in the Phoenix metropolitan area. The other course was at the H.J. Andrews LTER (AND LTER), near Blue River, Oregon. These professional development workshops were designed to highlight ecological content knowledge in a collegial atmosphere and allow for an immersion into the entire suite of activities needed to instigate and complete a field experiment.

The program consisted of a two-week course during which teachers participated in all stages of science inquiry through conduct of a field-based research project; alongside this, they developed a series of conceptual models and accompanying essays. Teachers participated in terrestrial invertebrate diversity research, an urban bird foraging study, a forest succession study, and a soil respiration research project. These projects were conducted with the collaboration of the lead scientist. Teachers helped to shape the research questions, implement the research protocols, conduct the data analysis, and discuss the significance of their findings with the direct guidance of several LTER scientists.

Teacher understanding about ecological complexity, diversity, and experimentation were documented by their models, their essays, through interviews with program staff, content tests and by using a pre-post-test design. Before designing their own conceptual models, participants learned the symbolic language of qualitative models. For example, predator prey interactions, which were perceived by the teachers as they classified the terrestrial invertebrate data by functional groups, were represented using (-/+). Using the variables from their research, teachers were asked to focus on the components and interactions they found to have been most important, and then design a model. Using these qualitative conceptual models, they were asked to respond to guided questions. These questions included explanations as to why participants chose each component depicted, verbal descriptions of the relationships between components, descriptions of the consequences of a disturbance to the system depicted, and descriptions of feedback and indirect effects in the system. After completing first drafts of their essays, teachers -pair-they described their understanding of their research projects using their models with their peers. Lastly, each teacher revised their essay to summarize their understanding. This process of model construction, discussion, writing, and editing was repeated three times for the Oregon group and two times for the Arizona group at particular points throughout their research experience. Teachers also wrote up research reports or research posters summarizing the results of their experiments.

Although the two workshops were generally parallel, there were differences in how the workshops were implemented. The Oregon site was a residential site where teachers worked for approximately 12 hours per day on research, readings, modeling and other related projects. They had time to discuss the significance of the data they had collected, conduct literature searches for their research papers, write extensive papers and to go into the field with other researchers on other projects. The Oregon site focused on native forested ecosystems. The urban Arizona site had no opportunity for a residential program and, by comparison, had only 6 contact hours per day. The Arizona site focused on urban ecology issues. Due to time constraints, the teachers from Arizona did not respond to the essay questions in as much depth as the Oregon teachers. Please see the essay questions provided in the resources section (see Resources).

The essays and models were collected and analyzed using a rubric to gain

see the rubric provided in the resources section (see Resources). Teachers were interviewed at the end of the workshop, using their models and accompanying essays to gain further insights about the impact of using models on their understanding. Their research reports or posters were also analyzed. We focused on three aspects of ecological understanding in this study: understanding of biological diversity, ecological complexity, and the overall research process. This paper is organized to follow each of these three topics by providing a description of how each was applied and an examination of the results found for each.

Understanding Patterns of Diversity

Although biological diversity is central to an understanding how ecological communities can be compared, we had previously found that most teachers had misconceptions about diversity. For example, they assumed that diversity and species richness were synonymous, and did not realize the importance of knowing about ecological function of the species present. Ecological content knowledge about biological diversity was provided through reading and discussion of classic and recent journal articles as well as scientist presentations and discussions on diversity and food webs. Our specific research questions were: How do qualitative conceptual models help teachers to apply their conceptual understanding of diversity to the particulars of their experiments? What is their degree of understanding, or misunderstanding, about diversity and food webs?

Understanding Ecological Complexity

workshops because of the importance placed on developing a greater public understanding of indirect causality. Complexity was defined in a particular way: complex ecosystems are not controlled by a central or linear function but are characterized by non-linear feedback loops; these systems demonstrate indirect effects from an action. (Li Bai-Lan, 2007). We asked the teachers to show how well they understood some of the causal mechanisms of systems, i.e., feedback, direct and indirect and multiple effects, by asking them to identify and describe these features in their qualitative conceptual models. We looked to see if they could provide a description of how the system they depicted works as a whole.

Understanding the Research Process

The most central aspects of this program involved science teachers working with ecologists, conducting field research projects. Our specific research questions were: How well do qualitative conceptual models assist teachers in obtaining insights about the ecosystem under study, and about their experiment? How well do they understand their research project as portrayed in their models? Do they make appropriate predictions? Can they design an appropriate second order experiment? In addition to the essay questions, several interview questions were posed to participants to uncover more details. For example, in the post-test interviews, teachers were asked to describe some of the insights they gained through qualitative conceptual modeling. They were asked to describe the differences they themselves perceived between their first and last models.

How scoring criteria were derived

All scoring criteria involved use of a scoring rubric where the degree of mastery of particular aspects of understanding diversity, complexity, and experimentation were defined and assigned a score. For example, 4 points were awarded a response that was exemplary (e.g., shows mastery of diversity concepts, appropriately applies several concepts to research project). Three points were awarded a response that was correct, but was less thorough (e.g., adequately applies diversity concepts to research project, but not thoroughly). Two points were awarded for a response that showed some understanding in applying one concept, but with mistakes in applying other concepts. One point was given for an answer that was inaccurate, and 0 points were given for no response. There were two scorers from each team, one assistant and one principal investigator. Discrepancies between scores were discussed and either changed or averaged. The scorers each abstracted the inputs from teacher -research experience) and the combination of interviews and essays (post research experience) and ascribed a score.

As the teachers gained more knowledge, we anticipated that their models would show greater accuracy in illustrating the details about the ecosystem they were studying and indirect effects and feedback. This knowledge gain would include their choice of variables and the connections between variables. Webb and Boltt (1990) found that their subjects depicted more accurate connections between variables in feeding relationships as they became more experienced. Structurally, the first models created often showed a single pathway, while more advanced models accurately depicted multiple connections between variables. See examples of novice and more advanced models in figures A-E below.

Teachers were also given a content knowledge test before and after their research experience. The pre-test was taken on-line before the course, and the post-test was taken in the lab during the last day of the course. The scores for questions applicable understanding of experimentation, complexity, and diversity were added on to each applicable category, forming three composite scores *(Complexity, Diversity*, and Research Process). Composite scores were cumulative; the highest possible scores for Diversity, Complexity, and Research were, respectively, 10, 14, and 16. We then compared their

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composite scores for both groups of teachers. A series of Wilcoxon matched pairs signed ranks test were run on each set of paired scores. This test is appropriate for experimental variability in cases using nonparametric paired measurements (Motulsky 1999). Since the two sets of teacher essays (Oregon and Arizona teachers) were different in the scope of responses, we

RESULTS

Understanding Patterns of Diversity

The first measure was an understanding of patterns of diversity. Results of

diversity scores (Table 1) s nificantly

improved ($p<0.01$)

had not done so significantly ($p=0.6$).

Table 1. Wilcoxin matched pair results for all pre-post test composite qualitative conceptual modeling scores for diversity, complexity and research process.

Composite Scores for each item	Diversity Oregon (max 10)	Diversity Arizona	Complexity Oregon (max 14)	Complexity Arizona	Research Process (max 16) (Oregon only)
Average pre-test score	5.5	4.1	7.4	6.5	5.1
Average post-test score	8.7	4.8	11.9	11.7	11.1
N	10	8	10	8	10
P value	<0.01	0.6	<0.01	<0.01	<0.01
St Dev.	1.8	1.1	3.2	1.3	2.1

We documented an overall shift in emphasis towards use of more accurate explanations using diversity concepts acquired during the course.
paired essays clearly showed a progression from amateur, sometimes weak attempts to apply theories about diversity to explain phenomenon to more sophisticated exhibition of their heightened conceptual understanding. For example, this teacher developed an ability to understand specific applications of diversity concepts so that she could critique her initial assumptions:

Pre:

Post:
lysis, the diversity index appears to have

Another teacher moved from a general recitation of an idea about diversity to specific application of his findings to a more appropriate understanding of functional groups.

Pre: web to remain intact

Post: -web, they link primary

of moths increased. However, the moth species diversity stayed the same. Because moths are sensitive to changes in plant distribution, it is likely that plant diversity al

Novice or beginning models did not illustrate any evidence that teachers understood ecological diversity. More advanced models illustrated applications of both functional groups and ecological trophic levels, as illustrated below in Figure 1. This model shows effects of light, nutrients and disturbance at a local level on forest vegetation, bacteria and fungi, arthropods feeding at different trophic levels. Triangles are used to represent abiotic factors, circles represent biotic factors, one-way arrows point in the direction indicating flow of material and energy (e.g., prey is eaten by a predator), two-way arrows represent mutualistic relationships, Lastly, an arrow circling back onto itself represents self-effect or self-regulation.

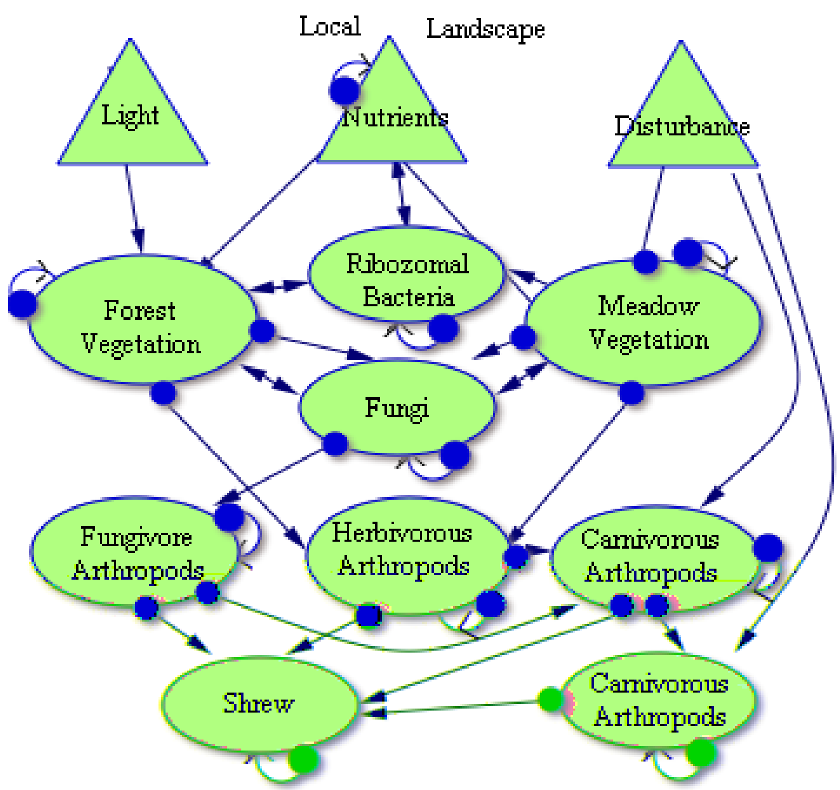

Figure 1. More advanced application of diversity concepts showing functional groups and trophic levels.

Understanding Ecological Complexity

The second measure was for understanding about ecological complexity. Results of Wilcoxo
composite ecological complexity scores (Table 1) s
had significantly improved ($p<0.01$) for both groups. Before receiving any instruction in how feedback operated in an ecosystem, participants did not show themselves capable of applying any acceptable theories to explain this phenomenon. After being shown illustrations of feedback, attempting to applying feedback to their own ecosystem diagrams, and reading and discussing scholarly articles about feedback, participants could more

The post-test models typically had 10 or more components and numerous feedback loops. Post-test models were generally more advanced and showed multi-stepped connections between variables, as shown in Figure 3 below.

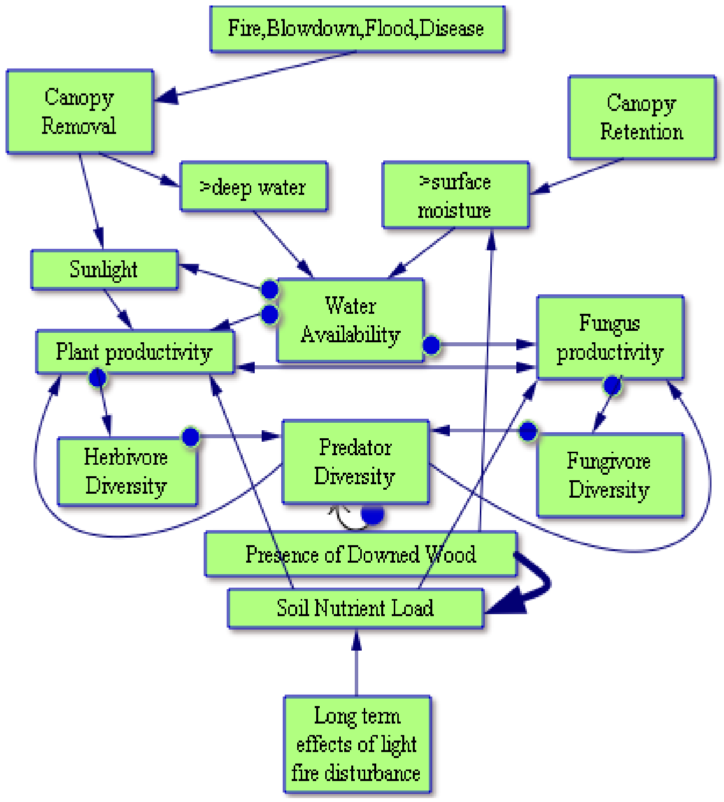

Figure 3. Example of more advanced application of complex, multi-stepped connections between variables, showing feedback (e.g., between predator diversity and fungus productivity and plant productivity), and more specific choice of variables.

Understanding the Research Process

The final measure assessed an understanding the research project. Results of Wilcoxo

process scores (Table 1) s nificantly improved (p<0.01) for the Oregon teachers. Since adequate pre-test scores were not collected from the Arizona group, analysis could not be completed for that

illustrate changes in their degree of understanding. In the first example, the two excerpts show how he had acquired an ability to critique the experiment, showing more advanced understanding about importance of procedures in understanding implications of results.

Pre:

Post:

communities not necessarily show a gradient, but individual species,

A second teacher le

Pre:

Post:

site had a preponderance of young trees, not grasses, indicating it was more likely an ecotone than a meadow. Available moisture was a main

Pre-test or novice models showed only a general understanding about the experimental variables and connections, as shown in Figure 4 below.

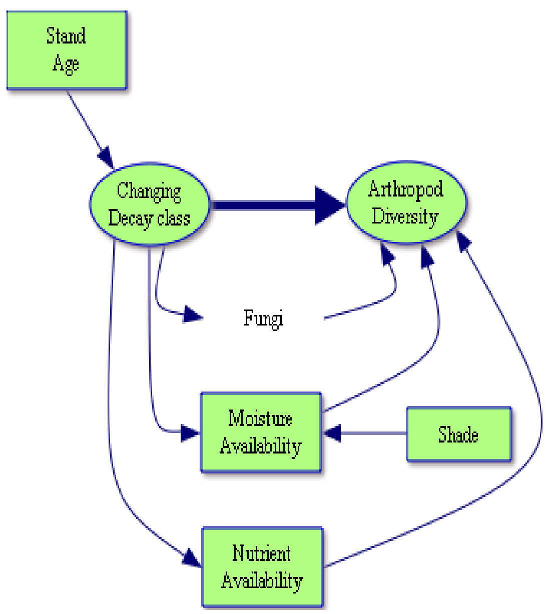

Figure 4. Novice or pre-test model showing general terms used in designating variables.

Post-test models correctly used appropriate variables from experiment, and appropriate used accurate connections between variables, as shown in figure 5 below.

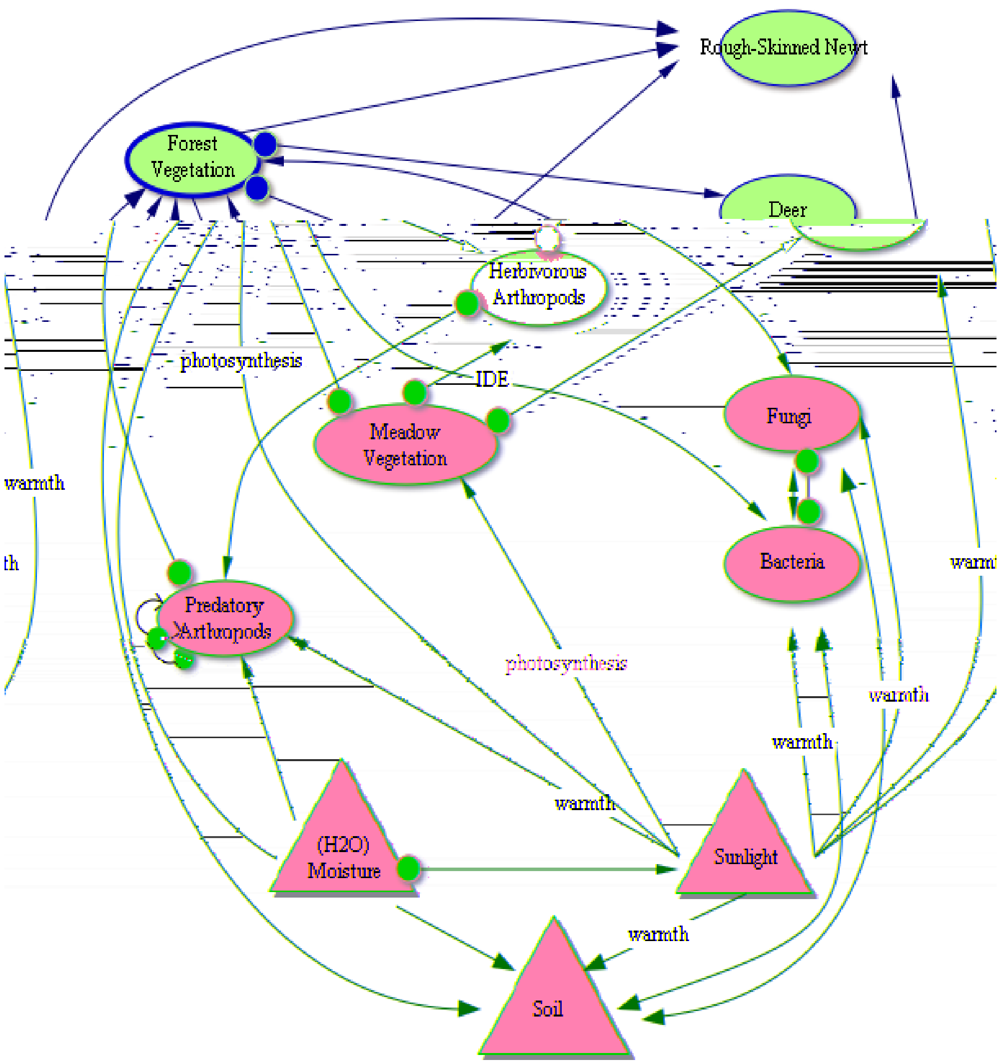

Figure 5. Example of a post-test model, showing choices that more appropriately represent experimental variables and connections.

e also looked at as a separate feature. They were scored (using the rubric) and analyzed using a Wilcoxon matched pairs test. Complexity scores showed a significant improvement (p> 0.05), understanding the research process scores approached significance (p<0.06) and, although diversity scores showed a trend towards improvement, it was not significantly different, as shown in Table 2 below. With practice, all teachers were able to show improvements in their ability to convey accurate scientific information using their models.

Table 2. Model Structure Scores, Oregon Group

Variable	Understanding Complexity (max score 12)	Understanding Research process (max score 12)	Understand Diversity concepts (max score is 8)
Average Novice score (pre-test)	1	3	1
Average Experienced score (post-test)	7	7	2.6
P values	<0.05	<0.06	<0.09

As would be expected, there were differences in scores between the two groups of participating teachers. There were differences in the content of each program, and differences in the number of hours spent by each group during each course. Overall pre-test scores were similar for Diversity and Complexity for both groups of teachers (see Table 1). Understanding complexity scores increased significantly for both groups. However, understanding diversity scores increased significantly only for the Oregon group. This can be explained by the length of time this group discussed issues of biological diversity as applied to their research projects and as represented in several research papers they discussed. Improvement in research process scores increased only for the Oregon group due to the fact that paired was not available for the Arizona group.

Participants were informally asked about utility of using qualitative conceptual modeling in combination with a research project. Their answers, in general, can be collapsed into the following statement: Models helped them construct meaning out of their research results. Some of their specific comments explained how the modeling activities helped them to either visualize connections between variables, focus on what was important to pay attention to, visualize links, feedback loops, indirect effects, or to appreciate the influence particular abiotic factors had on the system they were studying.

DISCUSSION

In this study, we worked with teachers using qualitative conceptual models coupled with participation in the research process to promote greater understanding about ecology. The emphasis on qualitative conceptual modeling encouraged them to examine their thinking about their knowledge of the actual ecological relationships. Through using conceptual models about their research, teachers re-evaluated their prior understanding about ecology concepts. Through reading ecological literature and discussions about the significance of their research findings they were able to acquire newer, more appropriate conceptual understanding. The modeling exercises essentially provide them with a means to visualize their conceptions of ecosystem processes. Teachers were able to develop a better understanding about ecological diversity concepts. Linking modeling to science inquiry was important to help synthesize and deepen their new understanding. A series of models can support the restructuring of their ideas about ecological research.

was particularly enhanced by the use of qualitative conceptual modeling. This may be explained by how appropriate qualitative conceptual modeling can be to make complex ecosystem behavior more understandable. The modeling exercises forced them to articulate what they understood about variables and interactions. Qualitative models are also appropriate for illustrating processes like feedbacks that are aspects of ecosystem functioning otherwise difficult to visualize. Qualitative conceptual modeling was found to be helpful for making some of the abstract features of complex ecosystem behavior more understandable by the high school teachers.

Qualitative Conceptual Modeling as a Metacognitive Tool

about ecology. In order to enable deeper learning, students also need an opportunity to structure their understanding. Conceptual models are concrete representations of knowledge structures (mental schema). They embody a conceptualization of the operation of the system. In this study, qualitative conceptual models were used as metacognitive tools during the course. Use of these tools enabled the teachers to monitor their own cognitive processes as they learned about ecosystem functioning. Metacognition works well in group situations; participants explain their thinking to a peer, witness counter evidence, and then negotiate between their original idea and a new explanation. Blank (2000) found that this process can help build connections between science experiences, ideas, and understanding, thus making science learning more meaningful and persistent. As participants document and recognize the changes in their own thinking, they build on their own former knowledge, and can observe how they themselves have learned something. Then, as teachers try to apply their knowledge to solve a new problem an even deeper understanding of the system can emerge.

Our results show that by using models metacognitively, teachers were able to replace their prior ideas about ecology, especially their inappropriate and overly simplistic understandings of causality, with newer and more accurate perceptions acquired through their participation. Most teachers initially described ecological processes either in very general concepts or by stringing related ideas together inappropriately. The modeling exercises required them to focus on specific relationships between elements of the ecosystem they were studying, which forced them to examine their thinking about the actual ecological relationships they were observing. They had to think about what they really knew about specific elements of the ecosystem they were studying instead of merely stating an abstraction or general concept. The results indicate that they were able to assimilate more accurate ecological explanations into their thinking about ecological complexity.

2005).

which they could explain and defend their understanding of ecological phenomena under study. Groetzer and Perkins (2000) similarly described how use of conceptual modeling helped participants to understand the phenomenon. Our teachers claimed they had learned more effectively by comparing their ideas derived from their models with those of other teachers. Through discussion, teachers were able to watch their own line of reasoning and consider whether or not their ideas made sense. In some cases, this discussion was a way to clear up a misconception in the representation of the idea in the model, but more importantly, it led to the correction of the idea itself. Then, the discussion facilitated a shift in their thinking. They gained a deeper understanding about the phenomenon. Mittlefehldt and Groetzer

discussions among their participants facilitated the restructuring of

We found a powerful combination when we combined the research experience with qualitative conceptual models to visualize what teachers understood and then asked them to discuss it with their peers. Using conceptual modeling reflectively and in a social structure helped teachers to better understand ecological phenomena.

These techniques are relatively new to our use, and as such there remain some problems to be sorted out. Ruiz-Primo and Shavelson (1996) pointed out a variety of data reliability and validity issues. As an example of reliability issues, we are not certain if teachers would produce more proficient models even without any intervening ecological instruction. As an example of an unresolved issues of validity, it is possible that qualitative conceptual model scores could vary due to socioeconomic status, English proficiency, or ethnicity. These issues may be better understood over time as our team continues to use this tool with teachers and their students.

The modeling exercises forced participants to restructure their understanding about ecological variables and interactions. This cannot be accomplished through lecture or use of a web-based curriculum. Labor intensive one-on-one interactions of teachers-on-scientists, teacher-to-teacher, forced teachers to convey their explanations to one another, take a look at results of their analysis, and consider new ideas about what questions they could ask about the system. Discussions about what one thinks one understands, facilitated through the creation of qualitative conceptual models, is a critical element of learning. Modeling ability itself is a type of science thinking skill that can be learned through practice over a lengthy period of time (Grosslight et.al., 1991).

Importance of the Research Experience
Students need the opportunity to engage in real world research to be able to develop more appropriate reasoning about ecological concepts. Collecting

experience (Manzanal et al. 1999). This experience can help drive the more tedious process of making sense out of the data, followed by the more thoughtful consideration of the meaning of the results. During the program described in this paper, teachers were actively involved in conducting one or two different ecological research study. They were palpably enthusiastic, and voluntarily spent their discretionary free time working on different aspects of a study. For example, some teachers spent many late night hours in the lab keying out the terrestrial invertebrate samples or analyzing their data sets. As the teachers learned more about the subject, we saw improvements in the degree of expertise with which they could explain their research study results.

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process. By the end of their experiments, they confronted the issue of why their initial hypotheses were not supported by the data they had collected. These teachers were asked to confront why their initial ideas about their systems were not supported and provide possible explanations. Many of their new explanations were incorporated into their final models as additional components and interactions. Their later models of complex ecosystem

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expected? er than their earlier ones, supplied them with insights into the ecosystem under study.

Classroom Practice

in their classrooms, their responses to post-course questions about their future intentions may be used as indications of future behavior. All the participants left the workshop committed to implementing field ecology research projects with their respective classes. All indicated that they planned to use qualitative conceptual modeling in a manner similar to the one they used during the course. They also indicated they would pay particular attention to research design, the rigor of investigations, random sampling of the population, and choice of statistical analysis.

Conclusions

The use of qualitative models enabled participants to express some of the causal relationships operating in an ecological experiment, thus helping them view their own progression of understanding. They moved away from their initial intuitive explanation, with misconceptions, to the development of a more complex and accurate understanding of ecological phenomenon. Our results

attention to system dynamics. Qualitative conceptual modeling based upon field-based ecological research can effectively help learners to better understand aspects of complex ecosystem functioning by making otherwise abstract concepts about interactions, feedback, subsystems, inputs, and outputs more accessible.

derstanding of the research process itself can be facilitated by their use of qualitative conceptual modeling. We documented a shift in emphasis to overall experimental design and interpretation of results. The emphasis on modeling encouraged them to examine their thinking about the actual relationships they knew about. The real world context of their experiments heightened their enthusiasm for following through with all the stages of experimentation. The overall quality of their investigations improved and they were able to communicate about specific elements of the ecosystem they were studying, as opposed to communicating using only abstract or general concepts. Exercises for reflection on what they knew, coupled with discussions with their peers, and in addition to new ecological content knowledge, facilitated a greater openness for learning. A research experience coupled with use of qualitative conceptual modeling, ongoing collegial discussion, and readings of classic ecological literature can focus science

PRACTITIONER REFLECTIONS

We have developed a heightened understanding about teacher professional development. High school science teachers need direct instruction in scientific research. This needs to be conducted with minimal lecture and with a high degree of interaction and hands-on instruction. But even the best immersion experience in following the steps of science inquiry does not necessarily lead to greater understanding. Newer insights we have gained suggest that engaging prior understanding and providing opportunities for metacognition are needed. If these intuitive understandings are not engaged, a person will only superficially learn a new concept. Engaging metacognition can help strengthen scientific understanding because it helps build connections between science experiences and ideas. The modeling exercises described in this article required participants to focus on specific relationships between elements of the ecosystem they were studying; forcing them to examine their thinking about the actual ecological relationships they were observing. They had to think about what they really knew about specific elements of the ecosystem they were studying were instead of merely stating a general concept. Teaching for understanding cannot be achieved without an examination and diagnosis of what a learner knows initially. Skills of building explanations about observed phenomenon must also be practiced. Taking the time to provide opportunities to reflect on what a learner comprehends at points in time through use of qualitative conceptual modeling, helps learners to understand more accurate or new concepts and learn how to monitor their own learning process. Teachers need to experience this for themselves before they can reasonably be expected to practice this with their students. Although there is so much content to cover, professional developers need to stay focused on fewer themes and allow the participants to go into more depth with the material.

A caution should be noted for those attempting to use this style of metacognitive modeling. The instructor should emphasize that, although many variables influencing organisms in ecosystems, only a few can be focused on at one time. The models produced by students become less meaningful if more than 7 variables are incorporated into a qualitative cognitive model, especially the first model constructed. It seems counter-intuitive to ask students to simplify the system in order to better understand complexity, but we have found that it is difficult for our participants to try to understand more than a few interactions at one time. And, they were still able to show an increased understanding of ecological complexity.

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RESOURCES

Essay Questions for Teachers' Qualitative Conceptual Models (DOC)

Rubric for Modeling Essay Questions (DOC)

The Ecoplexity website
The Ecoplexity website contains tools used in our teacher courses that allow the user to investigate patterns and structures of ecosystems first-hand. Various pages provide assistance in the development of a research question, selecting a protocol, developing a Student Portal to facilitate implementation of a project in the classroom, and links to scientific journals. Other pages allow users to learn more about the two-week teacher professional development workshops including research conducted while in the field and how to translate this new knowledge to students. Other sections of the ecoplexity website are devoted to different aspects of ecosystem modeling

and use of qualitative conceptual models. For examples, please visit the website.

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