

Using participant generated models to capture changes in understanding of ecological interactions resulting from research experiences

Abstract

We explored how field research, coupled with a series of participant-generated conceptual ecological models can be used to both facilitate and portray the improvement in ecological understanding over the span of a short course. Four different groups of high school teachers, 47 total, worked collaboratively with scientists on ecological research projects at each of four Long Term Ecological Research sites. Teachers constructed qualitative conceptual models (QCMs) along with accompanying explanatory essays at two or more points during their two-week research experience. The essays were paired, scored, and analysed. There was significant improvement in understanding about relationships between experimental variables, developing appropriate hypotheses, how feedback loops operate for two of the four groups. Participants were also given a pre-post 17-item environmental science knowledge test. There were significant improvements on items concerning knowledge about systems for the same two groups. Teacher classroom practises, measured before the course and again 9 months later, showed significant change for many factors most notably in use of inquiry and conceptual modeling. Rationale is provided describing why teachers need continued opportunities to engage in real world research. When coupled with reflective use of qualitative modeling, research experiences can help develop deeper understanding about ecological concepts and improvement in their teaching practises.

Introduction

Objectives:

Central to our work with teachers is the use of authentic, first hand field experiences, alongside with the use of visualization techniques to highlight particular ecosystem interactions. The process of making and modifying visualizations of participants' depictions of phenomena provides them with opportunities to confront their often inadequate prior understandings and replace them with more sound scientific explanations. Participants use reflective activities to trace how their understanding changes over the course of an ecological research project. Teachers' prior understandings are engaged in a metacognitive process that deepens participants understanding of ecological concepts.

Understanding ecological systems

Ecology focuses on understanding dynamic, intricate system involving multiple variables. We feel it is important for students to understand ecological relationships and particular ecosystems attributes: indirect effects, feedback, and time lags in response to disturbances. Scientific thinking based on simple linear causal patterns limits the public ability to understand the more complex causal patterns of natural ecosystems. Ecological processes that are invisible to the eye, for example, decomposition, are not well understood by most students (Webb & Boltt, 1990). Developing a capacity for systems thinking requires "immersion in challenging, real-world problem contexts" and "exposure to systems analysis language, tools and procedures," such as ecosystem modeling (Hogan

and Weathers 2003).

Being able to study and interpret ecological interactions is essential towards understanding ecology. However, this is not a straightforward process. Zohar (1995) described how novice scientists used fallacious reasoning when interpreting results and drawing conclusions. They made many inferences at an intuitive level because, in part, they lacked a conceptual framework to understand interacting variables. They used “theory-saving” inferences, which combined an accommodation of their experimental evidence while still holding onto prior beliefs. Opportunities to learn new scientific concepts, coupled with a research experience, can improve a novice’s ability to reason scientifically. Qualitative modeling, a visualization tool used in this study, can help students become attentive to ecological system attributes.

Deepening knowledge through authentic field experiences

Central to the authors’ work with science teachers is our belief that authentic field experiences are essential to appropriately understand ecology. Over the years of experience we have each had with teacher training workshops, we have captured teachers’ comments about the value of first-hand, visceral experiences in the natural environment for their students. Mazanal, Barreiro, and Jimenez (1999) investigated how fieldwork contributes towards understanding of concepts and principles of ecology. Students were given a food web and asked questions about trophic levels. After participating in field work, some of the student ideas appeared more complex. Conceptual maps were also used, and scored according to Wallace and Mintzes criteria (Wallace and

Mintzes, 1990). Students who participated in the field exercises were significantly better at expressing the organization of ecology concepts, appreciating the importance of abiotic components, and in understanding complex interrelationships. Students reported that due to having done fieldwork, they could later draw upon their concrete, visceral experiences in the ecosystem. Thus, their experiences helped them incorporate new concepts into their thinking.

Scientific inquiry is modeled for teachers by the ways in which scientists, with whom teachers work directly, do their work (e.g., Chinn and Malhotra, 2002; Edelson, 2003). For example, scientists conduct investigations and obtain evidence through experimentation. Scientists actively build up a body of evidence from their experiments, which, along with scientist-constructed models, build up a body of new knowledge in an iterative fashion. Next, direct participation in all the steps of an ecological research project approximates the “real life” work of a scientist. Teachers can form and subsequently test their own hypotheses through field experiments, actively model the relationships between hypothesized variables, write up and discuss their results among peers. Also important are the skills of interpreting the meaning of experimental results. They need sufficient conceptual knowledge in ecology to be able to appropriately interpret their results. This skill requires an ability to coordinate the experimental evidence alongside one’s understanding of ecological theories, and involves the search for patterns and regularities in the data and “negotiating” the meaning of that pattern among peers.

Most teachers who participate in our courses are novices at research. Novices typically cannot differentiate and coordinate theory and evidence. Experts think reflectively and view theory and evidence separately, thus they can evaluate the validity of the theory in the light of their own evidence. Novices typically do not distinguish between their own explanations (personal theories) and the evidence they have gathered (Kuhn, Amsel & O'Loughlin, 1988). Experts have been trained to focus on evidence that has been collected. Novices typically can explain what they have observed, but have difficulty in making a prediction about the relationship between variables. Experts are trained to think in terms of cause and effect questions. In this study, we focused teachers' attention on understanding the variables in ecological experiments, the interactions between these variables, and to be attentive to how their understanding changed over time. Alongside this process, we worked on building skills in forming testable hypotheses and making predictions about experimental outcomes.

Deepening understanding of scientific concepts

Participating in a rich, meaningful experiment can provide a conceptual framework for students to learn scientific concepts. The National Research Council (2005) suggests providing such a framework, along with several other specific pedagogical approaches to ensure that scientific phenomena are really understood. These include engaging prior understanding and providing opportunities for self-monitoring or metacognition. Prior understandings are intuitive understandings that everyone has about phenomena, typically poorly articulated. If these intuitive understandings are not engaged, a person will most likely learn a new concept only superficially (Butler, Buckley, Walkington, 2001).

Engaging metacognition helps build connections between science experiences and ideas (Blank 2000). Collaborative metacognition, or, reflective peer discussions about what students know at points in time can be important in restructuring ideas.

Learning is an interaction between new knowledge and existing knowledge. Because students have experienced nature in their own lives, either through hiking and camping experiences or through nature shows on TV, they come to class with their own plausible ideas. If the student's ideas are not reconciled with the new knowledge being presented, the science being taught may be seen as difficult or incomprehensible. Reflection can assist a student to reconcile new knowledge with their existing knowledge; reflection is important for deepening and making science understanding more meaningful (Hewson and Hewson, 2003). Teachers can emphasize both qualitative as well as quantitative expression of understanding.

Importance of models and other visualizations

A model is a simplification of a complex system. The use of modeling has become an important tool in the study of ecology. Qualitative models describe the important components of an ecosystem and the linkages among these components. Conceptual models are visual summaries that explain a person's thinking about a phenomenon.

Modeling activities can provide a context to integrate content with the process of inquiry.

Modeling can be an avenue for students to identify questions and generate explanations for the scientific phenomenon being investigated (Lehrer & Schauble, 1998). Resources

developed for the project in this study use a variety of modeling tools alongside direct measurement of ecological variables.

In a study that used models to enhance high-school students' understanding of chemistry (Frailich, Kesner & Hofstein 2008), one group of teachers used visual models in a student-centred learning environment. A second comparison group did not. The experimental group significantly outperformed the comparison group. The visualization tools along with the use of active and cooperative learning strategies provided students with opportunities to construct their knowledge regarding the concept of chemical bonding. Prior knowledge was a major determinant in the impact of visualization on learning (Cook, 2006). Students provided with more knowledgeable teachers, who can communicate this knowledge effectively, can build their understanding from a more accurate knowledge base.

Scientist-generated models capture essential fragments of how a scientist thinks. Depending upon the results, scientists may modify the model, until the model and experimental results agree. Modeling thus makes the modeler's reasoning both public and "inspectable" (Lehrer and Schauble, 2000). Model formation and revision involves the integration of information about the phenomenon and then improving that explanation as one's knowledge about the system grows (Gobert, 2000). Modeling-centred inquiry has been used as an instructional approach to help pre-service teachers learner alternative pedagogical approaches (Schwarz, 2009). Theories and teaching practises of model based teaching and learning have been reported in the International Journal of Science

Education (vol. 9, issue 9, 2000). Models developed with variables obtained from an experiment conducted by students can capture the essential fragments of how the student thinks the ecosystem works and thus provide feedback on student thinking. Under which circumstances would the use of modeling compliment learning acquired during an ecological field experiment? The authors of this study were interested in exploring these ideas. Would the use of reflective modeling accentuate participants' ecological knowledge?

Qualitative conceptual modeling

In order for students to develop a more accurate conceptual model of the environment, students must first make their own mental models of the environment explicit and understand the concepts and relationships between concepts that make up their mental model (Shepardson, Wee, Priddy & Harbor, 2007). These mental models are analogous to “prior understandings” described above. A student’s mental models often contradict the conceptual model learned in school. For example, the teacher might present a conceptual model about the fluxes of matter and energy in ecosystems that contradicts a mental model about the “balance of nature”. Students may hold on to these mental models alongside the accurate conceptual models learned in ecology class. These different models, mental model or conceptual model, may be recalled depending upon the context. It is likely that the more scientifically sound model can be “activated” with appropriate guidance from the teacher when students are taken outside to study natural ecosystems in a real world context (Glynn and Duit, 1995). This process is constructivist in that it supports active construction of knowledge and understanding of scientific phenomenon

(Henize, van Driel & Verloop, 2007). Alternatively, it is possible that one's personal mental model may be altered through a process of accommodation. If a student becomes dissatisfied with their existing conception, and the new conception is presented plausibly, the old conception might be replaced with new ones (Posner et. al., 1982, cited by Glynn and Duit, 1995). This process is necessarily metacognitive, where students are encouraged to reflect, in a non-judgmental atmosphere, on what they understand at critical moments and revise their earlier explanations. Students' existing mental models are more likely to be activated in a non-judgmental atmosphere

Models are ways of thinking about ecological functions and can also be effective in revealing "ways of ecological thinking" (D'Avanzo, 2003). Modeling activities can be effective for learning about system attributes (feedback, indirect effects) Modeling is useful as a means of conveying complex, dynamic interactions. Models of ecosystems can facilitate an ability to be attentive to whole systems by illustrating multiple factors of interaction, feedback, subsystems and inputs and outputs, which leads to a greater understanding of ecosystem functioning (Dresner and Elser, 2009). Students can develop complex understanding if their teachers have the competence to understand and communicate these features (Vikström, 2008).

Methodology

Background for this study

The Teaching Ecosystem Complexity project provides a two-week course for high school science teachers held at one of five Long Term Ecological Research site. This study includes results from four of the five sites. Participating high school science teachers focus on the first-hand creative work of field research as is done by scientists. Providing field research opportunities that encompass all the steps of inquiry is an essential part of the teachers' experience. Appropriate assessment tools are necessary to understand how teachers build up their knowledge about scientific concepts during the training course, as they are engaged in the process of experimentation. An appropriate test of knowledge should occur in the context of how the material was learned. Conceptual models depicting ecological theories (diversity/ resilience) show understanding of non-intuitive processes like feedbacks and indirect effects that are best represented with visual connections between environmental variables and ecosystem components (Dresner and Elser, 2009). The primary tool used in this project was qualitative conceptual modeling, (QCM), a process developed over four years at the H.J. Andrews LTER site.

A conceptual model helps explains a person's thinking about a phenomenon because it is drawn from the perspective of the participant. We asked participating teachers to devise a qualitative model of the variables in their experiment, discuss the models in essays and discuss what they understood with their peers. These activities were used in a pilot test with a small group of teachers, and we noticed that their models changed as the teachers learned more about these ecological ideas. We developed a rubric with which to score teachers' models. By studying more expert QCMs as compared with novice QCMs, we were able to develop sequences from novice to more expert for our criteria (e.g., the

degree to which the models' components connections can be explained meaningfully). Our rubric was modeled after one used by Grotzler (2008) and was pilot tested and revised twice. Teacher generated QCMs were then used throughout a series of two-week training to map the ideas a teacher had about how ecosystems work.

Current Study

The study reported below took place during the summer of 2008 at four Long Term Ecological Research sites: the H.J. Andrews LTER in Oregon, the Jornada LTER in New Mexico (Asombro Institute), the Luquillo LTER in Puerto Rico, and the Shortgrass Steppe (SGS) LTER in Colorado. Workshops with teachers were conducted over a two-week period at each of the four sites. The agendas were similar in that teachers learned content while developing their own field experiments and analyzing and presenting their findings. Teachers' understanding of ecological interactions as applied to their experiments were assessed through the use of pre-/post-assessment QCMs and essays that were scored by rubrics. In addition to working on individually chosen, scientist guided ecology research projects, teachers at three of the four sites engaged with working scientists on some of the participating scientists' own research projects in varying degrees. Specific research experiences thus varied at each of the workshops. Specific topics also varied.

H. J. Andrews LTER is a residential research site in the Oregon Cascade Mountains. Teachers remained at the site during the two weeks of the workshop, which afforded them a greater depth of experience than was possible at other sites. During this time, the

participating teachers took part in one of three research projects in collaboration with the lead scientist: leaf litter decomposition, arthropod diversity, and vegetation cover survey. The Asombro Institute did not have overnight accommodations so the sessions took place during business hours, with homework assigned to teachers most nights. The major theme for all teacher projects was the environmental causes and consequences of desertification in Chihuahuan desert ecosystems. During the first week of the workshop, teachers visited a variety of research sites with LTER scientists to learn about ongoing research and methods for studying climate, soil, vegetation, invertebrates, and vertebrates. During the second week of the workshop, teachers completed independent research projects, most using plots that had been previously set up in black grama (*Bouteloua eriopida*) grasslands and honey mesquite (*Prosopis glandulosa*) dominated shrublands. In Puerto Rico, teachers were engaged in an ongoing research project to understand the structure of secondary forests in urban areas near the Luquillo LTER site. The research site is dominated by the African Tulip *Spathodea campanulata* and is surrounded by urbanization. The teachers conducted census of birds, reptiles and amphibians, pitfall trapping of litter arthropods, measuring trees, and mist-netting bats. Teachers compared the biodiversity of species on each plot. During the second week, teachers completed an independent project in vegetation or wildlife working with a specialist. The SGS-LTER treated the Ecoplexity project as one of a number of efforts over the entire year to provide a group of local middle school and high school science teachers with scientific inquiry, fieldwork, and learning from scientists. The first week, they conducted stream macroinvertebrate, invasive species, and terrestrial invertebrate studies. The second week they participated in dispersed scientist-derived research projects; e.g., grazing studies,

Mt. Plover habitat census. Out of the 17 teachers who attended the workshop, 5 had not participated in any other SGS workshops before. Data was collected from teachers who had not attended a LTER workshop previously.

For each of these projects, the teachers worked through the scientific method by creating a hypothesis, collecting and analyzing data, interpreting the statistical results, and communicating their findings in a research paper or poster. During the course, teachers also took part in discussions of classic journal articles about diversity, experimentation, and complexity. Frequent presentations and group discussions helped to build knowledge of scientific ideas and connected those ideas to the research project. At the beginning of the two-week training, teachers created qualitative models to show their current ecological understandings. They were all required to answer a series of essay questions pertaining to their models. These questions basically asked them to tell a story about what they understood about the ecosystem they were studying, guided them in developing their hypotheses and making predictions, and further probed their thinking about systems aspects of ecology. This process was repeated again at the end of the two-week training. Therefore, for each teacher we had a model and set of essay questions from both the beginning and the end of the programme. All teachers were also given a pre and post-test environmental science content test.

Two sites, The H J. Andrews and the Asombro sites, used the QCMs reflectively, as a continuous reference over the course of their workshops, and as an assessment tool. The H.J. Andrews and the Asombro groups of teachers were introduced to QCM during the

first day of the workshop and were asked to add to their models frequently throughout the course of their experiments to reflect on their growing knowledge. Once they created their models, they formed small groups with one or two other teachers and shared their models through “Think-Pair-Share.” This exercise gave teachers the opportunity to articulate their ecological understandings, as shown in their models. The teachers then were asked to answer the same essay questions pertaining to their models as the other groups. Teachers at the H.J. Andrews site 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.

We were also concerned with how teachers translated their experiences back in their classrooms. At the summer workshop, teachers were asked to rate various aspects of their classroom practises on a comprehensive 38-item survey, including an open-ended question. During the spring of the following year, teachers sent an on-line version of the same survey to see if there were changes in classroom practises. Forty-six teachers completed the first survey while attending a workshop in Oregon, Colorado, New Mexico or Puerto Rico. Thirty-five of these teachers completed the second on-line post-surveys (overall response rate 76%).

The SGS and Luquillo sites used QCMs as a pre-post test assessment too but did not have their teachers engage in peer-discussions about their ideas. At SGS, teachers developed two different models over the summer session, and these were assigned as homework. Their pre-test model was on their first week’s team project and their second model was

developed in cooperation with the scientists whose project they worked on. At the Luquillo, teachers developed pre and post-test models of their own research projects.

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, four 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.

Two independent evaluators at the H.J. Andrews scored the models and essay questions (e.g., see Caracelli and Greene, 1993). The other sites used only one scorer. Inter-rater reliability was assured through a process whereby the scorers from each site reached agreements on interpretation of how each rating would be ascribed. A Wilcoxin signed pairs test was conducted comparing pre-test and post-test scores for each group. ANOVA were run on modeling scores from all groups and from the two groups having significant Wilcoxin test scores. T-tests were performed on particular sets of scores from these two groups to test the strength of the results. T-tests were also performed on the pre-post knowledge test scores.

A sixteen item content test was given to all participants, pre and post-course. These results were not utilized in our assessment of knowledge gains, since most participants scored high during the pre-test. However, the pre-test scores were used to help us gauge differences in teacher knowledge at the start of the courses across groups. A simultaneous multiple regression analysis was conducted to evaluate how well a variety of factors would predict scores on the ecology content assessment. The data for these factors was gathered via preliminary information collected from each teacher. The four predictors were: research site, teacher prior experience with field research and teaching ecology classes, and teacher grade level. The criterion variable was the score on the ecology content assessment.

Results

Although each two week workshop was roughly parallel, there were differences in the make up of the teacher participants (e.g., some groups included middle school teachers), the degree of focus on use of qualitative modeling, the focus of the research projects and the degree to which teachers shaped their own research inquiry projects. Each of these elements was seen as influential to the results. A one-way ANOVA conducted on scores for a pre-test of knowledge for all participating groups indicated that there were no significant differences in scores between teachers at the different sites on the content assessment administered before the workshop (see Table 1).

(insert Table 1 here)

There was considerable variation in teacher background between all four groups of teachers. We conducted a multiple regression to evaluate how well any of these factors were correlated with the teacher's achievement scores. The regression was performed on four predictor values: workshop site, teacher prior experience with field ecology and teaching ecology, and teacher grade level. The bivariate correlations between the four independent variables were considered small to medium, ranging from -0.164 to -0.324. A linear combination of the four variables related to teacher experience and workshop site was not found to be significantly related to scores on the ecology content assessment administered before the workshops. The results indicate that among the high school teachers in the four different workshops, there were comparable pre-test achievement scores within the larger group of high school teacher participants who had not had prior experience in the LTER training programme. Because of this distinction, only teachers who had no previous experience in LTER trainings were included in the data analysis.

We compared the pre-test and post-test scores for models and essays for all four groups. A Wilcoxon signed pair test was performed on all pre and post test essay and model scores. Significant improvements in scores for knowledge about ecosystems as portrayed through models were found for two (H.J. Andrews and Asombro) of the four groups ($p < 0.05$) for understanding all related concepts as shown in Table 2. This reflects the focus throughout both workshops on qualitative modeling. SGS-LTER teachers and Luquillo teachers did not show improvement in any of the concepts expressed through essay or model scores.

(insert Table 2 here)

An ANOVA was performed on the data from all groups of teachers. Results were not significant, as shown in Table 3, indicating that differences between groups were more substantial than the differences in scores before the training as compared with scores afterwards. A second ANOVA was performed with two groups, H.J. Andrews LTER and Asombro Institute, because the results from Wilcoxon test had indicated there was a larger difference between pre and post test scores. For these two groups of teachers, differences between pre test scores and post test scores were substantially different ($F=5.46$, $p=0.031$, F critical – 4.41). T-tests were performed on scores for each item of pre-post tests for these two groups. Overall, there was significant improvement in post-test scores (mean var. 1 = 31.15, mean var. 2 = 19.9. T stat = 7.28, T critical = 1.69). T-tests were also performed on each paired item of the knowledge test. An overwhelming majority (68%) of teachers scored high on most items on the pre-test, with the exception of items concerning system dynamics. These two items were compared using t-test. Results were significant for the same two groups, H.J. Andrews and Asombro Institute, as shown in Table 4.

(insert Tables 3 and 4 about here)

Qualitative Data Comparing First and Final QCMs

We collected and compared excerpts from teacher's essays to understand how their models and, assuming they used their models as references to develop their hypotheses,

their research hypotheses changed over time. Most teacher's first models and accompanying hypotheses were "all over the place", they either showed only simplified relationships or included every detail possible. Later models were more deliberate and meaningful, with more purposeful connections, and many connections were multi-stepped and complex. Initial expressions of research hypotheses were typically very general. Their final statements of their hypotheses were also more accurate. We interviewed the teachers from the H.J. Andrews group and asked them to explain the differences between what they understood as depicted in their first and final models about the variables and their experiments. Examples of teachers' descriptions of how their models improved over the span of the course are described below:

"First I thought rodents were important, then everything in the data pointed to trees and fungus. By my final model, I focused more on the main components. My last model looked simple, but it shows more (organized) information"

"My first model depicted how everything in the system is related to mycorrhizae. Later, I chose microbes, enzymes, and invertebrate decomposers as central variable because I learned they work directly to decompose Douglas fir needles."

Examples from the interviews of how teachers' research hypotheses took on new focuses over the span of the course is described below:

(First hypothesis) " Diversity is similar, species will differ". Midway, my model

kept expanding with every new aspect of what I was learning, it was hard to focus. It became important to set limits to how far out to branch, since these models could extend out forever.” My final statement of my hypothesis was more focused: “ Varied canopy cover in an old growth forest will create a higher diversity of plants growing within it as compared to a young forest.”

Teachers’ qualitative models reflected the state of their understanding of the ecosystem. For example, S.K. worked on a leaf litter decomposition study. She was not given any specific direction about which elements to choose, and she first assumed that the presence of springtails (an important soil invertebrate) in the soil should be linked directly to soil decomposition. Her first ecosystem model presents these organisms in a linear connection as a food chain, reflecting her initial understanding of how variables should be connected. Her final ecosystem model was complex, showing multiple connections with multiple steps (Figure 1). She offered the following explanation of her own change in understanding and finally, developed a more accurate statement about the decomposition process:

“I began to see that presence of springtails was dependent upon soil moisture, fungus, bacteria that are present. Positive and negative interactions go back and forth between so many organisms as well as from the abiotic influences.

Dependency is tentative. Organisms rely on several others, not just one. Nitrogen fixer (alder) leaf litter decomposes faster than non-nitrogen fixer leaf litter because Nitrogen fixers have relationship with microbes that create enzymes that

help break down the leaves and consequently support more shredders and springtails”.

In the second example, M.L. was provided with a set of initial core relationships, between black grama, honey mesquite, and precipitation, which she continued to build upon throughout the workshop. As shown in Figure 2, she started with an already complex diagram, which became more so as the two weeks went on. She first assumed that soil erosion was the main determining factor and reasoned that predator prey relationships between cottontails, grasshoppers, and coyotes (especially coyotes) were the most important set of interactions. Previously, she had only learned about more charismatic species. She reasoned that since coyotes were responsible for keeping overgrazing by herbivores in check, they were the key variable. By the end of the workshop, she had learned about many more factors that affected soil erosion. She re-wrote her initial statement of her research hypothesis to reflect her more accurate understanding.

“The black grama has many other components affecting it; cattle grazing damages soil, allowing for greater erosion and disturbance of cyanobacteria populations. I thought I would include the effect of soil compaction and its relationship to species diversity, and test for soil water infiltration. This will give me a better overall picture. There will be a difference in plant species diversity between desert grasslands and shrub communities due to soil erosion, compaction, and water infiltration.”

During interviews, participants in the H.J. Andrews group were asked to attribute which particular aspects of the course they thought had helped them most understand ecosystem complexity. Discussion with peers using their ecosystem models and aspects of the experiment was designated as the most influential activity (five out of eight teachers). The research activities themselves were the second most influential activity (two out of eight teachers).

Changes in teaching practises:

Teachers self-assessed their own teaching practises at the start of the course and again 10 months later (at the end of the spring term of the following academic year). Using the Mann-Whitney Test of statistical significance between the pre and post-test groups, a number of items had significant changes with $p \leq 0.05$. By the time of the post-test (10 months after the course), teachers had changed their classroom practises to include the following activities:

- Pose their own hypothesis and collect data and work out how to collect data to test their hypothesis ($p= 0.04$)
- Go into field to collect data related to questions they have posed ($p= 0.02$)
- Work in teams to conduct field work ($p= 0.006$)
- Learn to draw ecological modeling illustrating inter-relationships ($p= 0.03$)
- Interact with scientists ($p= 0.00$)
- Logically order their research information into written work ($p= 0.01$)
- Discuss the significance of their findings in class ($p= 0.05$)
- Read ecology journals ($p= 0.04$)

Significant differences were also found in teacher's views confidence. They felt more prepared to teach using field work ($p= 0.01$).

The open-ended question on the classroom practises assessment asked teachers to describe how the research course had influenced their teaching. Fifteen teachers (from all four sites) reported that they had used field research projects that lasted two weeks or more. Two teachers (from Luquillo site) had used models in their ecology lessons Eight teachers (from the Andrews and Asombro sites) reported that they had combined field research with qualitative modeling in their teaching. Some comments from this second group are included below:

- My students designed models to characterize different groups of organisms. This was a successful experience and helped many more of the ecological inter-relationships in the New Mexican desert (using models).
- We used the conceptual models with the feedback loops. Instead of the usual models of food webs and pyramids, the feedback loops help students to recognize the negative impacts on a species as well as the benefits.
- Using modeling, kids moved from linear thinking to more systematic thinking. Modeling was a new thing for us.
- Students did a project about the forest, and modeling was a great tool to illustrate multiple factors being related. Things aren't as simple as they appeared.

- The class did a comparison between forests in different successional stages. The more “scatterbrained” kids seemed to do better at modeling, using visualization seemed especially important to them.
- I used the concept models to teach basic principles of ecology on a field trip; it was a wonderful way to get them to really see what was going on in the ecosystem and dialogue and discuss interactions they observed or inferred. I think it showed good evidence of student learning.

Several teachers from the Asombro Institute site described how using QCM in their own classrooms had helped students understand important variables and the connections between these variables. Some of these teachers reported that they used student models to help pinpoint students’ misconceptions, and then tried alternative ways to present the information.

The results indicated from this survey are all highly correlated with the focus of the previous summer’s courses. Teachers who had completed a field research project during professional development were likely to engage their own students in a similar project. Teachers who had used qualitative models in combination with their field research during professional development were the only ones who had used qualitative modeling with their students along with student field research projects.

Discussion

Asombro and H.J. Andrews teachers both showed significant improvements in modeling and essay scores. Based upon this, along with evidence provided from interviews with teachers, we are confident that these participants' understanding about ecological processes improved over the course of the workshops. QCMs used with peer discussions, coupled with participation in ecological research, were the main strategies that helped enrich their insights about ecological relationships.

Peer discussions about individuals' QCMs provided opportunities to negotiate about what each participant understood or needed to understand at points in time, There was a significant amount of time devoted to modeling during these two workshops.

Presentations were made about how to create models, a variety of models were demonstrated by participating scientists, and time was devoted to discussions about participants' models throughout the workshops. Using teachers' QCMs throughout the workshops probably increased the perception of the importance of these tools in the context of doing research at an LTER site. These particular opportunities were not provided at the two other sites (SGS and Luquillo). This emphasis is the primary explanation for the differences in achievement we have documented. This claim is supported by responses to interview questions.

Differences between groups in achievement as documented by modeling scores can also be explained by differences in emphases between each of the sites. At the H.J. Andrews, a residential programme, teachers worked longer hours than teachers at the other sites.

They would continue their analysis, read pertinent scholarly articles, explore other visualizations available on the website or engage in discussion with colleagues late into the night. Teachers stayed with the same research topic for the entire two-weeks and were thereby able to research background studies and meet with other scientists at the site about their topic.

At the Asombro, all teachers shared the common focus of desertification. This focus allowed them to get in-depth information about the topic and learn about current research being conducted by LTER scientists. Each chose a specific focus for own research project (e.g. how does soil compaction differ in grasslands versus shrublands) and, in many cases found a project that fit their curriculum and could therefore be continued with their students during the school year. Since all individual projects tied back to the theme of desertification, teachers were able to both discuss their individual research projects (soil compaction, water infiltration, vegetation cover, and arthropod diversity) in a way that linked them together.

The SGS-LTER and the Luquillo groups of teachers worked on one research project their first week, then changed to a different project for their second week. The scientists at both the SGS and Luquillo observed that their teachers had developed deeper understanding of research questions and methods after spending a week in the field with them. The SGS teachers were able to ask the scientist why they came up with the question they have, how they decided to collect the data they need, and how their research project fits into the broader context of ecological knowledge. Between their pre and post-

workshop models, the Luquillo teachers evidenced improvements in understanding connections between ecosystem components. After their research experiences, the teachers helped write scientific manuscripts under the mentorship of a lead scientist. Many teachers at all four sites also worked with the participating scientist into the school year. Scientists made classroom visits and assisted teachers in implementing student research projects.

The emphasis on ecological complexity and use of visualizations increased teachers' abilities to think of a whole group of interactions and components concurrently.

Teachers used their models to help them build their understanding. Using models enabled them to develop more sound research hypotheses. Teachers used their models to help them comprehend the meaning of their results. As they analysed their data, they actively tested whether their initial explanatory ideas were accurate or not. As they revised their models, they subjected them to the scrutiny of their peers through "think-pair-share" activities. When they held a first model up to a reference (either someone else's model or their experimental results) each teacher would receive explicit feedback about whether their ideas made sense, or not. Models helped teachers to negotiate the meaning of a pattern with each other. This process helped teachers coordinate their experimental results with the ecological theories they learned. Models were useful to help search for patterns or regularities in their data.

Some of the differences in models pre workshop and post can be attributed to practice. As they became more skilled in how to model, teachers' models would become comparably

more sophisticated. However, their comments attributed the use of modeling and peer discussions as factors helping them to think more richly about their experiment indicate that the technique was valuable. The increase in scores was not just the effect of learning the mechanisms of modeling.

How QCMs contributed to teachers' understanding about complex interactions

The excerpts presented above from teachers' essays and interviews illustrate shifts in participants' thinking during their research to encompass better understanding of the ecological theories pertaining to their research.

Structured opportunities were provided to reflect on what they understood. Talking can scaffold the development of reasoning skills, and scientific understanding. Models are representations of teachers' thinking; they reflect an integration of science concepts. The series of models portrays the journey of understanding from initial prior understandings to more sound scientific explanations of ecological interactions. We observed how critical the initial step of "figuring out" what each person understood was, followed by discussions among teachers about their ideas were to develop a more accurate causal explanation of ecosystem function and structure.

Modeling can be useful to help a student build connections between the science experience and the scientific ideas a person has. Modeling activities helped the participants structure their understanding of the ecological interactions they studied. Evidence provided from analysis of QCMs and essays, show increased understanding

about feedback loops and indirect effects in ecosystems. In a previous study (XXXX, 2009) teachers' understanding about complex ecosystem functioning had also significantly improved via use of conceptual models. In this current study, we continued to find evidence about the value of QCMs to learn about complex causality in ecosystems.

In the example shown in figure 3, one participant showed an increased ability to show how feedback operates in the ecosystem she had studied experimentally. Her first model (Figure 3a) does not show any feedback, nor did her first essay. Interestingly, she had responded correctly to the question about complex causality on the multiple choice content test, indicating she had some understanding about it. In her final model (Figure 3b), she was able to illustrate both positive and negative feedback, and described in her accompanying essay how microbes and shredders both contributed to the decomposition of Douglas fir needles. She explained how plants benefit from the release of nutrients, how herbivores benefit, and how predators benefit from this increase.

“I chose microbes, enzymes, invertebrate decomposers, as the most important factors working to decompose Douglas fir needles. These organisms break down the material by digesting it and returning the ‘waste’ material to the soil. The trees and shrubs directly benefit from the release of nutrients into the soil, which benefits the herbivores and omnivores, which benefits the predators... If the amount of nutrients being returned to the soil decreased, the amount of new plant growth will decrease, which would decrease the number of herbivores.”

The discrepancy between scores on a multiple choice test and a more in-depth essay score indicates that the procedure using QCMs may be a more appropriate method to examine complex understanding.

Implications for Professional Development

In a study of outcomes of a similar course in ecology, the authors narrowed down three essential characteristics of effective professional development (Jeanpierre, Oberhauser, Freeman, 2005). These were: “deep” science content and numerous opportunities to practice science process skills, high expectations for teacher learning, and clear expectations for teachers to demonstrate their competency. Our results corroborate the importance of “deep” science immersion during professional development. All four groups of teachers were provided with a two week in-depth experience in field ecology research. Teachers from all groups expressed increased confidence in their ability to conduct research.

One aspect of this increased confidence came from a demystification of the process of scientific research. Scientists were no longer perceived as “all knowing others”. Participating scientists were exemplary in pointing out possibilities for creativity in all stages of experimentation. In particular, the advantage of field experimentation, as compared with cookbook lab activities, lies in their not knowing the outcome ahead of time. The mystery of things not working out as anticipated sometimes lead to an “Ah Ha” moment of mutual discovery. These precious opportunities were pivotal for many

participants. Their excitement in discovering something for themselves based on their own collected data provided them with evidence that their own students would likewise enjoy the same process. Teachers from all groups were able to implement student research projects at their schools. Teachers from the two groups who had experienced QCMs and peer discussions throughout their professional development course were the only ones who followed through with using conceptual modeling with their students.

A more systematic exploration of the relationship of teachers' experience during the training course in ecological experimentation and how they change their practises over the ensuing school year is needed. The author plans to make classroom observations along with continued use of the self-report classroom practises survey with another cadre of teacher participants. Tests for longer-term recall of ecological knowledge will also be administered.

Conclusions

Qualitative Conceptual Modeling was a useful tool that helped teachers to construct their new ecological understanding, but not universally. It was useful in improving teachers' understanding of key ecological concepts when it was used along with dialogue with peers, and as a reference throughout the course. These results highlight the importance of taking time for reflective discussion among teachers and with scientists during professional development. Lively discussions about the importance of different factors

appeared to contribute to the gains made in teachers' understanding. The resulting knowledge improved the teacher confidence in teaching non-intuitive complex ecological concept to their students. Teachers cited the modeling activities as central to their change in classroom practises. Thus, the use of reflective conceptual modeling can also lead to better application of what was learned during professional development to classroom application.

Reflective use of qualitative models may provide a more accurate means to measure relative change in teacher and student knowledge than the absolute measure represented by a multiple choice test. Use of QCMs may help in the process of conceptual change. The models help each participant visualize what they understand. Peer or cooperative learning requires students to talk about their ideas and helps them to shape concepts. Engaging students in activities where they use previous knowledge to answer questions, while working in non-competitive collegial groups, may allow them to begin to see flaws in their thinking and be more willing to accept more sound scientific explanations. Alongside instruction in ecological theory, this process can help participants fill in the gaps in their understanding. Teachers who have experienced using an alternative assessment and reflective learning tool for themselves were the only ones who had used it in a similar manner with their own students. Some participants' classroom practises changed towards experimental use of qualitative conceptual modeling to aid students' understanding about the ecological phenomenon being studied.

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Table 1. ANOVA results of all groups pre-test content scores

Group	N	Pre-test M	SD
Luquillo	10	10.0	1.25
Asombro	12	9.58	2.19
H.J. Andrews	8	9.50	1.69
SGS-LTER	17	11.60	2.19

Table 2. Wilcoxon signed pair test results showing level of significance for all groups of teachers' pre and post essay scores.

Group	Andrews	Asombro	Luquillo	SGS
Identifying variables	0.008	0.031	0.25	0.5
Relationship between variables	0.015	0.044	1	1
Concept of diversity	0.008	0.002	0.125	1
Forming hypothesis	0.015	0.031	1	1
Understanding Redundancy	0.008	0.005	1	0.5
Understanding feedback	0.06	0.031	0.5	1
Impact of disturbance on variables	0.008	0.002	0.25	1
Understanding Complexity	0.016	0.031	1	0.875
Understanding how climate affects variables	0.03	0.008	0.5	1

Table 3. Results of an ANOVA performed between all four groups of teachers using pre and post essay scores

<i>Source of Variation</i>	<i>SS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	756.7071429	12.628	1.45749	2.9113
Within Groups	619.1785714			
Total	1375.885714			

Table 4. Results of T-test run on pre and post content test results.

Item	T stat	mean	T critical	Sig.	Groups
Understanding feedback	2.43	0.5	1.68	yes	H.J. Andrews Asombro
System dynamics	2.40	0.9	1.70	yes	H.J. Andrews, Asombro, Luquillo

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