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ABSTRACT

The research literature suggests that developing an understanding of ecosystems and their functioning is difficult. Learners are often asked to conduct ecological inquiries to attempt to foster such understanding. This project examines the understanding of students engaged in ecological inquiries as a model-based teaching and learning framework. The coursework of preservice teachers enrolled in a field-based ecology course was analyzed for evidence of their models of particular ecosystems. In addition, investigations in the laboratory and the field were videotaped or audiotaped to provide evidence of the functioning and development of those models over time. This paper describes the ways in which their initial models influenced their investigations and interpretations of the data they collected and how their models developed. The conversations, representations, and tasks as well as the constraints that shape individual and group model building within inquiry groups are also described. (Contains 20 references and 3 tables.) (SAH)

Model-based teaching and learning during ecological inquiry

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Objectives

The research literature suggests that developing an understanding of ecosystems and their functioning is difficult (Leach, Driver, Scott & Wood-Robinson, 1995, 1996a, 1996b). Learners are often asked to conduct ecological inquiries in an attempt to foster such understanding. This project examines the understanding of students engaged in ecological inquiries using a model-based teaching and learning framework (Buckley, 1992; Boulter, 1992; Gilbert & Boulter, 1998). The coursework of preservice teachers enrolled in a field-based ecology course was analysed for evidence of their models of particular ecosystems. In addition, investigations in the laboratory and field were videotaped or audiotaped to provide evidence of the functioning and development of those models over time. This paper describes the ways in which their initial models influenced their investigations and interpretations of the data they collected and how their models developed. It also describes the conversations, representations and tasks as well as the constraints that shape individual and group model-building within inquiry groups.

Theoretical framework

Model based teaching and learning

Model-based teaching and learning integrates frameworks that emerged from earlier studies of model-based learning (Buckley 1992) and collaborative learning in science classrooms (Boulter 1992). It is part of our effort to create a model of science learning that encompasses both social and cognitive levels. Model-based learning, as described by Buckley (1992) and others (Johnson-Laird, 1983; Stewart & Hafner, 1991), focuses on each individual's construction of mental models of the phenomena under study. In response to some task, learners draw on prior knowledge and new information to form an initial model of some phenomenon, either intentionally to meet some learning goal or spontaneously. When the model is used successfully, the model is reinforced and may eventually become a precompiled, stable model (Vosniadou & Brewer, 1992). If the model is not satisfactory in use, it may be revised or rejected resulting in a progression of mental models (Clement, 1989; White & Frederiksen, 1990). Model-based teaching focuses on the patterns of participation, persuasion and model-building in the learning environment during which individuals construct their understanding of some phenomenon. This is accomplished through discourse with and about representations. This discourse is sometimes guided by a teacher who facilitates negotiation among the participants in the discourse, including those not present such as scientists and developers of instructional materials. Phenomena and representations of phenomena link individual and group levels of learning since they serve as the focus of both tasks and discourse. Representations serve also as tools for conducting the discourse and constructing meaning. The relationship between phenomena or reality and representations has been considered from diverse perspectives. For our purposes, we consider representations to be simplifications of the phenomenon constructed for particular purposes such as communication, exploration, assessment and problem-solving.

The development of the target model for soils and biological habitats

It is very difficult, probably impossible, to create one representation that captures our target model as teachers of the soils and habitats course. In jointly creating our target model we began by articulating the parts or structures of the systems that interact to form the particular habitats the students studied in our inquiry-based fieldwork course. Table 1 displays the hierarchy structures we identified after much discussion.

Table 1. Levels of structural organisation in Soils and Habitats.

Biological organisation	Soils organisation
Geosphere	Geosphere
Ecosystem	Ecosystem
Organism	Pedon
Organ system	Horizon
Cells	Peds and pores
Organelles	Minerals
Molecules	Molecules
Atoms	Atoms

You will notice that at both extremes of the scale Habitats and Soils share the same structures. Both participate in and are affected by the geosphere and ecosystem levels. Both are ultimately dependent on the interactions of atoms and molecules. While many of the terms for biological organisation are familiar to anyone who has taken biology, the structures in soils are less well known outside the field. Pedon refers to a three dimensional unit of soil sharing the same history. Horizons are layers within the pedon, characterised both by district and properties. Peds are clusters or clumps of soil separated by pores, which are the spaces among the peds through which air and water (and any materials carried by the water) can move. Minerals are characterisable mixtures of molecules with particular properties and history of formation.

Soils and habitats are interactive systems in that their parts participate in simultaneous processes that in turn affect the parts. Thus at the organism level, the vegetation that grows in a particular pedon affects soil formation processes in the pedon by sending roots through the soil, opening up pores among the peds, and taking up minerals and water from the soil. The vegetation also contributes dead organic matter to the surface of the soil where it begins to break down and becomes part of the soil horizons (leaf litter, fermentation layer, humus layer). The vegetation, both living and decaying, provides habitats for other organisms such as earth worms that in turn mix the soil and open up channels that ease root growth as well as the movement of air and water. Changes in the character of the soil brought about by these processes influence what vegetation can then grow on that pedon. This iterative process supports ecological succession, a series of changes in the populations and communities of organisms that inhabit a place. These changes result from the interacting behaviours of the parts, an example of emergent causality.

The previous paragraph is an expressed model in the terms of Gilbert and Boulter (eds) (2000) of our mental model of a woodland ecosystem and its associated pedons. That mental model (or collection of mental models) developed as we articulated the processes or behaviours of the parts at each level (Table 2).

Table 2. Processes and behaviours at each level of structural organisation.

Biological	Soils	Processes/behaviours
+2 Geosphere	Geosphere	Climate processes->biomes
+1 Ecosystem	Ecosystem	Population dynamics, soil dynamics pedogenisis,
1 Organism	Pedon	Feeding, dying, worms mixing soil
-1 Organ system	Horizon	Digestion, respiration, photosynthesis, leaching
-2 Cells	Peds and pores	Cell growth, death, ingestion and secretion of materials. movement of materials
-3 Organelles	Minerals	Mitochondria, chloroplasts generating ATP, dissolution
-4 Molecules	Molecules	Biochemical cycles, dissolving
-5 Atoms	Atoms	Chemical reactions

For each level we can describe the effects of the cycling of material and the flows of energy. In each habitat studied we have a spatial arrangement of layers or zones within which distinct communities of organisms and pedons exist (Table 3).

Table 3. The Woodland habitat

Layers	Structures	Energy flow Materials cycling
BIOTA		Sun
Canopy layer	Carnivores	
Shrub layer		Energy
Field layer	Detritus feeders	
Ground layer	Herbivores	
SOIL		
Leaf litter layer	Producers (plants)	Materials
Fermentation layer		
Humus layer	Decomposers (Bacteria and fungi)	Oxygen Carbon Nitrogen
A horizon		
B Mineral horizon		Water
C Parent material	Pedon types	

Key to Table 3
Canopy —trees 5-20 metres
Shrub —shrubs 2-5 metres
Field — 0-2 metres
Ground — up to 3 cm
Leaf litter —leaves from within the last year's cycle
Fermentation layer — leaves from the previous year's cycle that can no longer be recognised as complete leaves
Humus layer — If less than 10cm thick it is humus, a black sticky amorphous substance that stains the hands.
If over 10cm thick it is classed as peat and is likely to be lower in the profile.
A – mixture of organic and mineral material.
Often more than one A horizon can be distinguished on the basis of colour or the way that the organic material is distributed, For instance, humus can stain quartz grains (A) or can act as the material which binds them together (Ah). There is a net loss of minerals from this horizon.
B – a purely mineral horizon.
C – the parent material that directly underlies the soil. It may be solid or drift geology.

In such a habitat what causes the behaviours and changes over time? Based on Buckley's (1992) description of the heart the mechanisms of a system are seen as resulting from the interacting behaviours of the component parts. Each of the parts can be considered in terms of its components, but more importantly, how each of these parts behaves is a function of its state at a particular instant. This is another example of emergent behaviour.

In soils and habitats there is a progressive cycle leading to ecological succession, evolution, and soil formation. The state of an ecosystem and its associated pedon is the result of the cumulative history of these processes. The more general statement of causality would be that the state of any particular level of organisation emerges from the interacting behaviours and processes of the components of the subordinate level, indeed, of all the subordinate levels. Understanding such systems requires building many models of components and their behaviours or parts and processes, that are embedded within the levels of organisation relevant to the phenomenon under study as we have shown in the last set of tables. The course and the subsequent research was set within the context of model based teaching and learning and the developing target model that we, as teachers, had for our students in the Habitats and Soils course.

Settings, context and methods

The preservice teachers course: Habitats and Soils

A group of 31 British preservice teachers on this course collected data in woodlands, meadows, ponds and rivers in order to build models of the structures, behaviours, and mechanisms operating in different ecosystems. The focus of the course was on interactions between soils and habitats that determine what lives and grows in a given habitat. The course met once a week for 10 weeks. Students worked in the same groups of 4-6 people to conduct field investigations. Groups shared the collected data with the whole class. Pairs of students created and presented posters that displayed the interactions within a site of their choosing. During the presentations, course instructors probed for clarifications and understanding. At the end of the course students individually produced extensive reports of their field investigations.

The data and its analysis

Student work and taped classroom and field activities provide the data for our study, augmented by an initial representation task designed to elicit prior knowledge. Classroom and field activities were taped (audio or video). In addition, semi-structured interviews of a self-selected subset of the students were conducted at the end of the course to probe and clarify their understandings. The data set therefore included initial representations of a woodland ecosystem, posters, episodes in the field, field investigation reports and final interviews. During field work a different group was taped each week so that by the end of the course all groups had been taped.

Data analysis was conducted by all authors collaboratively. Videotapes of field work were viewed and outlined to select episodes rich in collaborative inquiry and model-building. These episodes were transcribed for more detailed analysis. The initial representations, posters and presentations of the individuals in the group and their field investigation files and final interviews, where available, were incorporated into the data analysis to create narratives. These narratives traced the models used to pose questions, guide data collection in the field, and influence the interpretation of field data as well as summarising the negotiations among group members.

To create the narratives of model development all the data from initial representation, poster, file and final interview were analysed for each individual in the group who were videoed in the woodland using a method developed by Buckley & Boulter (1997, 1999, 2000). Aspects of phenomena were analysed in terms of structure (component parts and their spatial relations), behaviour (time-based changes and processes), and mechanism (the causes of the behaviour). To show how students chose to express their mental models in a particular task, we analysed the mode of representation (concept map, diagram, text) and the dynamic properties of students' representations (system, cycle, linear flow) as well as the general approach (habitats, populations, management, ecosystems) that students used. Because, as we have already shown, the functioning of ecosystems operates over multiple levels of scale, the levels of organisation were identified as well as the structures and behaviours at the different levels. In each ecosystem this involves different species and spatial relationships although they fall into similar trophic categories (Table 3).

The conversations of student groups both in the classroom and in the field were similarly analysed for model-building aspects in order to produce a schematic of the agreed models emerging from group deliberations (Boulter et al., 2000). Through systematic analysis of the conversations and representations, we have been able to document students' use of prior models as well as models constructed from instructional materials to interpret unexpected data in the field. Thus we are able to describe how these models influence their data collection and interpretation. The field investigation files and final interviews provide further evidence of how conflicts among the discrepant models and data were dealt with and thus informed students' revision of their mental models of specific ecological systems.

Key findings from the whole group

- In their initial representations students present models that are clearly related to the illustrations in advanced school text books in biology and geography. The representations fall into the populations, ecosystems and management approaches but do not provide an integrated model for a particular habitat in the field. The levels used in these representations are at the organism and molecular level for biology and at the pedon level for soils. Students use diagrams of chains, and webs and cycles in their initial representations.

- Critical incidences arise in the field when students' models from prior knowledge or instructional materials don't match the data well enough to generate the coherent explanations that students are seeking.

- Students negotiate differences among their models and the data during discussions in the field. These discussions are often influenced by group dynamics.

- From these negotiations to resolve the dilemma, a group model or a decision to pursue further enquires usually emerges.

- These dilemmas motivate students individually to seek out additional information in order to make sense of the divergences encountered in the field as well as during poster presentations.

- When exposed to a succession of different habitats, students struggle with the competing models. One independently-held personal model tends to win over the group consensus model previously agreed.

- When producing a poster, students try to reconcile and integrate their models. This is truly collaborative as the pairs must negotiate and build an agreed model for presentation to the class.

- Students use a wide variety of modes of representation in posters. Most represent cycling with arrows. Few show relationships in systems. There is a focus on organisms and molecules but representations of causal mechanisms are rare.

- In response to probing questions during poster presentations students tend to rely on their individual models, often abandoning the agreed model presented in the poster.

- Students also rely on their individual mental models to write up their work for the field investigation files required at the end of the course.

- In the final interviews students appear to have addressed the challenges to their models during the poster session. All sought to revise those models. Most have reflected on the nature of models. Although a wider range of levels of organisation is employed in their answers, their models of ecosystems are still very incomplete. whole levels are absent and mechanisms are seldom given for the behaviours discussed.

We perceive from the data analysis a model-building sequence that occurs during the course. It begins with students expressing initial models. They face challenges to their existing models in the field along with the need to negotiate new group models. They report models in their poster presentations and endure more challenges. Students summarise their models in field investigation files and express final models during the interview. We have no evidence that students perceived this process. We illustrate this sequence in the following narrative.

The narrative of Liz's development of models

Liz is a geography student who had not studied advanced biology and had no prior experience with field work. Neither had she received any input on models and modelling.
Her initial representation of the relationships between ecosystems and soils in a woodland prompted her to draw a number of diagrams with supporting text that showed nutrient and water cycles that included soil, food chains and webs. The biological levels that she described were organisms, where she described feeding behaviours and dying. She also mentioned behaviours at the level of cells, such as respiration and decomposition. She showed a number of biochemical cycles. For soil levels she only mentioned humus (level -1) but not what it did. At the start of the course Liz has a surprising amount of knowledge about ecosystems given her lack of advanced

biology coursework. She only expresses models for organisms and molecules but no mechanisms were described.

In the field Liz actively engaged in sampling the soil in the woodland and engaged the others in a discussion of the top layers of the soil, through discussion of the sticky properties of the humus which did not look as they expected.

Carol	Shall I pull it out?
Karen	It feels like pastry mix
Karen	I can hear it grinding
Carol	Do you know how far down it has to go?
Karen	Well, in theory we would like to get three horizons.
Liz	Last time they said 40cm; didn't they?
Karen	So, is this the organic horizon or is it something different as well? I think that's just the stuff at the top; isn't it?
Liz	Is it humus? It's that sticky stuff, isn't it? Leaf litter that's decomposed.
Karen	So that's [points] not that [points]?
Liz	I don't know. It could be. It's the fermentation layer I think.
Karen	So that's that [points] layer
Liz	I think so because it [fermentation layer] goes down and decomposes [becoming the humus layer].

Liz recognises that the horizons in the soil can be identified by properties other than those visible. She tries to persuade the rest of the group not to keep on testing in the hope of matching the textbook illustration. In the field she responds to the challenge to her model of horizons by working through the probable process of decomposition of the leaves through the leaf litter to form humus. She suggests checking with the teacher-cut soil pit, which they do but it fails to resolve the conflict.

In the poster session Liz presents a poster of the stream using a wide variety of representations that present a model that is still mainly at the organism and molecular levels and is not integrated. Soil interactions are rather sparse, perhaps because the substratum of the stream is not such an obvious interaction as the formation of leaf litter. In discussion of the poster she has to defend the assertion in the poster that calcium facilitates the breakdown of organic matter in water. When pushed she argues for a mechanism which recalls her investigation of peat formation in the meadow being caused by lack of oxygen. She relates the model built in one habitat to another and argues that Calcium carbonate contains oxygen, which is needed for the breakdown of organic matter. In the videotape we see her actively taking her incomplete and fragmented models of decay and working very hard with them to make sense of the statements she and her partner have put in the poster.

Liz's field investigation file moves from an emphasis on ecosystems and habitats to that of management. She is very concerned with the human impact on the woodland and the creation of habitats. She builds on the experience of the poster presentation and describes the fact that some leaves decompose faster than others because of their chemical composition and surroundings. She shows a good understanding of why acidity increases with depth in soil.

In the final interview Liz is enthusiastic about the value of using models:

> "Models show what's there, how it works, and link things together. They are built round the things you encounter like the River Pang and are a visual way of explaining a theory."

During the final interview she chose to talk rather than draw any diagrams as she describes how a leaf decomposes. Her understanding now includes structures and processes at the organism and organ system level for biological aspects and includes mechanisms. The soil aspects show some structures and processes at the the geosphere level as well as at the pedon and molecule levels as she tries to present her model of decomposition that includes the effect of calcium in the water and of leaching in soils. She has sought advice about the role of calcium carbonate from a chemist and now describes the process by which the calcium carbonate neutralises the acidic byproducts of decomposing leaves and speeds up decomposition.

During the course Liz developed her initial model and had it memorably challenged both by unexpected field results and by questioning during the poster session. It has led her to express a more integrated and slightly more complete model that contains more causal mechanisms.

Conclusion

This narrative illuminates the ways in which discourse about representations, data and phenomena in field-based inquiry both facilitates and hinders the elaboration and integration of different aspects of individuals' mental models as well as influencing the conduct of an inquiry and the achievement of the group's goals. From these narratives and from the general findings across individuals we can begin to develop understandings that link the cognitive and socio-cultural perspectives of model-based teaching and learning in different biological contexts and to generate hypotheses about the effects of tasks and modes of representation on the expression and construction of an individual's mental models.

For these students, who are training to be primary teachers and who will soon be taking children into natural habitats and using and producing various representations, this experience of model based teaching and learning allows them to make sense of the environment and to develop a critical awareness of how understandings are built through modelling. For the trainers the experience of designing and teaching a model based ecology and soils course is also an exercise in critical evaluation. With each year group of students it has allowed us to continually reconsider the individual and group learning of our students and how they learn through, from, and how to model the natural world.

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