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AUTHOR	Howse, Melissa A.
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ABSTRACT

The purpose of this study was to determine the procedural knowledge brought to, and created within, a pond ecology simulation by students. Environmental Decision Making (EDM) is an ecosystems modeling tool that allows users to pose their own problems and seek satisfying solutions. Of specific interest was the performance of biology majors who had taken one ecology course at the university 300 level as they manipulated the amounts of living components until they understood the objects and processes involved. Results should allow the construction of a model for novice problem solvers, a first step in understanding how teaching and learning using ecosystems problems can best proceed. Fifteen students were given a pond scenario and asked to think aloud as they posed and solved problems using EDM. Sixteen meaningful problems available in the simulation were identified. An idealized pattern of searching through the problems was used as a template for analysis. This pattern involved building one entity into the simulation at a time and running three or more iterations of a given system, changing only one entity at a time. None of the participants explored all of the problems, but all explored some of the problems. Participants varied greatly with regard to awareness of their use of heuristics which was largely connected to their lack of systematic search. (Author/PVD)

Student Ecosystems Problem Solving Using Computer Simulation

by

Melissa A. Howse

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Melissa A. Howse, Western Michigan University

Purpose

The purpose of this study was to determine the procedural knowledge brought to, and created within, a pond ecology simulation by students. Environmental Decision Making (EDM) (Odum, Odum, & Peterson,1991) is an ecosystems modeling tool, which allows the user to pose their own problems and seek satisfying solutions. The ecosystems ecologist H. T. Odum designed electrical diagrams, which have evolved into a specific form used in his program EDM, which allow a user to indicate the behavior of components of a system. A user can (or the default function on a computer can), for example, designate components as storage bins, producers of material, consumers of material and energy, etc. When a simulation is run, the system, as a whole exhibits dynamic behaviors. Ecosystems ecology simulations for the classroom include several similar to EDM, but there are also more complex ones used by practicing ecologists and theorists.

Ecology is an important field for students today for three primary reasons. First, students will need to understand environmental issues. Second, understanding ecology is important to understanding biology at large. Thirdly, ecology involves systems thinking (von Bertalanffy, 1968; Mandinach, 1986) which is useful for decision making in science as well nonscience disciplines.

The specific problem of interest is: "What are the similarities and differences in performance between students who have taken one ecology course at the university 300 level?". This allows the construction of a model for novice problem solvers, a first step in understanding how teaching and learning using ecosystems problems can best proceed. Of primary interest is the procedural knowledge used by students in posing and solving these problems. Four components of systems thinking have been summarized from relevant literature (e.g., Kim, 1994). They are: emergent properties, causality, inside/outside constraints, and self-stabilization. Therefore, the research questions to be answered are:

1. What subset of meaningful problems, as conceived by a rational analysis of EDM (Environmental Decision Making, an ecosystems simulation), do they pose?
2. What procedural knowledge associated with the four components of systems thinking (i.e. how to explore an existing system of related interacting parts, and how to build such a system) do students bring to the simulation that allows them to pose and solve ecosystems problems?
3. What insight does the performance of students give us into their conceptions of the nature of science, specifically the role and limitations of simulation models like EDM which will be used in this study?

Practical significance

This study is significant on a practical level, because it can lead to improvements in ecology/biology instruction. First, by understanding problems in ecology in a simulated realistic task, students can learn much of the ecology which is worth knowing, essentially, concepts surrounding the nature of matter and energy cycling in complex ecosystems. This study addresses this concern by giving students a pond scenario, and asking them to manipulate the amounts of living components until they understand the objects and processes involved. Second, students can also understand the limitations and uses of ecosystems models which use the logistic equation and derivations of the logistic, to simulate the growth of populations. This study addresses this concern by examining heuristics utilized by students solving ecology problems. Students can, by becoming aware of how ecology problems are posed and solved, come to understand how many ecologists see the world with respect to problems. They can also reflect on the nature of science, specifically the limited nature of models.

Ecology is an important field for students today, because they will need to understand and act upon environmental issues. Students must understand the science, in order to make informed decisions on issues; the subjects of this study, preservice teachers and future biologists, must understand how to prepare their own students to make those same decisions. The problem task for this study involves a strictly ecological scenario. By differentiating between environmentalism and the <u>science</u> of ecology, one can understand the basic ecological principles used in making environmental decisions.

Basic systems thinking, instantiated by the program I used for this study, is necessary and useful in science as well nonscience disciplines, such as economics, sociology, and political science. EDM, in combination with its math engine, Extend, is a very good vehicle for all of the abovementioned goals.

<u>Theoretical underpinnings</u>

This study extends the realms of problem solving and systems theory, because EDM (Figure 1) is an ecosystems modelling tool, which allows the user to pose his/her own problems. In biology, the problem solving research tradition enjoys a vast, rich literature. Genetics problem solving has explored declarative knowledge (such as terms and definitions) and procedural knowledge (in the form of heuristics), used by problem solvers at various abilities from novice to expert (for example, Hafner & Stewart, 1995). Problem solving in evolution is a tradition just beginning (Brewer, 1996). Arguably, genetics, ecology, and evolution are three of the most important subjects of biology. Although researchers have studied students' genetics and evolution problem solving, nothing has been done to investigate ecology problem solving, until now.

Systems theory, and ecosystems ecology share similar roots, in their concern about holistic systems, such as: ecosystems, the body, complex machines, etc. H. T. Odum's work which has led to EDM, corresponds with a philsophical/theoretical realm of "systems theory" (for example, Lazslo, 1972), in which systems exhibit typical dynamic behaviors. If students can get introduced to systems, they will better understand what ecosystems ecologists understand about systems, as practicing scientists.

<u>Design and procedures</u>

A rational analysis was conducted in which all possible problems that can be simulated with EDM were examined. The problems were selected because they are exhaustive of the conceptual knowledge available in EDM

(Table 1). From the set of possible problems, realistic ones were selected, and from the set of more realistic problems, meaningful ones were selected. Next, the biological emergent properties embedded within the problems were listed, and the other three components of systems thinking (causality, inside/outside constraints, and self-stabilization) were listed that arise from the problems. From those four components of systems thinking, the meaningful, realistic combinations were selected chosen for this study. Thus, the problems chosen have the best likelihood to elicit systems thinking heuristics.

Fifteen college biology students who have had one university level ecology course were asked to think aloud as they posed and solved problems using EDM, a simulation program that was used to present a strictly ecological pond scenario. EDM was used to simulate a pond ecosystem, consisting of sunlight, plankton "pond life", sunfish, and bass. Participants were either assigned the task of constructing the system from it's components or deconstructing the existing full system. EDM was also used to simulate <u>open</u> systems, such that students could pose their own problems within subsets of the pond problem space. That is, they were given each subsystem in order one at a time, such as sunlight and pond life; sunlight, pond life, and sunfish, etc.

<u>Findings</u>

The researcher identified 16 meaningful problems available in the simulation. An idealized pattern of search through the problems was used as a template for analysis. This pattern involved building one entity into the simulation at a time and running three or more iterations of a given system changing only one entity at a time. Three iterations were considered ideal because it is the minimum required to confirm a hypothesis. None of the participants explored all of the problems, but all explored some of the problems. None used the idealized pattern, but all explored subsets of the pattern. On average, 35% of participants posed the average problem during the construct/deconstruct tasks, while 17% of participants posed the average problem during the constrained task. Most students did not explore the simulation in a systematic manner.

The heuristics found in the transcripts included systems-specific and non-systems-specific examples. The systems-specific heuristics were associated with the four components of systems thinking. There were 12 heuristics identified which participants used (Table 2). Participants varied greatly with respect to awareness of their use of heuristics. This was largely connected to their lack of systematic search. Additional heuristics exist which were possible but which students didn't use or which couldn't be detected.

These results are in keeping with other studies of novice performance. Fragments existed of expert use of procedural knowledge and problem posing. As these students have only been exposed to one ecology course, it will be interesting in the future to compare them with students exposed to graduate-level ecology and true experts in the field of ecology.

Ecology instructors should be aware of helpful heuristics which should be used in ecosystems simulation. The possible problem space is so large and complex that students apparently need scaffolding in order to see important problems to pose in order to make declarative knowledge available.

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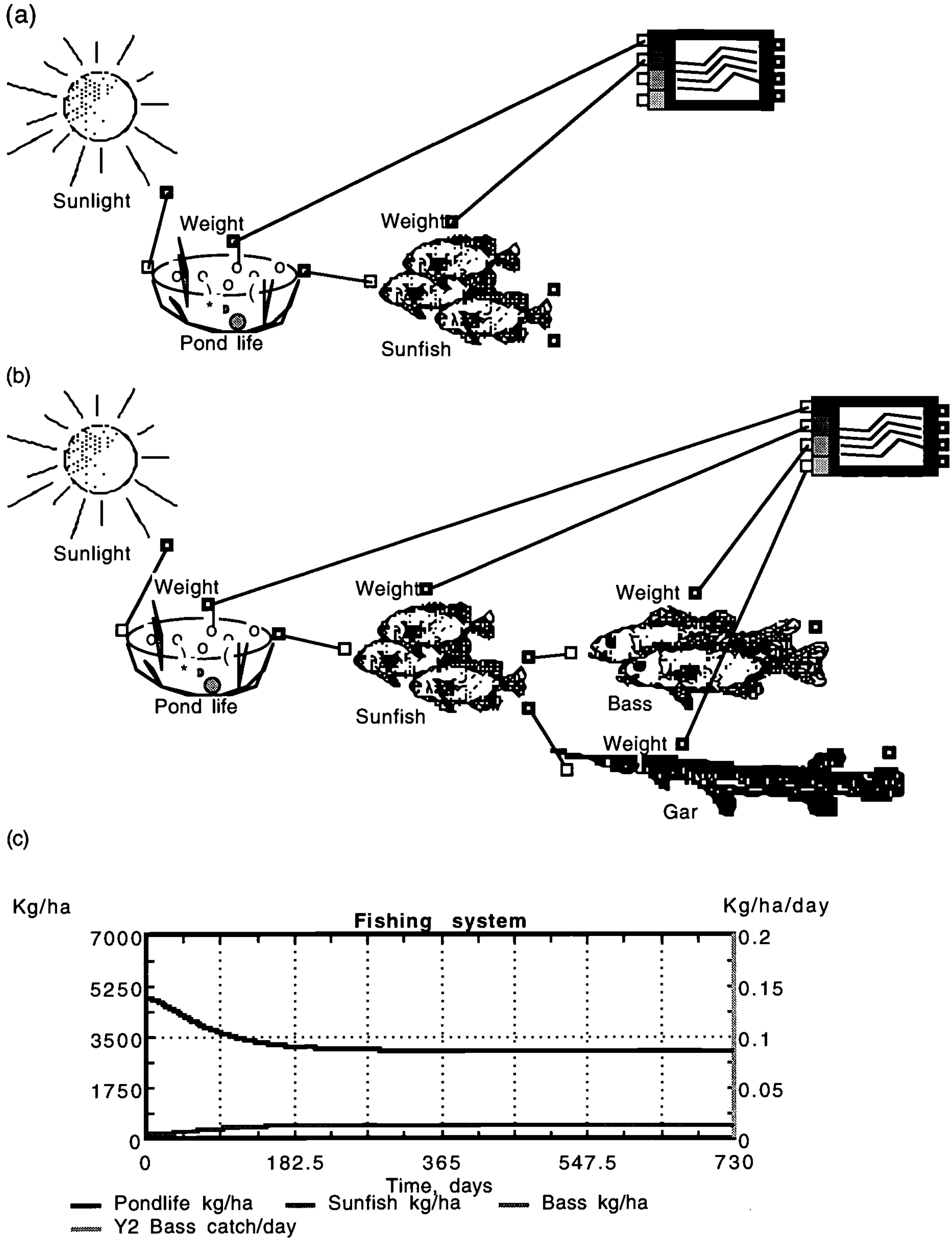

Figure 1. Sunfish (a) and Gar (b) EDM Worsheets and Sunfish (c) Graph Display, Showing Pond Dynamics. In this simulation, the starting value of sunlight has been set to 3200 kcal/m2/day 4790 Kg/ha pond life,

and 107 Kg/ha sunfish. After 42 days, a stable carrying capacity of 3000 Kg/ha of pond life and 469 Kg/ha sunfish has been reached. The cycles of pond life and sunfish are paired as predator and prey. The decrease in biomass with increase in trophic level is apparent in the relative values at this plural carrying capacity. This simulation illustrates the closed system involving only pond life, sunfish, and the outside influence of sun. The density of sunfish is indirectly caused by the sunlight level.

Table 1

Principles of Conceptual Ecology Knowledge Embedded in EDM

Pond life:

1) The time to reach carrying capacity is a function of starting biomass and energy input.

2) The biomass of a trophic level entity and the direction of change is a function of the difference in relative birth and death rates (r-reproductive rate).

3) Intraspecific competition is a density dependent phenomenon which slows the rate of population growth/decrease (by affecting birth and death) as a population reaches its carrying capacity.

4) r is an intrinsic property of an entity which is modified by density-dependent factors.

5) Intraspecific competition is a function of death rate times the entity's biomass.

Sunfish:

6) r is a function of birth rate times the population size of the entity, times the population size of any predator.

7) Respiration accounts for the loss of energy as it flows through trophic levels [Loss of energy results in an inverse relationship between biomass and trophic level.].

8) Population growth responses at higher trophic levels display a time lag due to bioaccumulation of prey by predator.

9) Predation lowers prey carrying capacity to a set level which can be independent of starting predator biomass.

10) Each trophic level entity has a carrying capacity which is ultimately due to available energy and nutrients available from 'below' and, if present, modified by predation from 'above'.

11) The degree of oscillation of the growth rate of prey is a function of starting biomass of predator; the further from carrying capacity the biomass of the predator, the greater the oscillation; this is due to the effects of instability and growth effects of temporary escape of predation.

12) Relatively low predator values result in the prey overshooting its carrying capacity.

13) Predation, a density dependent phenomenon, from one trophic level increases death at the next lower level as a function of its biomass; prey increases births of predator as a function of its biomass.

14) Rate of predation depends on the quantity of prey and quantity of predator.

15) At the intermediate population level, growth is a function of components, individually as well as collectively

Bass:

16) Growth rate changes from predation from above down through the levels are dampened due to the inverse relation between biomass and trophic level.

17) Effect of the rate of change of growth of lowest prey entity on predator is dampened in severity up trophic levels.

Gar:

18) Competitors can behave jointly as a single predator, but day to day values and results of birth and death rates are different.

19) At any given time, effects of two competing predators is directly proportional to their cumulative biomass.

20) Interspecific competition is density dependent.

21) Competition coefficients for the two competing predators are the same and so interpreting what is happening with one is just a function of the biomass of the other.

22) Interspecific competitors appear to respond to one another through the level of their shared prey.

Table 2

Participants' General and Systems-specific Heuristics

Systems-specific heuristics	specific instances
emergent:	
1) Use values that reflect trophic pyramid relationships of decreasing biomass with decreasing levels because they show the stable system.	Decrease biomasses by one decimal place each time. Use realistic proportions in sunfish system. Use realistic proportions in gar system.
2) Inverse the trophic pyramid because you will see the effect [test thresholds].	Change pond, sunfish, bass.
causality:	
3) Keep extra entities out of explanations because it isolates causality to predation from above or competition from either below or at the level of interest:	a) Start problem solving with a smaller loop or process because it reduces possible effects of competition and predation.
	b) Explain effects using processes, such as nutrient cycling, which change rates of predation and competition.
	c) Add one entity at a time because it isolates causes such as predation and growth. Add an entity in each new problem from sunfish to gar. Start with sunfish.
	d) Compare intact simulations/change only one system entity at a time because it exposes consistent causes such as predation and competition.
	e) Remove a system entity because it isolates cause to predation and competition.
	f) Compare competitive system entities by alternating their presence because it exposes whether their effects are equal. Compare competitive effects of bass and gar.

4) Use known values as fixed points in systems because they will isolate cause such as predation and competition:	Start with carrying capacity. Fix pond. Fix sunfish. Fix bass and gar.
inside/outside constraints:	
5) Use constant starting values between sub- and full systems because you can compare the effects of competition and predation with and without additional forces. [This heuristic is also associated with emergent properties, because each additional entity brings new emergent properties.]	Compare pond, sunfish, and bass systems. Compare pond, sunfish, bass, and gar sytems. Compare sunfish, bass, and gar systems. Compare sunfish and bass systems. Compare sunfish and gar systems.
stability:	
6) Use zero starting value because it tests the system for crashing ability.	Make pond zero. Make sunfish zero. Make bass zero. Make bass and gar zero.

Non-systems-specific heuristics specific instances

7) Try proportional changes in starting values between runs because curves will expose patterns such as linearity in predation and competition.	Change pond. Change pond, sunfish, bass, and gar. Change sunfish. Change sunfish and bass. Change sunfish and gar. Change bass.
8) Try extremes beyond ecosystem thresholds because they will test effects of births and deaths due to predation and competition.	Extreme values were tried when the entities were given values one order of ten or more away from meaningful values. Try extreme sun. Try extreme pond. Try non-meaningful sun values.
9) Run several (3 or more) simulations holding all entities constant except one because it will allow one to confirm hypotheses.	
10) Explore full ranges (low, med., high) of an ecosystem's meaningful energy input values because it allows one to see the effects of changing locations on death and growth.	

11) Look at very small segments of time because effects may be only visible there.	
12) Use written aids:	a) Write equations to find patterns of predation and reproduction in data.
	b) Write data for future comparisons because you can compare to similar situations.
	c) Make a chart to compare values because it exposes patterns.
	d) Use abbreviations because it will simplify explanations.
	e) Draw diagrams to represent multiple causes because they simplify things.

C=Construct, D=Deconstruct; s=sun, p=pond life, su=sunfish, b=bass, g=gar; P=Pond life system, SU=Sunfish system, B=Bass system, G=Gar system.

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