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ABSTRACT

Researchers from BBN Laboratories and Lesley College (Massachusetts) have begun exploratory studies to build an understanding of the learning that occurs when middle school students interact with science-based simulations. Sixty hours of discussion among eight middle school students were videotaped as they used the simulations from the "Physics and Biology Explorer Series" (1992, Scotts Valley, California: Wings for Learning). The videotape analysis suggests the need for a better understanding of the dynamics of mental-model development as middle school students use simulations to learn science. The need to better understand the role of prior knowledge and the students' ability to use scientific problem-solving skills in a modeling environment is also apparent. Four figures illustrate the discussion. An appendix presents a proposed Modeling Skills Assessment Inventory Checklist (MOSAIC). (Contains 12 references.) (Author/SLD)

Using Simulations for Learning Science

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Introduction/Abstract

Researchers from BBN and Lesley College have begun exploratory studies to build an understanding of the learning that occurs when middle school students interact with science-based simulations. We videotaped 60 hours of discussion among middle school students as they used simulations from the *Physics and Biology Explorer Series*. The videotape analysis suggests the need for a better understanding of:

- the dynamics of mental model development as middle school students use simulations to learn science, and
- the role of prior knowledge and interest on students' ability to use scientific problem-solving skills in a modeling environment.

Background

Using Simulations for Learning Science is a project to investigate the thinking and learning behavior of middle school students. The work is being guided by three research questions:

1. What simulation-specific skills do middle school students possess and how well developed are these skills?

2. What higher-order simulation-related analytical skills do middle school students possess and how well developed are these skills?

3. Can middle school students transfer modeling and simulation skills across subject domains?

Protocol analysis (Chi & Bassok) of videotaped interviews is the primary means of data collection. We are taking a social semiotic approach in this study. Lemke describes this as asking "how we make sense of and to one another and how we make sense of the world." (p. 186) The research begins with a prestudy involving 2 pairs of seventh grade students, one male and the other female, from a suburban town in Massachusetts.

The pilot clinical interviews did not provide information on either the students' general understanding of "models" or scientific models in particular. Consequently we modified our procedure and added an initial structured interview developed by Grosslight. This interview examines and classifies students' understandings of models. Following the Grosslight interview we conduct the baseline clinical interview using the *Explorer* "Waves" simulation. "Waves" was selected for the baseline interview because it is the most abstract of the *Explorer* series and unlikely that middle school students have previously studied the topic.

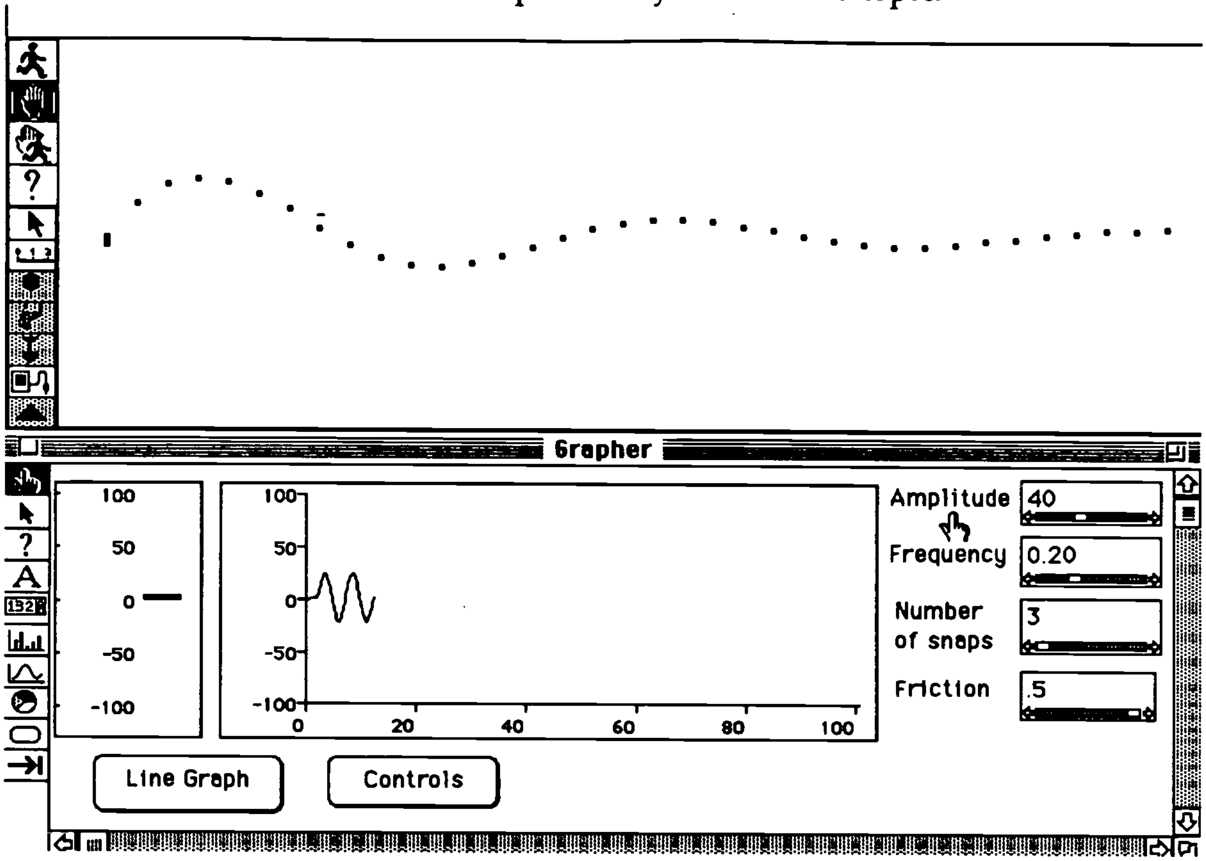


Figure 1. Screen from the *Explorer* "Waves" simulation

We worked intensively with 8 seventh grade students from an inner-city, Massachusetts school. The students were teacher selected to represent a wide spectrum of abilities. Following the Grosslight and Explorer "Waves" interviews, we engaged the students in teaching experiments using the *Explorer* "Population Ecology" model to study the concept of equilibrium in aquatic populations. The "Population" simulation represents a middle level of abstraction. The students with whom we worked had studied ecology in science with the aid of a classroom aquarium. However, the *Explorer* representation for the "Population" model is abstract.

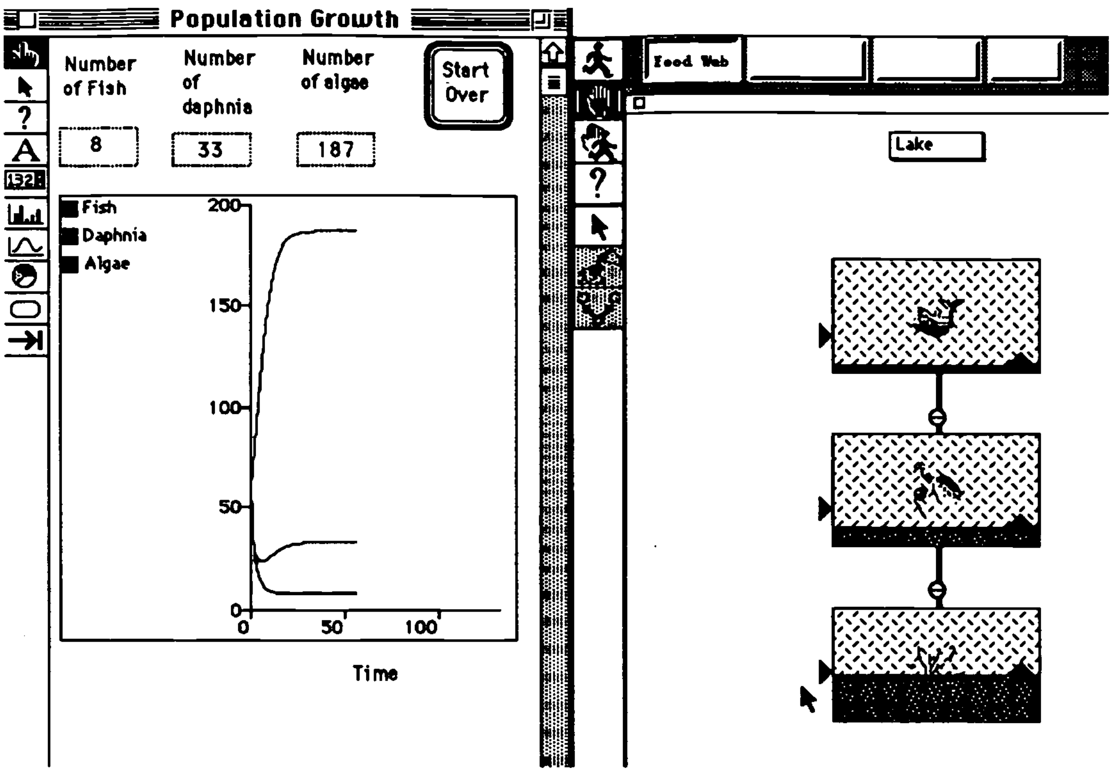


Figure 2. Screen from the *explorer* "Population Ecology" simulation

The students all attended eight hour-long sessions with 4 students present each time. The classroom teacher worked with one pair of students while one of the researchers worked with the other pair. Each pair of students was videotaped at each session.

The analysis of the "Population Ecology" teaching experiment suggested that the teacher's participation and presentation style restricted our ability to elicit model related behavior and thinking. The teacher was unable to function in other than a directive style. Consequently, we developed a second teaching experiment, focusing on the cardiovascular system using the *Explorer* "Cardiovascular" simulation. The "Cardio" simulation is the least abstract of the *Explorer* series. These students had just finished studying the heart and the simulation is an animation of a body showing the heart functioning.

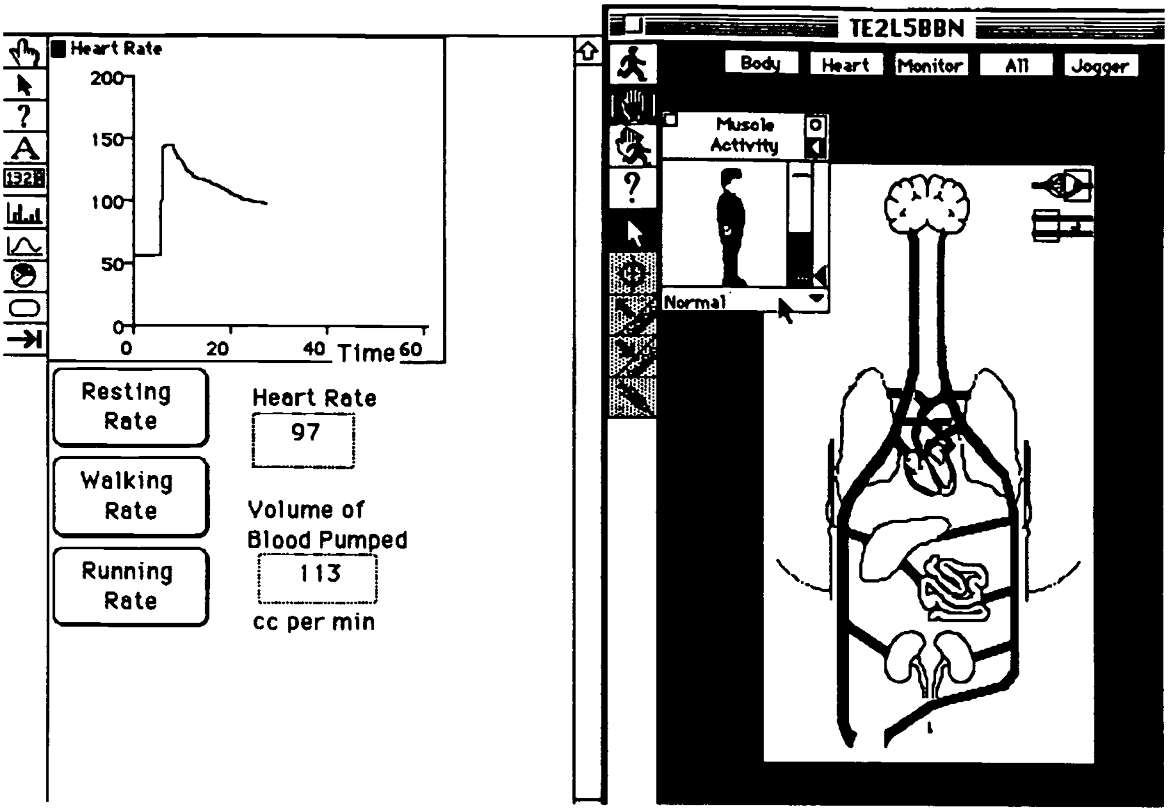


Figure 3. Screen from the *Explorer* Cardiovascular" similation

During these sessions we introduced dynamic feedback systems thinking (Roberts) and microcomputer based laboratory data collection along with the simulation. We modified our teaching style to allow maximum student expression and investigation. The same 8 Massachusetts middle school students participated in the "Cardiovascular" teaching experiment. We regrouped them into 2 groups of four in order to study in more depth 3 boys and 1 girl who each responded uniquely and differently to the simulations. These four students also represented a wide range of subject knowledge and abilities. In order to reduce the effect of the teacher and school setting, this group was brought to BBN Laboratories for their sessions.

Investigation

The project was conducted in three overlapping phases. Phase 1 is the baseline clinical interview designed to establish maximum student engagement with the computer model and minimum student-interviewer interaction. We use the *Explorer* "Waves" model and initially employ a "cold introduction" approach which consists of showing the students the salient features of the Macintosh computer and the "Waves" model. The "Waves" model was chosen because the topic is not included in the school's elementary or middle school curricula and therefore not formally studied by the students. However, it is a phenomenon they might have had experience with in a variety of other ways. We are interested in how the students go about exploring this novel computer simulation and how they bring to bear previous experience. To elicit model related thinking from the students we ask them to explain, out loud, their reaction to and reasoning about the computer program (we avoided using the word *model*) as they explore it.

By the end of the fourth interview we realized that middle school students find the "Waves" model to be unique, but not necessarily interesting. Subsequently, when interest waned, we asked leading questions about two screen buttons—"graph" and "controls". We also developed an intervention approach, when needed, that consists of presenting the students with a challenge to make the model behave in some particular way. This intervention proved helpful in differentiating students' levels of operational skill.

Phase 2 consists of a multi-session teaching experiment in which the students use a simulation model to learn science. We begin this phase with the Grosslight structured interview about models. The use of the Grosslight interview allows us to categorize our subjects' knowledge level about models and permits us to connect our work to related modeling research.

The teaching experiment was designed to coincide with a unit on population ecology then being studied in school. This permited us to explore the relationship between subject specific knowledge and model related thinking skills. Through presenting students with challenges we test the extent to which student knowledge of population ecology can be made operational in a computer simulation setting.

Phase 3 is an expanded teaching experiment of a specific science content area—the cardiovascular system—that the students had already studied in school. We introduce two new thinking tools: causal-loop (feedback) thinking and microcomputer based laboratory (MBL) data collection. This phase began by asking the students what they know about the behavior of the heart and circulatory system. Having studied the subject in school, the students show a fair degree of systemic knowledge and take very readily to expressing this understanding from a feedback perspective using causal-loop diagrams.

We next presented the students with an exercise scenario and asked them to predict how the cardiovascular system behaves and how we might test their predictions. We introduce microcomputer based laboratory tools and encourage the students to design experiments to test their predictions. Finally we introduced them to the *Explorer* "Cardiovascular" simulation and challenged them to replicate the experiment using the computer simulation. The students then compared and debated the results.

Preliminary Results

The preliminary results of this study suggest two lines of investigation. One is the need for a better understanding of the dynamics of mental model development as middle school students use computer simulations to learn science. The second is the need to better understand the role of prior knowledge and interest on students' ability to use scientific problem-solving skills in a modeling environment.

Protocol analysis (Chi & Bassok) of all the videotapes has been conducted to identify both the dynamics of mental model development and the appearance of model related, as well as general thinking and problem solving, skills. The preliminary data suggest that middle school students learn science with computer simulation models along three dynamic dimensions: 1) as a unique, possibly novel, phenomenon; 2) by comparing the model to prior experience; and 3) as a model of a real phenomenon. See figure 1.

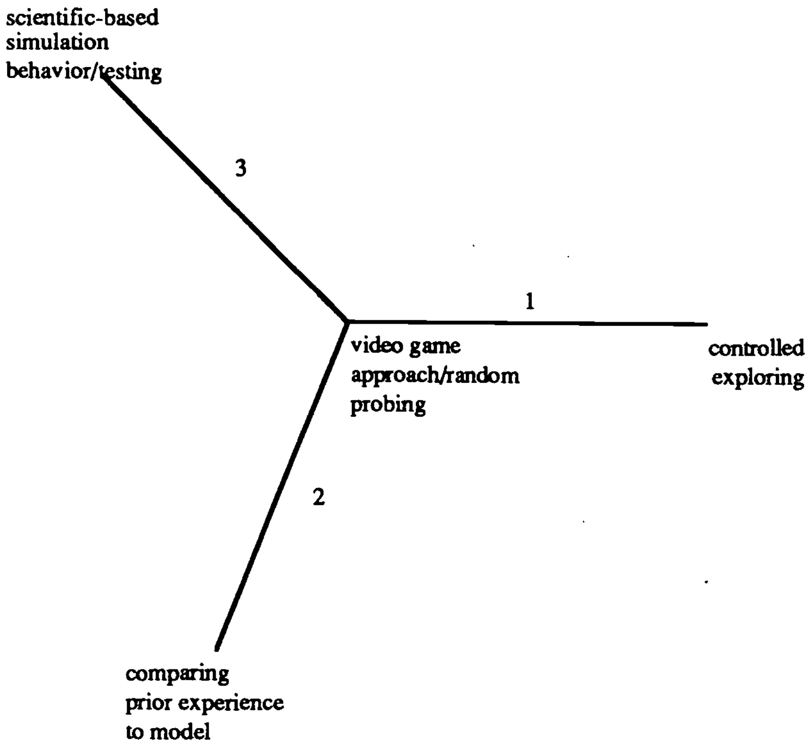


Figure 4. Dimensions of Student Learning

In addition, this work has produced a preliminary version of a proposed Modeling Skills Assessment Inventory Checklist (MOSAIC). See Appendix. This instrument is based on the type developed by Loucks & Crandall (1982).

Using Simulations for Mental Model Construction

The results of this preliminary study suggest that middle school students define models primarily as physical constructions or recognizable illustrations. This process is referred to by Sutton as "figuring," applying "something we already have in order to make sense of the relatively unfamiliar" (p. 1217) Grosslight catorgorized these students as level one in their understanding of the concept "model". Models are generally understood to be created for demonstration or educational purposes.

We found that middle school students can and do learn science with computer simulation models. The process is complex. It involves three interrelated sets of modeling skills given a dynamic, hands-on learning environment and appears strongly influenced by prior experience, interest, and the teaching-learning context.

Controlled Exploring (see #1 on figure 4)

We observe three sets of modeling skills in middle schools students during the clinical interviews and teaching experiments. First, a student's initial experience with a computer simulation model requires a set of general exploratory learning skills. These skills must be transferred from other learning experiences because, until sufficient information has been elicited from the model's behavior to categorize the experience, the student is faced with a new phenomenon. The computer simulation models we use display numerical, graphical, and representational images. Therefore the exploratory skills needed by students are those of variable control and numerical and graphical interpretation.

We observe a continuum of variable manipulation and numerical and graphical interpretation skills among our middle school students ranging from random probing, which a RAND study of students interacting with microworlds labeled "thrashing" (McArthur and Lewis), to classic variable control. At this stage students frequently refer to the model with pronouns and use variable names as reference labels (Sutton) rather than functional concepts. The following excerpts from transcripts of experimental sessions illustrate this continuum of skills.

<u>Exploring a computer model as a novel event</u>.

<u>An example of vidoe game/random testing</u>. George is the researcher.

George: "What have you changed?"

Nathanielle: "The frequency."

George: "Do you have a guess as to what you think is going to happen to the wave?"

Nathanielle: "It's gonna go higher."

George: "Why do you think it's going to go higher?"

Nathanielle: "Because more frequency. I don't know what it means but..."

<u>An example of random testing with one, but not the other, of the students able to transfer the skills of controlling variables</u>. Bill is the researcher.

Susan: "She changed all of them [variables], and if you wanted to see what the difference was then you keep only one variable because then you don't know what's causing it to be different."

Bill: "Is that something you've learned here?"

Susan and Jill: "Yeah, in science."

and a few minutes later:

Susan: "So let's not fool around with the 40 [amplitude] since we have a good guess. Let's try one we don't know about like friction." [sets friction up to mid point]

Jill: "But lets see if it [amplitude] goes to 30 this time [is changing friction value at same time]

Susan: "But you don't want to test two things at the same time because then you don't know what's causing it [sets amplitude back to 40 and runs simulation]. It's kind of wider, more subtle, smoother, not as extreme —I'm not positive though. Let me try again ... it's not going up to 40 ... that's because we changed [increased] the friction. The higher the friction, the less height it goes.

<u>Example of testing using the extreme case:</u>

Brione changed two of the variables by putting them in the middle to see what would happen.

Nathanielle and Brione change the other two variables by putting them in the middle too. Brione increases frequency and friction while decreasing number of snaps and the amplitude. A straight line results. Through trial and error the students are trying to achieve one wave on the screen with not much luck yet. The students increase all the numbers and get many waves.

Nathanielle: "How about we take off the friction, put the friction on zero and leave the rest up?"

Brione puts the number of snaps [snaps create the energy source for the waves] all the way up and puts everything else on zero. Nathanielle tries to tell him it will still just give them a straight line, but Brione disagrees because he put the number of snaps up. Nathanielle was right. They get a straight line. Now they try what Nathanielle suggested—friction at zero and everything else up. They get many waves.

Another example of using the testing of extremes as a trial and error strategy rather than as a modeling strategy.

Nancy sets up for line graph trial by setting variables to the largest value she thinks will be accepted.

Nancy has no idea why the line graph comes out as it does. She giggles and then suggests changing the frequency.

Bill shows them how to use the variable slider bar.
"Lets move them [variables] as far as they will go [up]."

Bill asks why they are setting all the variables to their upper limit.

Nancy: "I want to see what happens."

Nancy couldn't make any sense of the resulting screens.

Nancy: "Let's put them [variables] as low as they go and see what happens."

Peggy: "We put them as far down as they go and that's what [pointing to wave animation] it's doing [no amplitude]. So now we put them in the middle and we're going to see what happens."

An example of random trial and error that leads to some conclusions about computer models. The following transcript is from the same interview and shows Nancy beginning to see the model's consistency:

Bill: "Is there anything you haven't figured out about the controls [variables]?"

Nancy: "No, nothing. We've done them all."

Bill then asks about each variable and gets the following answers:
amplitude - "Makes it higher and lower"
frequency - "Makes it skinny and fat"; then relates amplitude and frequency "skinny makes it go higher; fat lower"
snaps - "gives it [wave] a push. If you just give it three [snaps] it doesn't go as far."
friction - "don't know - we really haven't done much with it."

Another example of students' beginning to notice the model's consistent behavior:

George asks what they are thinking. The program is running and a wave moves across the screen.

George: "Have you ever seen anything like that before?"

Brione: "Yes, just a minute ago."

Comparing Prior Experience to Model (see #2 in figure 4)

A second set of modeling skills are seen when students have had prior contact with the target phenomenon—hands-on experience or formal study—and recognize the computer simulation model as an example of a class of phenomena, rather than as a unique event. We observe a continuum of skills in these situations that range from simple recognition to functional replication. The student's exploratory skills are employed at this stage to compare and match the computer simulation's behavior with prior experiences. The student's language now includes analogy, as described by Clement, to prior experience and the use of prior experience to explain the model's behavior. We also observe model-controlled reasoning based on the discovery of consistent model behaviors—what we have come to call "video game" behavior.

<u>An example of students matching the behavior of the simulation to a prior experience</u> (The word "wave" is not used initially by the researcher and does not appear on the computer screen):

George explores what they know about the words:
amplitude "size of the wave" (only David has heard it before but didn't know what it meant);
frequency - David: "number of waves by the speed they travel at."
Colin: "yeah"; snaps - "number of times the wave snaps down" (flicks his wrist for number of snaps)
David: "The number of times it is going to go like this [makes undulating motion through the air with his hand].

But the students' knowledge is not necessarily immediately operational:

George gives Colin & David a challenge to test if students are really relating the simulation to waves: "Use the controls and buttons to put three waves on the screen."

Colin: "Oh, just to put three waves on screen ... that's easy."

David sets friction to maximum, amplitude to middle, frequency to middle, snaps to 3 and starts the simulation.

Both students count number of snaps: "1, 2, 3."

David: "See it goes down." [Friction is dampening leading waves.]

Colin: " That one almost disappears. We've got to lessen the friction. Count that one out. Don't put no amplitude. It's going too slow. You have to raise the amplitude."

David: "Do you know what you're doing?"

Colin: "Yes, I do. 100% amplitude; frequency - what does frequency do - oh yeah, how wide they are, 20%; number of snaps, 3. We got to less down the friction to 2."

Colin : "There - 1,2. Do they all have to be on at the same time?"

George: "Yes."

Colin: "3, aw that one disappeared."

George: "I would like to see 3 waves on the screen at the same time. What would you change to make it do that? Do you think you're close?"

Colin: "Yeah, lower the amplitude."

Colin misunderstood the role of amplitude. Frequency changes the width and thus the number of waves shown on the screen.

Example of students connecting simulation to a prior related idea. This behavior is similar to what Wong points out as "finding a particular analogy is closely associated with getting the correct answer." (p. 1271)

Nathanielle: "It looks like it's going on forever. It's not gonna stop. I think that makes it go longer—friction."

George: "Does that make any sense to you?"

Brione: "Yeah, because I know that if you use friction, friction makes things stop. So if there's less friction or no friction then it goes on for a long long time."

George: "Where have you used friction before?"

Brione: "I haven't used it but I've talked and heard of it in one of my science classes."

Examples of students connecting to other experiences with wave phenomena:

George asks what they are thinking. The program is running and a wave moves across the screen.

George: "Have you ever seen anything like that before?"

Brione: "Yes, just a minute ago."

Nathanielle: "The water."

George: "Like water?"

Brione: "Yeah, it flows like water actually it does. Even though it's not water it flows like water."

Nathanielle: "The waves and the ocean."

George: "Is that exactly like water you see?"

They both say no.

Brione: 'The water I've seen keeps on going and going.'

George: 'And what's this doing?'

Brione: "It seems to stop."

Nathanielle: "It's slowing down. Does it ever stop?"

George: "Could you find out?"

Nathanielle: "Yeah"

George: "How could you find out?"

Brione: "Cause see how it stays there?"

Nathanielle: "It never stopped."

George: "Have you ever seen a wave that stops?"

Brione: "Yeah, it stops when it hits the ground, like when it hits the shore but another one comes again."

Brione: "It looks like one of those heart beat things."

Nathanielle: "Yeah, like at the hospital when someone's in critical condition. (They all laugh) They're about to die the lines going straight."

<u>Another example of students connecting the simulation to prior experiences.</u>

Bill: "Click on the running man, that will make it go. Why don't you try doing that." [Ocean waves]

John: "Yeah, it sort of looks like it."

Bill "Does it sort of seem the same to you?"

Paul: "Yeah, it looks like waves."

John: "Like museum of science. That thing."

Bill "Where have you seen that?"

John: "In Boston, at the Museum of Science. That simulator thing."

Paul: "Like a wavemaking machine."

Bill: "Does it act just like that [wave model]?"

Paul: "I don't think they are that high. They're mostly the same [moving hand in wave like fashion] where that [wave model display] has one big one and the others are kind of smaller and it [museum of science wave machine] has like a big board that goes back and forth and the waves are all the same basically."

Bill: "Why do they do that [have a wave machine]?"

Paul: "Its like simulation to show you how things work."

Bill "How do they work? Have you ever thought about that before?"

Both boys: "No, not really."

Paul: "It's kind of like a rope where the loop keeps falling through and getting smaller and smaller kind of like that [wave model display]. You flip it like that and the loops keep getting smaller to the end like that.

Bill: "I was wondering, have you noticed any other differences or things the same?"

Paul: "Not really. There is not really a pattern—they're all different sizes except sort of like a heart monitor. It goes up and down like that except when the heart stops and it's a straight line. That thing [snaps] is like with the rope. You make it go up and down once except the wave doesn't come back."

Bill: "Now click on controls."

John: "It might be a radio wave now that I see all this [points to variables]. Frequency and Amplitude refer to radio waves and they're sort of like that [points to wave model display] too."

Bill: "Frequency and Amplitude? Where have you seen that mentioned?"

John: "AM and FM radio."

Bill: "Radio is waves then?"

Both boys: "Yeah."

Paul: "Friction is like the rope - it gets smaller and is not going as far. The rope must be tighter - suppose it was a rope. So it won' t go as far - it doesn't have enough slack.

Bill: "Is this like anything you've seen?"

Paul: "Do you mean the wave like? I've done it with my garden hose when I'm going to water the lawn and it gets too tight. So you have to loosen it up and do like that [makes flipping motion with hand] to get it over."

Bill: "So you flip it and it goes over and what happens? Does it keep going?"

Paul: You make the loop like that [points to initial large wave on the display] and it gets smaller and smaller and you hope it will be high enough to get over."

Behavior Testing (see #3 in figure 4)

A third set of modeling skills appear when students have developed a functional understanding (mental model or concept) of the target phenomenon. The computer simulation is accepted as a reasonable representation of the concept. We observe a continuum of skills at this point ranging from concept confirmation to behavior prediction. Students begin to use the computer simulation model to test ideas and to propose hypotheses. Their language changes to use the model's behavior to explain observations of the target phenomenon or to justify predictions of the target phenomenon's behavior.

The next set of transcripts, part of eight lessons on population dynamics in a simulation environment of fish, daphnia, and algae, illustrate how students' skills and concepts develop in a teaching/learning environment. The more formal study creates a context in which variable control skills improve and ability to replicate computer model behavior is acquired through experience. Pam is the classroom teacher.

<u>An example of using the behavior of the model to explore a content concept.</u> Consistent model behavior can be identified and the implication that the computer model results can be applied to the target phenomenon.

Bill notices that Nancy figures out a setting that keeps everything alive and stable. He shows them the numbers she comes out with (12 fish and 25 daphnia) and reminds them that they will have only 5 fish in their aquariums.

Katie wants to halve all the present numbers to equal 6 fish and 15 daphnia. Nancy resets the model. The girls go on to try other small numbers such as 3 fish. They discuss how to figure out the closest ratios.

Nancy resets the variables to those they decide are closest to 5 fish and run their test. They are both glued to the screen counting the rise in the population of fish.

Nancy has been changing the initial amounts and finds that they always come back to the same ending amounts.

Trying a new set of ratios:

Nancy: "Just to see how it works, right?"

The model comes out to 12 fish again.

Bill and Katie: "Why?"

Bill: "Because it's set up to be a bigger aquarium. You can try changing the habitat support as long as you keep it the same for all of them."

Bill asks for a prediction.

Katie: "If all habitats are set lower, then it should be OK with fewer fish." (Katie constantly moves about, scratching head with pencil, playing with hair, doodling on notebook.)

New settings are 4 fish and 7 daphnia.

Nancy counts as fish multiply. Again they end up with 12. Lower habitat more fish. They try again.

Nancy: "6 fish, 5 fish, 4 fish, thank you so much! Five, eight, and 46, it's not changing! [To Katie] Do you have this written down? Let me do it. You weren't listening to me.

<u>And another example</u>.

David: "We should experiment ..."

Brione shows David & Bill the bottle aquarium.

David: "We need to find out how many this can support. We can only put in about 10 fish. I've got it leveled off." Then describes ratio of fish to daphnia to algae."

Brione asks about changing habitat support.

David gives answer with 2 conditions: one why you shouldn't change; one why you should. "We'll be playing with their lives."

Brione: "What does habitat support mean in real terms?"

David: "Do they have enough to eat, room to swim, ..."

Pam: "Was having the aquarium here helpful?"

David: "The computer is the basic tool."

Brione: "It takes a while for 2 fish to have more fish."

Last 3 minutes show that work with simulation has generated a lot of questions about the real aquarium.

The following transcripts are from the last set of lessons using the "Cardio" model chosen because the students had just finished studying the heart in school.

<u>An example of students who have a well developed mental model of a phenomenon</u>—dynamic behavior can be diagrammed and causal reasoning used to predict and explain expected results of both experimental activities and computer model results. This reinforces Schwartz's findings on the power of visualization. Nancy R. is a researcher.

Nancy R: "Have you studied the heart and what it's function is in the body?"

Nathanielle: "Sort of, we just started to."

Bill: "You just started to in school with Ms. Hunter?"

Nancy: "Yeah."

Bill: "What have you learned so far?"

Nancy: "We learned about a pacemaker."

Bill: "What is a pacemaker?"

Nancy: "It um performs the beats in your heart."

Nathanielle: "That the veins lead to the heart and about the arteries."

Nancy: "The arteries, capillaries, the red blood cells and the white blood cells."

Bill: "So veins, arteries and capillaries I can never keep them separated, what's the difference?"

Nancy: "The veins lead blood to the heart. The arteries take it away from the heart."

Nathanielle: "Away from the heart."

Bill: "Away from the heart?"

Nancy: "The capillaries—they pick up from the where the arteries and bring it to the veins and the veins bring it back."

Bill: "Okay."

Nancy: "I can draw a picture better."

Nancy R: "Do you have any idea of what the heart does, the function of the organ?"

Nancy: "It like takes blood in and pumps it out."

Nancy R: "Pumps it out—and do you have any idea why the blood has to go throughout the body?"

Nancy: "So you can move."

Nancy: "We worked with stethoscopes last week."

Bill: "Did you?"

Nancy: "We took our pulses and did exercises."

Nathanielle: "We did jumping jacks."

Nancy: "And took our pulses and running in place and walking in place."

Bill: "Yeah but what happened to everybody else?"

Nancy: "Their heart beat got faster."

Bill: "Their heart beat got faster? Does that make any sense? Is that a reasonable thing to do?"

Nancy: "Yeah, because if you move faster then your heart beat gets faster."

Bill: "Okay, if you move faster then your heart beat goes faster, but yeah why should it work that way?"

Nancy: "Because movement makes your heart beat, it has to do things faster if your doing things faster."

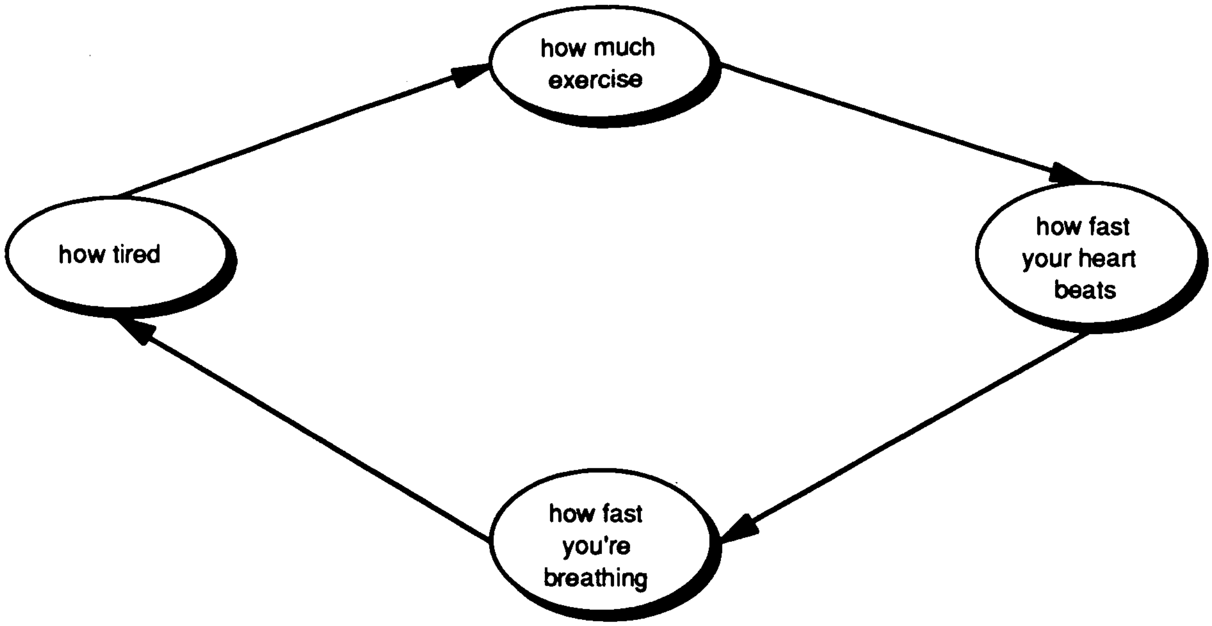
Bill: "So you guys have some very interesting data, it seems. You got pulse rates, before and after exercise. You have some different exercises and you found that the pulse rates changed. Did you discuss any of that in class?"

Nancy: "Not really, she gave us questions to do but I don't think that anybody did them." [They giggle.]

Bill: "That's great, I would like to discuss some of that now. I would like to try and make some sense of what that is, of why that data is the way it is. An I'm interested in any ideas that you have. Have you guys thought about it?"

Nancy: "Can I go to the board?"

Bill: "Go right ahead. I'd like to see. [Nancy goes to the board and draws the diagram below] Wow there's something we haven't thought of."



Nancy R: "Now tell us, talk through it."

Bill: "Wait, she's still drawing. Okay, so tell us what you got so I can figure out."

Nancy: "I don't know. I think if you exercise and then your heart beat goes faster then you breathe faster and that tires you out."

Bill: "Okay, so that affects how tired you are."

Nancy R: "And so why does that cause you to do less exercise when you start breathing quickly?"

Nancy: "Yeah it causes you to do no exercise."

An example of students comparing the computer "Cardio" simulation graphs to their predictions (generated from their own experiments of running, resting, and recording their changing pulse rates graphed).

Bill: "Do you remember what we were doing last time? We were making Brione run and we got some data."

Nancy: "Um huh, and I proved the theory."

Bill: "What was that?"

Nancy: "That no matter if you run, walk, or run and sit, your heart rate will come down at the same time and it did. It took 45 seconds for both."

Bill: "So what we're interested in doing this time is doing a simulation. We have a simulation of the cardiovascular system. Okay, and one of the things we can look at is heart rate. Alright, um, so one of the things I want to show you if you guys grab the mouse there are a couple things to show you. There are buttons over on the left. If you click on those they cause our simulated man to either be resting, running or walking. Okay and it's like he's been doing that for a long time. So if you hit walking rate I want you to notice his heart rate is somewhere around 78 beats/minute. And if you hit running rate it is somewhere around 129."

....

Bill: "How do you guys think—does it seem possible to do the experiment that we were doing before this way?" [using the simulation]

All: "Ah huh."

Bill: "What do you think we have to do now to test?"

Nancy: "Go from running to walking and then go from running to resting and see how long it takes."

....

Nancy: "I'm going to do running to walking."

David: "So far it's taken this guy 77 seconds to slow his heart rate down to a little bit over walking, I'm still waiting for it to go down to 57."

Bill: "Okay."

....

Bill: "What kind of results are you getting? Are they anything like what you thought you would get?"

....

Nancy: "It takes a lot longer to go from running to resting, mine is almost down there and it's only been 51 seconds."

Nancy R: "Is that what you had predicted Nancy last week?"

Nancy: "No last week we had 45 seconds for both so."

Nancy R: "So last week your prediction was that it would take the same amount of time?"

Nancy: "Yeah, so far that one's taken a lot longer."

Bill: "Which one's taken longer?"

Nancy: "That one—126 seconds and mine's almost down there, it's only 56 seconds."

Bill: "And you're doing running to walking and Peter you're doing running to resting and it's taking longer to go from running to resting than it is to go from running to walking. Okay."

Nancy R: "So which do you think is right, your predictions from last week or the computer simulation? Which do think is more acurate?"

Nancy: "The simulation."

Bill: "The simulation, why?"

Peter: "Because then we don't have to run again." [everyone laughs]

Nancy: "What if it's not accurate. Don't ask him a question, please."

David: "The simulation is better because you could do the heart beat of three or four different people and with our experiments you can..."

Peter: "But also it seems right because it seems that if it's going down further it should take longer."

Nancy: "It does seem right."

Notice the change in Nancy's behavior from her interaction with the waves simulation, the aquarium unit, and finally the cardiovascular unit. Initially we assumed Nancy had no modeling skills on any of the dimensions we delineated. However, during the cardiovascular sessions Nancy emerged from a background position to a leader in this investigation. We are proposing that because Nancy would like to become a doctor and therefore enjoyed and found relevant her classroom lessons on the heart, she could muster all the necessary modeling skills during these last sessions to behave as a scientist. We do not believe that during her six hours exposure to these models before we introduced "Cardio" to the group that Nancy could have learned modeling in an operational way. We believe her total change in personality is closely related to her prior knowledge and interest now coming to bear (Clement, Wong). As Norman puts it, "People's views of the world, of themselves, of their own capabilities, and of the tasks that they are asked to perform, or topics they are asked to learn, depend heavily on the conceptualizations that they bring to the task." (p. 7)

Conclusions

The three stages of model related skill use are not independent of one another. Each successive stage builds on those before, specifically the recognition and replication dimension calls upon exploration skills, and the confirmation and prediction dimension requires replication skills. As students' experience with the phenomenon and the computer simulation model grow their mental model develops through the three stages represented by the three axes of figure 1. It appears that until the computer model comes to be understood as a representation of the target phenomenon the simulation will not be used in a scientifically meaningful way by the student.

This paper represents one view of the data generated by the three student-simulation interactions—"Waves", "Population", and "Cardio". The research team is looking at the tapes from several other perspectives to gain additional insights concerning the nature of the interactions of science simulations and middle school students.

Appendix

A proposed Modeling Skills Assessment Inventory Checklist (MOSAIC)

MOSAIC is designed to identify major categories of model-related thinking skills along the three dimensions of computer simulation-facilitated mental model development shown in figure 1. These categories emerged from the videotapes. The researchers' hope is that this inventory will inform other researchers/teachers on students current modeling abilities.

1. Controlled Exploring

- Model Internal Skills - those needed to arrive at an understanding of the behavior of a model, and to determine it's consistency, and logic.
- Model External Skills - those needed to compare a model against observed data and to determine it's validity and complexity.

2. Comparing to Prior Experiences

- Model Interpretation Skills - those needed to interpret and infer meaning from numerical and graphical displays.
- *Model Recognition and Replication Skills is currently missing from MOSAIC*

3. Behavior Testing

- Model-Related Thinking Skills - those needed to understand cause and effect, feedback, change over time, and to consider alternative versions of the modeled system.
- General Modeling Issue Skills - those needed to understand the value and limitation of a model, to derive meaning from animated screen images, to differentiate the model from experience, and to develop an understanding of the relationship between a model and the target phenomena.

MOSAIC - Modeling Skill Assessment Inventory Checklist

Controlled Explorating

1. "Model-internal skills" - Exploring a model
   Skills to arrive at an understanding of the behavior of a model.
   Posing questions and exploring a model by:
   a) isolating variables
      <u>Single</u>
      1. none
      2. one (then another/no reset)
      3. one (then another/reset)
      4. one (various settings)
      <u>Sets</u>

5. not all or set
6. all or set (random)
7. all or set (pattern)
8. all or set (with reason)

b) testing limits

1. none
2. possible setting among many
3. trial & error "just to see"
4. methodical checking

c) examining interrelationships between parameters.

1. none
2. notice, not used
3. notice pattern
4. methodical checking

d) controlling parameters,

1. none
2. accidental
3. repeat pattern (video game)
4. set with reason

Testing a model to see if its behavior is consistent and logical under a wide variety of conditions by:

a) collecting evidence

1. none
2. recollection of settings & screen action
3. explore with different parameters
4. explore with one parameter

b) looking for patterns in the model behavior

1. none
2. describe screen appearance
3. correlate screen action with parameter setting
4. express conceptual reason for screen action

c) correlating model displays

1. none
2. accidental
3. screen correlation (video game)
4. express conceptual reason for correlation

2. "Model-external skills" - Skill in determining model validity by comparing model with target phenomenon

Comparing the model against observed data

a) assessing the applicability of the model to the data

1. no connection
2. connection (rejected)
3. connection by analogy

b) analyzing analogy for reliability, reasonableness, and fit.

1. confirming, analogy semi-quantitative

a. not explored
b. explored
c. predictions
2. confirming, analogy quantitative
a. not explored
b. explored
c. predictions
3. disconfirming, analogy semi-quantitative
a. not explored
b. explored
c. predictions
4. disconfirming, analogy quantitative
a. not explored
b. explored
c. predictions

Skills in determining the complexity of the model.
a) Propose the phenomena be modeled in a simpler fashion?
b) Propose critical elements of the system are missing and need to be included in the model?

Comparing to Prior Experiences

3. Model Interpretation Skills
   a) Reading and interpreting graphs, and using graphs as tools for expressing and identifying behavior.
      1. recognize
      2. decode - mechanical
      3. decode - meaningful
      4. reason with meaning
   b) Drawing inferences from data.
      1. none
      2. recall past model behavior
      3. about model with model
      4. about model with experience
      5. predictions
   c) Using basic arithmetic reasoning to infer relationships.
      1. none
      2. accidental
      3. decode - mechanical
      4. decode - meaningful
      5. reason with meaning
   d) Using and interpreting statistical information.
   e) See patterns in the underlying structure of a problem.

4. *Model Recognition and Replication Skills missing from our MOSAIC*

Testing Behavior

5. Model-Related Thinking
   a) Identifying a complex system - Quantitative
      Identifying a complex system - Semi-Quantitative (Qualitative)
   b) Identifying in a complex system:
      1. cause-and-effect - Quantitative
         cause-and-effect - Semi-Quantitative (Qualitative)
      2. feedback - Quantitative
         feedback - Semi-Quantitative (Qualitative)
      3. change over time - Quantitative
         change over time - Semi-Quantitative (Qualitative
   c) Grappling with alternative explanations for the same phenomenon
      1. making a reasoned decision about which to support or where further exploration is needed
      2. conducting further exploration

6. General Modeling Issues
   a) Shows an understanding of both the value and limitations of a model.
   b) Considers the meaning derived from animated screen images.
   c) Differentiate between the model and experience.
   d) Considers the relationship between a model and target phenomenon and processes and expresses a sense of how the model explains the phenomenon.

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