MODELING TOOLS FOR PROBLEM-SOLVING

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ABSTRACT

During the last year, the Technical Education Research Centers (TERC) has been combining microcomputer-based data gathering instruments with model-building software using the system dynamics approach to develop curriculum materials and software for high school students. The microcomputer laboratory aids students in collecting real-time data in such areas as heat, light, sound, motion, and water movement. Model-building helps students develop and test theories to study the data. An integrated software environment is being developed that will allow the data collected to be input directly into the models. In addition, the software will include an icon driven modeling language, algebraic function grapher, and spreadsheet to provide students with several different approaches to expressing model-building and simulation.

The first trial of curriculum materials was conducted during the summer of 1986. During the 1986-87 academic year the curriculum materials and software will be refined. The 1987-88 academic year will provide an opportunity for more extensive pilot testing in regular classroom settings. The goal of the project is to research high school students' ability to use computer-based tools for natural and social science investigation without the prerequisite of calculus. In addition the project will:

- look at students' ability to transfer concepts of basic structure between problem areas;
- attempt to identify elements that lead to successful learning environments, and;

- study differences in acheivement between males and females.

PROJECT OVERVIEW

This project builds on work underway at TERC for the past three years. The Microcomputer Based Laboratory project (MBL) demonstrated that middle school students can intuitively interpret the graphs of data they collect in real-time with the aid of a computer. Sophisticated concepts such as heat and temperature, and velocity and acceleration, were understood by these middle school children. Looking for ways to extend students' problem-solving skills by taking advantage of their ability to understand graphs led to our current project.

Hardware, software, and curriculum are being developed for integration into high school science, social science, and applied mathematics courses. The curriculum packages deal with subject matter normally found in these high school courses. The hardware allows for real-time data gathering using a Macintosh computer while the software provides an integrated tool for problem solving. The software has four parts, all outputing data in tabular and graphical form:

1. data from microcomputer probes;
2. an icon based model-building language similar to STELLA;
3. a simplified spreadsheet;
4. an interactive algebraic function grapher.

The thrust of this project is to give students strategies and tools for solving complex problems. The curricular materials present students with realistic natural or social science problems. The computer based tools aid students in developing hypotheses, collecting data, and testing their hypotheses using simulation models validated, when possible, with data collected by the student. Structuring a data collecting experiment focuses on the problem-solving strategy of dividing a problem into small, manageable parts. Theory building with the aid of modeling and simulation requires a holistic and integrated approach to problem-solving. Students are given experience with both strategies so as to develop a facility with both and a sense of when each is appropriate.

The curriculum is being designed to allow students to apply their intuitive mathematical knowledge without the prerequisite of formal study. The algebraic function grapher is included to further develop mathematical understandings through interactive software.

Transfer of learning between disciplines is another focus of the project. Taking the system dynamics approach to model building, the students are introduced to a uniform way of expressing the underlying structure of problems amenable to analysis by identifying the causal links and feedback loops that account for the observed behavior. (Forrester) Such problems are found in all the natural and social sciences.

All the materials being developed emphasize the multiple representations of abstract ideas. Theories about behavior, such as exponential growth, can be expressed using the standard rate level diagram icons, as equations, in a spreadsheet format, as an algebraic function, or using probes (see Summer Experience below). Each one of these pieces of the software output the results of the model as a graph or table. The icons, equations, or probe experiments can be manipulated by the students to ask *what if* questions that give immediate results through graphical output.

RESEARCH QUESTIONS

The curriculum and software being developed for this project allows the researching of several important questions on the impact of computers on teaching and learning. Most critical, from the perspective of the project staff, is the potential for providing students with an intuitive sense of calculus and an ability to use the analytic power of this branch of mathematics without necessitating its formal study. Work by Roberts and others over the past 10 years has provided evidence to suggest this is possible.

A second area is documenting the results of giving students the ability to build and and use simulation models for social and natural science investigation. Providing high school students with these powerful tools creates a truely interactive problem-solving environment.

For some time now educators have been recommending interactive environments as the most natural way to provide students with meaningful problem-solving skills. In addition, model-building requires synthesis thinking creating a natural way to engage students in higher-level thinking.

Another area of general interest, especially to science, mathematics, and computer oriented researchers, is differences in learning styles, achievement rates, and abilities of male and female students. This project hopes to contribute more data on this topic. Our main hypothese, that both sexes can learn equally well given an appropriate curriculum, is based on developing multiple representations of ideas, especially mathematical ideas such as *function* and *change over time.* The curriculum presents each concept in graphic, iconic, number, and word representation. In addition, the tools being developed have a high degree of interactiveness both physical and mental, to provide for a diversity of learning styles.

One area of research, only recently possible due to advances in microcomputers, is studying the impact of interactive iconic environments for teaching difficult concepts. Our hypothese is that these dynamic, interactive pictures of abstract concepts will reach a group of students traditionally lost at this level. The MBL project has produced some evidence that middle school students, involved in producing on-line graphs, are able to understand distinctions between heat and temperature, velocity and acceleration in relatively short periods of times. We are extending this pedagogy to other environments that present ideas as pictures.

Finally, the true pedagogic rewards, recognized by researchers such as Bruner for quite some time, is the ability of students to identify the underlying structure of a problem and transfer this understanding to other problem areas. To facilitate this happening the curriculum being developed encompasses several disciplines. For example, units looking at the cooling curve in physics, exponential growth of terrorism in social studies, and the exponential decline of endangered species in ecology are included. Modeling the same phenomenon in several different disciplines will hopefully strengthen the perceived value to problem-solving skills of identifying the underlying structures that cause the observed behaviors.

PREPILOT SUMMER OF 1986 EXPERIENCE

During the summer of 1986, we ran a summer school program as a chance to try out many of the modeling curriculum ideas we are considering. Sixteen incoming tenth and eleventh graders came from 9 am to 12 noon each day for four weeks. This trial program was an opportunity to both test the feasibility of our ideas and develop new material. None of the students had more than one year of algebra. Those that had a second year of high school mathematics had taken geometry. The students algebra knowledge, as measured by a standardized algebra test given on the first day of class, was quite spread.

During the first week students became familiar with the Macintosh computer, with using probes to collect data and to generate real-time graphs, and with graphs and functions and the ways in which graphs can be transformed. The functions and graphs activities use a fast graphing utility developed for the Macintosh. This allows the user to change, using the scroll bar, any of the coefficients and constants of an algebraic function and get an immediate replot of the graph. In addition to providing a manipulative way to learn how to transform graphs on the coordinate grid, this adjusting capability becomes a powerful modeling tool when trying to fit a graph to a data plot.

During the second week the focus was on growth functions as exemplified by bank balances and populations. Students modeled these phenomena using a physical model involving the movement of water into and out of beakers, which we call Leaky Buckets. Since we interface these buckets to the Macintosh, it is possible to generate real-time graphs of the water level as a function of time. Linear growth is modelled by adding a fixed amount of water to the beaker at each time increment; exponential growth by adding an amount proportional to the level of water in the bucket. These same situations are then modelled using a spreadsheet and iterative functions to generate the growth data.

During the third and fourth weeks causal-loop and system flow diagrams were introduced as a way to think about systems involving feedback. This lead to the icon modeling software for building dynamic models. Two probe activities were also included, this time with the opportunity to make a model of the system and then test it against real data collected with a probe. The activities included a cooling curve experiment and an electrical capacitor discharge experiment. Several problems from the social sciences, such as arms races (Kreutzer), urban growth and terrorism, as well as more population problems were also included.

Another component of the course was the discussion of commonly occuring system principles. Simple causal loop diagram models were use to illustrate the floating goals, shifting the burden to the intervener, and addiction structures, as well as the ideas of policy resistance, short-term long-term tradeoffs, and unintended side effects.

Throughout the four weeks there were two goals: the first more skill oriented, involving learning to use the Macintosh and the probes and the software tools; the second more concept and process oriented, learning to use systems thinking and modeling as a way to understand complex systems and to make predictions about behavior over time. The first goal was easy to accomplish. The students had little trouble mastering the use of the hardware and software. The second goal was harder to attain and harder to evaluate. What was exciting was student success in working with the problems and challenges that were presented; what was disappointing was the minimal carry-over of systems thinking and problem solving from one activity to the next. This latter is perhaps not surprising, given the short time of four weeks and the trial nature of the activites. On the positive side, all the students had significant learning, as demonstrated in the analysis of the pre-post test scores, and all students, regardless of their mathematical backgrounds, learned propotionate amounts. Some comments made by the students at the end of the summer were:

"I'd recommend this to anyone. I don't think it matters whether you like math or not; it's just something that helps you and gives you information."

"We did things in different fields like accounting, we did savings accounts; we used things like leaky buckets, we did trigonometry. We just went into a lot of different fields, and it was really fun and I had a great time."

And by the teacher:

"We as a society need to learn how to make better long-range solutions. If we are going to develop the future leaders of this country, we have to give them the tools for doing this. Mathematical modeling is one tool that really looks like it is going to work, and I think students should have it in their hands."

"Kids love it because now they are learning about problems by playing with them. They are not learning about equations and ways of manipulating equations; they are learning about real-life situations and how things change in the real world. They also have a great deal of control over their learning because they can make their own assumptions and see what happens. A very exciting classroom situation is created when you start using these materials."

While these subjective evaluations are encouraging, much work still needs to be done to identify the component skills involved in systems thinking and to develop more useful tests to detect when it is being successfully cultivated.

GOALS AND TIMELINE FOR 1987-1988

Informal pilot testing is scheduled for several sites in the spring of 1987. At this time only partial units and some software will be available so the testing will be as enrichment for current units. We are planning to try small pieces of material in a social studies, chemistry, physics, biology, and mathematics class. For the 1987-88 academic year we plan to develop totally integrated units that will reflect our spring pilot findings and change the traditional curriculum to integrate the new teaching strategies and computer-based tools. We also hope to develop and pilot a one or two term course in system thinking and model building. A more formal data collection will occur.

SUMMARY

The products at the completion of this project will include:
1. An integrated tool software package that outputs data in graphic and tabular form from probes, algebraic functions, a simplified spreadsheet, and a modeling program;

2. Five units on general aspects of the curriculum, system thinking, and problem-solving including an introduction to:

- modeling;
- causal-loop diagramming;

- document and introductory lessons on each of the components of the integrated software package;
- system thinking including the Leaky Buckets physical apparatus to introduce the concepts of levels, rates, and feedback; and
- the use of probes and reading graphs through the MBL unit on motion.

3. Written materials consisting of student activities and teacher guides for three to five content specific units in the areas of physics, biology, chemistry, mathematics, and social studies. In addition, a one or two term course on system thinking and model building will be developed.

4. Evaluations and research results based on the pilot testing of the curriculum materials.

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