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ABSTRACT

The Soloworks project is based on the belief that student-controlled computing is a promising innovation in secondary mathematics instruction. The Soloworks project is following up three years of experience in the Pittsburgh public school system with a new program encorporating both student-controlled computing and modern math curricula. The work is organized around five labs: a computer lab, focusing on those aspects of mathematics that are well described by algorithms; a dynamics lab, focusing on mathematics that describe processes that take place in time, a logical design lab that uses both digital and analog circuit modules; a synthesis lab which is concerned with mathematics that make use of superimposition and synthetic music, and a modeling/simulation lab that uses mathematics as a tool for creating, studying, and manipulating new models of reality. (JY)

Soloworks: Computer-Based Laboratories for High School Mathematics

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Background

School mathematics currently finds itself in a peculiar position. To begin with, it is the object of much criticism, most of which centers on the new math, and its "needless obfuscations." If the criticism has validity (and I believe much of it does), then new ideas are called for. Yet the nature of the current criticism makes it difficult to propose substantive change; there is a tendency to resist new ideas because of a general atmosphere of distrust.

Despite these problems, there have also been recent developments of a very positive nature. For the past five years or so, a small (but by no means limited) number of schools have been generating a quite favorable image of mathematics, both in the eyes of the students "doing" the math, and in the eyes of those who have had the chance to observe what's going on. Their secret seems to be connected with activities that directly involve both students and teachers in applying mathematics to student-controlled explorations. The phenomenon has most frequently arisen in conjunction with what is called "student-controlled" or "solo-mode" computing, that is, a use of a computer which requires student programming of the machine.[1]

Factors Favoring Student-Controlled Computing

Because solo-mode implies local control, the practitioners of student-controlled computing seem to be very open to innovation; they are not as wary of new ideas as the general educational community. I suspect this is because they know that they have the power to try a new idea, not just be told about it. They've learned that writing, debugging, and running programs is an excellent tool for weeding out the irrelevant and trivial. It's also almost always true that a student can improve upon someone else's idea, given the chance to work with that idea on a computer.

These are all powerful educational factors, and it makes sense to ask how they can best be taken advantage of in future mathematics

1. Such use is at the opposite end of the spectrum from "author-controlled" or "dual-mode" computing where programs written by others are used to manage student drills, tests, and tutorials. Dual-mode computing can complement solo-mode in the same way that dual (with an instructor) flight training prepares a student to go). Both experiences are important to good learning.

education. One approach to answering this question is to test the feasibility of deliberately reorganizing a segment of school mathematics around computer-based labs. Ideally, these should be mathematics laboratories that preserve the best features of both student-controlled computing and modern math curricula. The labs should also try to integrate other disciplines with mathematics, an important goal that has received little more than lip service in the past.

Such an experiment is currently taking place at Project Solo. The experiment is a follow-up to three years of experience with student-controlled computing in the Pittsburgh public school system. The new work, which will be described in the remainder of this article, is called Soloworks.[2]

Soloworks

The name Soloworks is meant to conjure up images of both a place and a philosophy. The place is a lab at the University of Pittsburgh where a small group consisting of project staff, high school teachers, and high school students are working together to develop and test these ideas. This lab is meant to be the prototype of larger math-lab centers to be placed in either conventional high schools, or in central learning centers that serve several high schools. "Soloworks" is also a statement of philosophy, affirming our belief that *any* student can be brought into the world of solo-mode learning by an intelligent use of technology.

In general we take the view that solo-mode learning through contact with rich environments and structured activities is the real key to developing a "life of the mind" for children of diverse backgrounds, and that the importance of modern mathematics in education crystallizes once this is understood.

The Soloworks Labs

The kind of math to be studied in the Soloworks curriculum is going to be (mainly) determined by what we call a "top-down" approach. This means that we will start by defining both research-level projects and major skills. These in turn will determine the mathematics to be studied.

Our work is organized around five labs, the names of which are intended to act as a simple but powerful means of organizing content. The five labs are called Computer Lab, Dynamics Lab, Logical Design Lab, Synthesis Lab, and Modeling/Simulation Lab. Each lab focuses on the achievement of major skills, and on the pursuit of research projects.

2. Supported in part by NSF grant EC-38063 as "A Computer-Based Laboratory for High School Mathematics."

Our current work is on an ad hoc basis with small groups of students who are helping us keep our feet on the ground in terms of the reality of adolescents; their interests, feelings, capabilities, imaginations, and aspirations. The presence of high school teachers on our staff is also giving us a strong sense of reality, especially in terms of what the needs in teacher training will be.

The Computer Lab

The Computer Lab will focus on those aspects of mathematics that are well described by algorithms, and encourage student access of a local computer and terminals. A major skill students will achieve in this lab is that of computer programmer. Examples of some projects that have already been done by students in this lab are developing programs to do accounting and inventory for a small store, programs to play all kinds of games, programs to simulate transportation system, generation of random ballet dances, a program to interpret "macro" commands for a multi-media show, programs to plot mathematical curves and predict and plot their intersections, etc.

The significance of the project approach is that although students have made available to them past "heritage" appropriate to attacking the project, they are also expected to develop new and unique extensions of that heritage. Most students find this difficult at first. It is necessary to work with them on a one-to-one basis to get past this challenge. Once the first breakthrough is made, things run much more smoothly.

The Dynamics Lab

The Dynamics Lab focuses on mathematics that describes processes that take place in time. One form of technology to be used in this lab is a flight simulator, shown in figure 1. The skill acquired in using this particular equipment is that of making a full instrument landing, or becoming good at instructing a fellow student to do the same. An example of a project would be to sample analogue readings of heading, time, and speed from the flight simulator, translate these into digital data, and then write a program that plots the path of the flight simulator. Another type of artifact being considered for the Dynamics Lab is the "Rube Goldberg" machine, a gadget designed by the student to do nothing useful, but to be a mind-stretching exercise in imagination. Some other work will center on the use of mechanical ball-disc integrators. We think learning to work with the concept of "rate" can become a very natural thing for relatively young students; rate-of-change and integration are certainly classical examples of powerful mathematical ideas.

FIG. 1. Flight Simulator for the Dynamics Lab

Logical Design Lab

The Logical Design Lab is a new idea which came about as a consequence of our need to have students understand the control circuits in the other labs. The technology used will be digital and analogue circuit modules. We're tempted to call the skill involved "electronic wizardry." Projects will include light trees, color organs, crytography machines, burglar alarms, foolproof control systems for the other projects (e.g. a model elevator), computer-to-lab-device interfaces, etc.

Another area we will include in this lab is suggested by an intense interest in stereo and quadraphonic sound we have noted in young people today. Phrases like "matrix decoder" are known to them, and of great interest. But they don't have the slightest idea how these things work. We intend doing something about that, and math will be front stage and center in the explanations.

We would like to eventually come up with some ideas for a kit of logic modules, amplifiers, etc., that takes advantage of recent strides in IC (Integrated Circuit) technology. Such technology is becoming very low cost. We also think that the "visible" logic of relays and mechanical linkages should be included.

Synthesis Lab

The Synthesis Lab is concerned with mathematics that makes use of the principle of superimposition, producing complex effects by adding together simple ones. Two special pieces of technology we will use are the "Music Monster" (a kind of programmable band-organ), and a multi-media programmer together with suitable projection equipment. The obvious skills associated with these devices are

composer and media-designer. Projects will focus on the design, debugging, and performing of original works.

Our initial forays into the music field have been in terms of real organ pipes to be run under program control (shown in figure 2). Next we'll look at a modularly designed synthesizer. This later technology is replete with applications of the concepts of function, algebraic products and sums, periodicity, summation of series, local linearity, transforms, etc.

FIG. 2. Part of the "Music Monster" for the Synthesis Lab

Modeling/Simulation Lab

The Modeling/Simulation Lab uses mathematics as a tool for creating new models of reality that can be studied and manipulated. Some of the models will be physical (e.g. bridges, elevators, lunar landing modules, etc.), some abstract (e.g. an ecology, an economy, etc.). The skill developed here is really that of applied mathematician, while the range of possible projects is open-ended. This is because the computer available to students is general purpose, allowing them to simulate systems not heretofore dealt with. Good software is essential too, which is why we prefer an advanced version of BASIC (e.g. NEWBASIC or BASIC PLUS). The Rube Goldberg machines (figure 3) also fall into this lab (although we're not sure what they simulate!). Perhaps it's semi-accurate to say that they model a fertile imagination.

Summary

This has been a preliminary report on a computer-based laboratory approach to mathematics education. It is of course too early to say

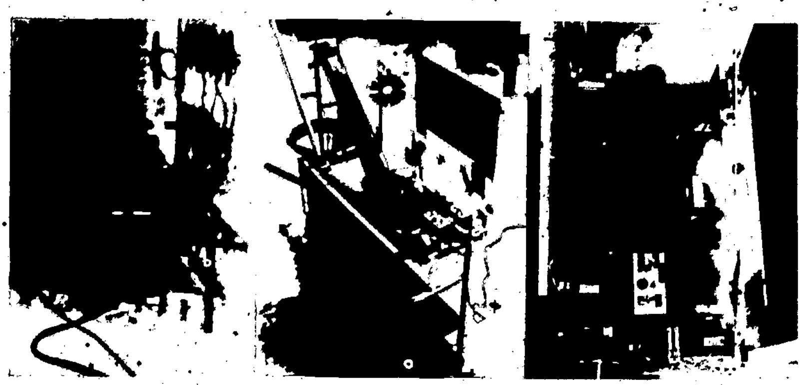

FIG. 3. "Rube Goldberg" Machines Designed and Built in Modeling Lab

precisely what kind of mathematics curriculum might evolve from our work. However it is clear that content-wise, the curriculum will be a very rich one. The more we work with the labs, the clearer it becomes that the inclusion of mathematical content is not a serious problem, despite any indication to the contrary our hardware orientation might suggest.

Another positive factor is that the rather intriguing nature of the lab devices generates enthusiasm for the concept in most visitors. We have not had any of the unfavorable reaction to post-new-math innovation that was mentioned at the beginning of this article.

On the negative side, the Soloworks labs clearly call for a generous equipment budget, at least compared to traditional math department allocations for hardware. Capital expense and annual upkeep would be much closer to the level found in, say, well-supported athletic programs. This comparison is not meant to be critical, but rather to suggest that community priorities set budgets more than resources. We think that quality in any area is persuasive, and that this will in turn establish priorities. Of course this is only true if the community that supports the school is sympathetic to what is being done. Our initial experience is that the Soloworks labs have exceptional promise in this area. In fact the most common remark made by visitors is something like "I wish math had been like that when I went to school."

A final factor in the economics of math labs that must be taken into account is the fact that it is a tradition of the "do-it-yourselfer" to find an ingenious poor-man's version of a good idea. Solo-mode people are (by definition!) do-it-yourselfers, and our student testers are already finding economic versions of our more sophisticated ideas. We are convinced that these cheaper versions would not have been

thought about if our no-holds-barred, advanced versions had not first been available.

There are, of course, many other questions to be answered: student responsibility in handling complicated equipment, teacher training, curriculum materials, self-study aids, and the development of an adequate psychological theory to guide future application of laboratory curricula.

We intend exploring all of these issues at appropriate times. One helpful factor is that the Technological Innovation in Education group at NSF is supporting similar work at other grade levels. We are quite hopeful that the mutual discoveries of such projects will lay the foundations for school mathematics programs distinguished by the joy of spirit and richness of intellect they bring to the children they serve.