Will software ever replace human tutors? Probably not, but it can enhance student learning and guide self-paced study.

It isn't getting the amount of hype Windows 95 did, but a tutorial software program under development at WCER is nonetheless helping students think and work more productively. Tutorials in Problem Solving (TiPS) helps math students develop their problem-solving skills as they set up and work through mathematics word problems. Like a human tutor, it monitors their problem-solving strategies, offers advice, and tracks their progress.

UW–Madison Education Professor Sharon Derry and her team are studying the interaction between students and human tutors in order to build software that behaves like effective human tutors behave.

No matter what line of work we're in, we continually solve problems, little and big. Many adults have difficulty solving complex arithmetic word problems. But when such problems are solved incorrectly in real life, waste and damage can result: If complex medical dosages are calculated incorrectly, for example, a patient can die. Knowing how
WCER welcomes national centers

Our WCER family continues to grow with the addition of four Centers.

The new Comprehensive Regional Assistance Center Consortium—Region VI offers staff development and technical assistance to teachers in six Midwest states, where schools are striving to meet the needs of 1.5 million students targeted for special assistance under the Elementary and Secondary Education Act. Director Minerva Coyne leads the way, building on her success with the Multifunctional Resource Center.

We also welcome three Centers funded by the Office of Educational Research and Improvement. Tom Romberg will direct the new National Research and Development Center on Achievement in School Mathematics and Science. The Center will create a set of principles for the design of classrooms that promote understanding in mathematics and science, grades kindergarten through high school. Tom’s team will design instructional innovations in teaching, curriculum, instructional technology, and assessments.

The National Research and Development Center on Increasing the Effectiveness of State and Local Education Reform Efforts will operate under the auspices of the Consortium for Policy Research in Education. The Center, with a home base at the University of Pennsylvania, consists of 10 research projects focusing on school reform, policy and governance, and school finance. The school finance program area, located in WCER, is directed by Allan Odden.

Marty Nystrand will direct the WCER branch of the new National Research Center on Improving Student Learning and Achievement in English. This Center will specify the features of curriculum and instruction that are essential to students’ success in English, including skills with oral and written language, literature, and other forms of communication. The Center’s main office is at the State University of New York at Albany.

From the outset, WCER proposals for these Centers were designed to complement each other and the work of the National Institute for Science Education (NISE), which opened its doors at WCER in July 1995. Together, the new Centers will continue and build on the results WCER has produced over the past three decades. For more information about WCER, visit our Web site at http://www.wcer.wisc.edu.

Andy Porter

From the Director

How human tutors think

To make the software mimic important features of human tutoring, Derry and colleagues Don Wortham and Michael Potts are studying expert tutors and how they think about their students and the art of effective tutoring. If designers of tutoring software want to model the work of effective tutors, they need to know how tutors describe and think about their students, and how they select or change their tutoring methods accordingly, software programmer Naiyi Jiang points out.

Derry and Potts studied how five experienced tutors (four math tutors and one writing tutor) characterized and tutored their students, then developed a set of basic concepts the tutors used. The tutors all described and categorized their students in terms of two essential traits: learning ability and motivation. But there were differences in the ways these tutors specifically defined these traits, differences apparently influenced by tutors’ personal world views as well as the types of settings in which they tutored. For example, one tutor defined motivation as academic assertiveness, another defined it as cooperative attitude, and a third said it involved sociability and friendliness. Learning ability for some tutors included consideration of students’ competence with computers; for others, computer skills were a separate or irrelevant issue. The most experienced tutor ranked students’ learning ability hierarchically, involving both intelligence and cognitive effort. For others, learning “schemas,” that help them properly analyze and set up problems.

But can’t students learn these skills from math textbooks? Derry says that textbooks use only a limited set of schemas, and they often use key words that make the desired operation overly obvious. The problems rarely achieve the complexity students will face in real life. Because basic schema knowledge has not been taught in textbooks and schools, most adults aren’t able to solve complex word problems. For that reason, TiPS trains students to recognize, and use, five basic arithmetic schemas to solve complex problems.

In each TiPS lesson, one story line is continued across a number of different problem scenarios. TiPS gradually builds students’ skills and abilities to the point that they can reason about complex real-world problems.

“We are incorporating features that encourage students to learn independently,” Derry says. “TiPS will help them learn to manage their own time, to evaluate their own performance, to monitor their progress, and to select lessons and exercises that will benefit them.”

to break down complicated problems into manageable chunks really helps. That’s what TiPS teaches students to do.

Derry colleague Don Wortham says the relative difficulty of math story problems depends more on the semantic structures in the problems—dealing with the words and constructing conceptual models of situations—than on the mathematical calculations involved. How do expert problem solvers do it? They use mental constructs, called
ability was a simpler, almost unidimensional trait. Such differences in tutorial approach are considered when designing the TiPS software—not an easy task.

The five tutors reported using many different techniques and strategies for adapting their tutoring to students’ motivational level and learning ability. For example, all tutors watched for indicators of students’ level of motivation and adjusted their tutoring accordingly. Three of the five tutors said that judgments of students’ motivation were more important for their tutoring than judgments of students’ cognitive ability.

How did tutors deal with low student motivation? How can software be designed to handle the problem? Human tutors studied used relatively complex and relatively simple techniques. Complex techniques included a method of questioning designed to draw unengaged students into active thinking about their problem solving. In another method the tutor and student swapped roles. Examples of simpler techniques were shortening tutoring sessions and attempting to personalize problems or assignments. TiPS is being designed to address such issues.

Sample problem: Duke and Chester join the gold rush

Derry colleague David Webb is producing a series of tutorial problems that introduce students to the software interface, familiarize them with schemas and tools, and teach them problem-solving strategies. The student reads the story narrative on the screen while a digitized sound file reads the problem aloud and suggests some problem-solving strategies. As students practice, the software evaluates their performance, telling them how they’re doing.

The lessons are set in story contexts, one of which is a Klondike Gold Rush. Two characters living at the turn of the century, Duke and Chester, find a map showing the way to a gold mine in Alaska. They plan to strike it rich. As the story unfolds, one problem leads to another.

One problem asks: “How many ounces of gold must Duke and Chester sell to make a million dollars, given that the current selling price is $40 per ounce?” The student sets up the problem graphically on the screen, using a mouse. If the student needs prompting, the computer performs a demonstration, drawing geometric shapes on the screen that demonstrate various ways to set up the problem (see illustration).

In another problem, Duke and Chester need to buy supplies for their one-year trip into the Klondike. They know that six weeks’ worth of supplies costs $85. How much do they need to spend to buy supplies for a 52-week journey? Again, the student is guided through setting up and solving the problem.

How tutors categorize students

Derry and Potts found some important similarities and differences among tutors with respect to how they categorized students. All four math tutors had a “problem student model” for those who were both unmotivated and less competent. The math tutors also had a single large “other student” category that subsumed several subgroupings. Three tutors’ “other students” were all motivated, but
Restructuring high schools helps improve student achievement

By Valerie E. Lee, Julia B. Smith, and Robert G. Croninger

High school restructuring can make a difference for students. By analyzing data on students enrolled in secondary schools nationwide, strong links we found between restructuring and improved learning by high school students.

In a study conducted for the Center on Organization and Restructuring of Schools, we found that, where schools make significant departures from conventional school organization and practice, students post bigger academic gains in math, science, history and reading. The achievement gaps between students from high vs. low socioeconomic groups are smaller in those schools as well. Further, students learn more, and learning is distributed more equitably, in smaller high schools.

The better performance of restructuring schools can be explained by looking at the contrast between schools that are organized bureaucratically and schools that are organized communally.

A bureaucratic model has guided the development of secondary schools in the United States, especially since the 1950s. This model calls for the creation of large, comprehensive schools, which offer students a wide choice of courses and activities. Such schools are meant to let each student pursue his or her particular interests, talents and ambitions. The schools offer something—but not the same something—for everyone.

Under this model, a typical large high school is managed by professional administrators, usually led by the principal. This group governs teachers, students and staff in a "top-down" manner through formalized goals and procedures. Within such schools, educators typically divide the different subjects they teach into specific departments. Across departments, students are placed in different tracks, depending on their academic abilities and career objectives. The tracks guide students' selections of courses within departments.

As dissatisfaction with the performance of U.S. schools has grown, especially at the high school level, reforms consistent with this governance structure have sought to boost student achievement. These reforms typically have included efforts to strengthen formal controls over teaching and learning by raising graduation requirements, standardizing classroom practice, and holding teachers accountable for student achievement as measured by standardized tests.

These reforms have had some positive effects, such as enrolling more low-achieving students in academic courses. But they haven't brought about the dramatic improvements in student performance the critics have called for. Also, many observers feel that the tightening of bureaucratic controls has diminished teacher commitment, satisfaction and performance.

Such concerns have helped to foster the development of another school of thought on reform, an "organic" or "communal" model that views teaching and learning as processes that can't be controlled through standardized procedures directed from central authorities.

Instead of directing teachers to follow specific, rigid rules and respond blindly to the decrees of

Restructuring study available

The results of a five-year study of school restructuring, conducted by the Center on Organization and Restructuring of Schools, were recently published in the booklet, Successful School Restructuring: A Report to the Public and Educators, by Fred Newmann and Gary Wehlage. The book is available for $9.95 from the following agencies: the National Association of Secondary School Principals (703–860–0200); National Association of Elementary School Principals (800–386–2377); Association for Supervision and Curriculum Development (800–933–2723); and the American Federation of Teachers, Attention AFT/School Restructuring, 555 New Jersey Avenue, N.W., Washington, DC 20001.
administrators, the organic model says teachers should be encouraged to work together to examine the challenges they face, and then decide—as a team of thoughtful, committed professionals—how best to proceed.

The organic model calls for giving teachers much greater authority over issues of curriculum and instruction. The aim is to engender a more professional orientation among teachers toward their work. Instead of responding to specific rules and evaluations, teachers are motivated by commitment to, and identification with, the school's mission. They work together to identify the challenges faced in their particular school and craft the "best practice" to address them. Teachers might, for example, organize instruction around interdisciplinary teams, and then rely mainly on collaboration to decide what works and what needs revision. The school might also create formal mechanisms for giving teachers more power in the decision-making process.

The rhetoric of organic school reform is plentiful, but real change remains rare. High schools that implement reforms often make only incremental changes in how the school operates. Many reform efforts begin on the drawing board as serious undertakings aimed at fundamental change, but end up being modified or watered down in order to avoid threatening the school's existing hierarchy. Those projects that do implement dramatic reform are often run as small "demonstration projects" within a larger school that remains largely untouched by the innovative programs.

Some schools do, however, operate under more organic organizational models. What effects do these kinds of schools have on students?

We examined this question by looking at two important aspects of schools—academic organization and social organization—and identifying certain qualities associated with schools that are more organically organized. We found that schools with higher levels of these qualities are more effective and more equitable. In other words, students in those schools learn more, and the gaps in learning between students of different social backgrounds are narrower.

Academic organizational features consistent with an organic model include (1) a common academic curriculum with a clear focus on high-level learning for all students; (2) communication of expectations of high academic standards; and (3) "authentic" models of instruction that ask students to engage in sustained, disciplined, critical thought on topics relevant beyond school.

Our study used data from the National Educational Longitudinal Study (NELS) collected in 1988, 1990, and 1992. We examined the academic progress made, and levels of student engagement with school, for about 9,000 students in almost 800 secondary schools across the country. We measured their academic progress from 8th grade to 10th grade, and from 10th grade to 12th grade. We also looked at the types of school reform taking place in, or absent from, those schools. We identified 30 school practices and classified them as traditional, moderate, or restructuring, based on the degree to which they represented significant departures from conventional practice (see sidebar at right for some examples).

### Social organization

Schools that demonstrate a higher level of social organization post greater and more equitable gains in student achievement in math and science. For the

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**A sample of surveyed practices**

- **Traditional practices**
  - Departmentalization with chairs
  - Common classes for same curricular track
  - Staff development focusing on adolescents
  - PTA or PTO
  - Parent-teacher conferences each semester
  - Focus on critical thinking in curriculum

- **Moderate practices**
  - Parent workshops on adolescent problems
  - Student satisfaction with courses important
  - Strong emphasis on parental involvement
  - Strong emphasis on increasing academic requirements
  - Student evaluation of course content important
  - Outstanding teachers are recognized

- **Restructuring practices**
  - Students keep same homeroom throughout HS
  - Emphasis on staff solving school problems
  - Parents volunteer in the school
  - Interdisciplinary teaching teams
  - Independent study in English/social studies
  - Mixed-ability classes in math/science
  - Cooperative learning focus

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In schools where most teachers feel they can make a real difference in students' academic performance, students learn more and learning is more equitably distributed.

continued on page 9
Innovative courses boost math achievement

Upgraded math courses implemented in New York and California are raising student achievement and improving students' chances of mastering college preparatory math.

Four school districts in California and New York offer "transition" math courses that serve as a bridge between basic math and college preparatory math (see WCER Highlights, Summer 1994, p. 4). New York initiated its transition math courses 10 years ago; California initiated different, but equally effective, courses about five years ago. The point of the courses is to help break the vicious cycle of the "basic" or "general" track, in which teachers set low expectations for students in lower-level math courses, and students hold low expectations of themselves.

New York's Stretch Regents courses emphasize the integration of math topics, but at a pace more accessible to students who have struggled in math. The University of Chicago School Math Project (UCSMP) courses in place in Buffalo, New York, and California's Math A focus on the use of manipulatives, group work, and problem-solving strategies that actively engage students in understanding mathematics and how it is applied.

Researchers at the WCER branch of the Consortium for Policy Research in Education studied these innovative courses to determine how and why they were effective. Adam Gamoran, Andrew Porter, John Smithson, and Paula White gathered data from seven high schools across four districts (Buffalo and Rochester, New York, and San Diego and San Francisco, Calif.). They selected schools with high percentages of minority and low-income students, because the problem of dead-end classes for low-achieving students is most severe in such schools.

The study found good news—that students in transition courses are much more likely than students in "basic" math courses to complete a college preparatory sequence (i.e., algebra and geometry, or their equivalent) by the end of high school (see Figure 1).

California's Math A

In California high schools, lower-level math courses such as "fundamental math" and "general math" had effectively served as a "dead-end" sequence for lower-achieving students. In 1985 California introduced Math A to upgrade high school general math courses and to serve as a bridge for lower-achieving students to cross over into college preparatory math courses. The participating schools were moving toward eliminating their ninth-grade general math classes and replacing them with a course that stresses powerful mathematical content. Math A emphasizes problem solving, real-world applications, and empirical reasoning. It requires students to use questioning strategies, manipulatives, calculators, and cooperative learning. And Math A is flexible enough that schools can vary implementation to suit their needs. For example, student placement policy, instructional materials used, and the math courses students take following Math A all varied from school to school.

New York's courses

New York schools offer a college preparatory math curriculum called Regents math. To enable low-achieving math students to complete Regents level math, the Rochester district developed a "Stretch" Regents course, which covers the same material as the "Regents" course, but over a period of two years rather than one. In the Buffalo school district, the failure rate in the Regents level courses was high, with many students dropping out after only two years of math. Buffalo high schools opted for the University of Chicago School Math Project

John Smithson, Paula White, Andrew Porter, and Adam Gamoran (standing) found that students taking transition mathematics courses are much more likely than students in "basic" math courses to complete a college preparatory sequence by the end of high school.
(UCSMP) courses as an alternative to both lower and upper math tracks. Entering high school students now may enroll in general math, Regents Course I, or the UCSMP course. While UCSMP was not designed specifically as a bridge program, the first course in the sequence (UCSMP Transition Mathematics) does provide a bridge between lower-level math and college preparatory math. By emphasizing problem solving, word problems, and real-world applications, teachers hope that more students will continue with the UCSMP sequence of courses than they typically have with the Regents sequence.

**Changes in content and strategy**

The transition math courses have resulted in changes in content and teaching strategy, including:

- Math problems based on “real-life situations,” such as calculating taxes, reading a newspaper, and conducting surveys.
- An integrated curriculum. The material is more comprehensive and better presented as integrated units that complement one another, rather than as isolated, unrelated topics. Several of the Math A and UCSMP units integrate not only various math topics, but also science, geography, history, and language arts.
- A focus on technology, emphasizing the use of calculators. UCSMP courses incorporate computer technology and hold sessions in computer labs.
- Active student participation. The Math A and UCSMP courses call for more group work than the traditional, lower-level math classes or the Stretch Regents courses. Teachers in the Math A and UCSMP courses spend much less time lecturing and more time working with student groups.
- An emphasis on problem-solving, including the use of questioning strategies, reasoning, and communicating. Math A and UCSMP courses de-emphasize direct instruction and emphasize coaching, discussion, and exploring alternative solutions.
- Use of manipulatives. Math A and UCSMP courses emphasize the use of cubes, blocks, dice, and tiles, and other hands-on materials to promote conceptual understanding.

**Benefits of the transition math courses**

Wholesale replacement of the weak general math courses by transition courses is feasible, say the researchers. However, some flaws in implementa-

![Figure 1](#)

**Figure 1**

Four year cohorts
Percentage of students completing two years of college prep math
By track and district

- Buffalo results are based on three years of data, and represent students “on track” to complete two years of college prep math.

1. **Students have a better opinion of math and a higher sense of self-esteem.**
   Rochester teachers said that the Stretch Regents courses improved students’ math experiences, and that student self-esteem has benefitted. San Francisco and San Diego teachers said that Math A students have a better image of themselves as math learners and are glad not to be doing drill and practice.

2. **Students are taking more useful math.**
   In each of the seven high schools studied, the introduction of the transition math courses
were distinguished from one another roughly on the basis of competence. This suggests that a feasible strategy for designing software-based tutoring systems for mathematics would be to create a distinctive tutoring strategy assuming motivated students that could be modified on the basis of student competence. Another approach would be needed for more difficult and unique students with problems in both motivation and competence.

The writing tutor differed from the math tutors by identifying no student as both unmotivated and incompetent, but by identifying numerous students as both competent and unmotivated. (No math tutor viewed any competent student as unmotivated.) "Whether this difference reflects a difference in subject matter, tutor perspective, or student samples is unclear," says Derry, "but it poses an interesting question for further study."

The study of tutors continues, as does development and refinement of TiPS, with a planned public release date in 1996. When TiPS is published commercially, it will benefit students in differing learning environments across the country. While it probably won't appear on as many desktops as Windows 95, it will help many students learn to "work smarter" in and beyond the classroom.

This study is funded by the Office of the Chief of Naval Research, Manpower, Personnel, and Training R&D. For more information, contact Sharon Derry at (608) 263–3676, or e-mail sderry@macc.wisc.edu.

Software continued from page 3

resulted in more students learning new mathematics as opposed to studying once again the mathematics skills of the first eight grades. Six of the seven high schools in the study eliminated general math classes and reduced the number of prealgebra sections. The number of students taking college preparatory math has increased. All students in the two Rochester high schools were enrolled in Regents level math courses, as a result of eliminating general math classes and the introduction of Stretch Regents. In one of the San Diego high schools, the number of students taking algebra increased by 35% after the introduction of Math A.

3. Students are learning more.
To analyze student achievement, the researchers tested in fall, winter, and spring in the 1992–93 school year. Test results support teachers' perceptions that students in the transition math courses made gains in achievement that were higher than in the more traditional general math courses. Regents classes exhibited the most growth and general math classes exhibited the least. Achievement growth for students in Algebra, Math A, and Stretch Regents classes fell between those for Regents and general math.

Researcher Paula White says much of the difference in achievement between course types can be attributed to differences in the coverage of math content. The researchers found the best coverage of tested content in Regents and Algebra classes and the least in general math, with the transition classes falling in between. Greater content coverage is part of the reason students learn more in transition than general math classes, but the most coverage—and the most learning—occurs in the college preparatory classes.

4. The material covered is more practical and relevant to real life situations.
Respondents from California and New York schools said the transition courses give students practical math experience. Buffalo teachers see the strengths of the UCSMP courses as including math that is more relevant to students' everyday lives.

This study was funded by the Office of Educational Research and Improvement, U.S. Department of Education. For more information about study results, contact the Wisconsin Center for Education Research, 608–263–8814.
purposes of this study, we define social organization by examining one factor: collective responsibility for student learning. In schools where most teachers feel they can make a real difference in the academic performance of students—instead of blaming low performance on students’ attitudes, background and other factors beyond teachers’ control—students learn more and learning is more equitably distributed. In schools organized under a more organic model, teachers are more likely to assume this responsibility. The organic model also provides more opportunity for teachers, working together, to examine and adapt their practices to reflect student needs.

The impact of each of these factors on student learning in math and science is impressive. For example, an “average” student who attended a school with a high level of authentic instruction would learn about 78 percent more math between 8th grade and 10th grade than a comparable student in a school with a low level of authentic instruction.

Students in schools scoring high on the other factors we studied also had advantages over students in other schools. But this doesn’t mean that schools can boost student learning merely by adopting the specific reform practices listed here (see the sidebar). It is the organizational characteristics, not the specific practices, that seem to make the difference.

The results of the study were clear and consistent: Schools that implemented three or more restructuring practices posted significantly higher academic achievement than other schools. Those gains also were more equitably distributed among students from different socioeconomic backgrounds. Achievement benefits in the first two years of high school were sustained in the last two. And students in smaller schools also experienced higher and more equitable achievement gains. Though schools with restructured practices showed the greatest success with students, our analysis shows that reasons for success lie mainly in the academic and social organizational features described here, not mere adoption of restructuring practices.

This study was funded by a grant from the Office of Educational Research and Improvement, U.S. Department of Education. For more details, see a full report in “Issues in Restructuring Schools,” Issue Report No. 9, Fall 1995, published by the Center on Organization and Restructuring of Schools (608) 263–7575. The full text of our report will also be made available on our Web site at http://www.wcer.wisc.edu.