WCER Highlights

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Building models enhances understanding

Students construct models to help them reason and solve problems.

Most students in American mathematics and science classrooms do pretty well at factual recall and basic computation. But ask them to reason in more complex ways, or to solve problems that require novel solutions, and they don't do as well as their peers in other developed countries.

University of Wisconsin–Madison Education Professors Richard Lehrer and Leona Schauble hope to rectify this. They are showing students and their teachers how to understand fundamental mathematical and scientific principles—while having some fun in the process—by building and discussing models, from three-dimensional physical models to maps and mathematical models.

In a recent classroom experiment David Penner and Nancy Giles, who work on Lehrer's and Schauble's research team, supplied students with materials including cardboard tubes, rubber bands, clay, popsicle sticks, and balloons. They asked the students to construct working models of their elbows.

After completing their model elbows, students showed them to the class and explained their designs. Their teachers asked friendly yet specific questions: Does your model bend just like an elbow? Or does it bend all different ways? Can you change your model so that the elbow doesn't bend backward?

Lehrer and Schauble observed how first- and second-grade students discussed their simple representations of their elbows, and how the models became more "model-like"

WCER Highlights

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From the Director

Making school reform work


JEFF MILLER

The last five years have been exceptionally productive ones here at WCER. Some of our major projects, including the National Center for Research in Mathematical Sciences Education and the Center on Organization and Restructuring of Schools, recently concluded their studies. Researchers have been reporting their findings in professional journals, at conferences, and in mass media. In this issue of *Highlights* you'll read about what it takes to make school reform work.

- Fred Newmann and colleagues at the Center on Organization and Restructuring of Schools found that schools are more successful if educators constantly work toward advancing the intellectual quality of student learning and nurturing professional community in the school.
- Allan Odden and colleagues at the Consortium for Policy Research in Education found that effective school-based management requires that school staff be given real authority over budget, personnel, and curriculum.
- The central task in improving K–12 mathematics instruction is to create professional communities of teachers, according to WCER's Walter Secada.When high school teachers create a professional community focused on student learning, they can enhance student achievement in mathematics and science and student learning overall.
- In science education, Richard Lehrer and Leona Schauble report that fundamental ideas about mathematics and science become clearer to elementary school students when they create and discuss models. In turn, teachers can better facilitate student learning by constructing "models" of student thinking.

For more information about this and other WCER research, visit our Web site at http://www.wcer.wisc.edu.

Andy Porter

— that is,

- how students acknowledged the separation between a model and the object it refers to
- how students considered models theoretical tools rather than literal copies, and
- how students progressively abstracted, formalized, and mathematized their models to preserve features considered theoretically important.

Models—whether of atoms, the solar system, or elbows—are similar to the things they refer to in theoretically important ways. Scientists and mathematicians develop models to help them solve problems and search for evidence. Lehrer and Schauble want "model-based" reasoning to become part of students' intellectual tool kit. "Students should be able to approach science through fundamental mathematical ideas such as spatial visualization, data, measure, and uncertainty," says Schauble. "Few classrooms use this approach. But it reflects the way real scientists and mathematicians do their work. And whether or not students are considering careers in science or mathematics, learning this form of reasoning capitalizes on their sense-making."

The model-building first and second graders in one Wisconsin school district are learning to think as scientists think—refining and discussing models to develop a deeper understanding of how things work. Lehrer and Schauble found that, even as early as first grade, these students' model-evaluation skills may be open to development. At first, students tend to expect models to be mere copies, and believe that only one model is acceptable. But as their experience grows, they understand that models can represent rival hypotheses about the world. Students can use models to reason and solve problems if given appropriate experience in constructing, revising, and evaluating models in the context of classroom design.

Back to the drawing table

At first, many students built model elbows that could bend in ways that no normal elbow ever would. To illustrate the idea of limitations in motion, Penner used masking tape to fasten a student's upper arm to her body. Penner then asked the student to bend her arm as far back as she could. The student's arm movement reached its limit when the elbow refused to bend backward. The students got the idea, and set about to redesign their models to incorporate this constraint on motion.

When compared to children who did not build models, the modeling students understood more. They did a better job of emphasizing an elbow's function over creating mere visual similarity in their models. They better understood the purpose of revising models, and better appreciated the value of multiple models of the same phenomenon, an aspect on which they had received no instruction. The researchers interviewed 13 second-grade students and 9 fourth- and fifth-grade children who had no model-based reasoning experience. Student ratings of the functional quality of four elbow models ranged from 1 ("Don't like it at all") to 5 ("Like a lot"). Researchers measured students' mean ratings by group and model. The non-modeling Grade 2 group showed little understanding of the need to capture function in one's model, of revision as a means for reflecting one's growing knowledge of a phenomenon, or of the usefulness of considering phenomena from multiple perspectives. The second-grade modeling students did a better job of focusing on function over similarity,

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Supports and impediments to mathematics reform

How can a professional community of teachers support the reform of school mathematics? That's one of the issues explored by the School Level Study of Mathematics Reform, part of WCER's National Center for Research in Mathematical Sciences Education. The NCRMSE study team, chaired by UW–Madison Education Professor Walter Secada, examined how 21 schools (eight elementary schools, four middle schools, eight secondary, and one K–12 school) were trying to improve their mathematics programs. The study also collected survey data from more than 1,200 teachers in nearly 350 schools across the United States. The study's findings on professional community agree with the more general work on school restructuring that was conducted by the Center on Organization and Restructuring of Schools (see article next page).

There is a complex relationship between teachers' professional communities and their classroom practices, especially when changing those practices results in teachers experiencing increased uncertainty about the craft of teaching. Secada says that a professional community can spur some teachers to change their practices, and it can support teachers who encounter difficulties in their efforts. (On the other hand, a strong professional community can also pressure a resisting teacher into leaving.)

"In a way," Secada says, "our study found that teachers get what they work for." Thus setting the purpose of a professional community is extremely important. For example, in two secondary schools studied, mathematics teachers saw their central task as curriculum development and their professional community's focus as curriculum. The teachers' teaching and assessment practices did not reflect many of the changes the reform movement calls for. Although the teachers' content coverage did depart from conventional practice, their teaching and assessment practices were quite uneven in reflecting the changes the reform movement calls for. In contrast, teachers in one elementary school focused on making mathematics more meaningful to their students. As a result, their teaching and assessment practices focused on students' reasoning and justification for answers. They shifted their curriculum to include more realistic problem-solving applications. These teachers were focusing on the intellectual quality of student learning and achievement.

Walter Secada says enlisting support for mathematics reform is not risk-free.

Reformers face resistance

Every school comprises a dynamic set of organizational units where actions at one level can support or impede reform efforts at other levels. In one high school, for example, the mathematics department eliminated student tracking, but the English department continued to track. As a result, the mathematics teachers found they were teaching *de facto* tracked classes. Regardless where the spark for reform ignites, actions taken within the school can help or hinder reform. For example, reform-minded teachers may find themselves in constant conflict with others in the school who resist change. They may disagree over deeply held competing ideas about how to teach mathematics or what mathematics should be taught, or over issues of who controls resources and how a school or department should be governed. Alternatively, teachers who initially support reform may compromise their ideals and moderate their teaching reforms to avoid conflict, or they may "retro-fit" their beliefs and practices to accommodate existing circumstances.

Some teachers are able, however, to transform the existing structure, culture, and teaching practices on a schoolwide or departmentwide basis. The success of reform efforts depends on the dynamic interplay among (1) schools' and departments' cultural values and structures, (2) teachers' beliefs, and

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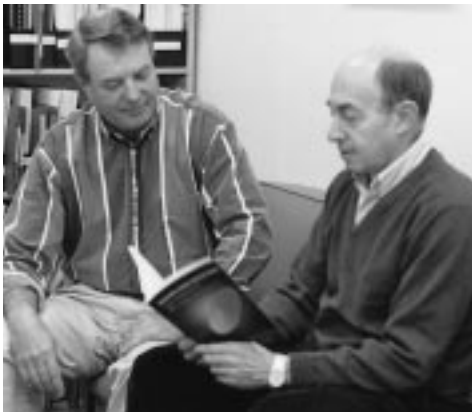
Parents often become a program's strongest supporters when they experience what their children experience.

Let's focus on intellectual quality

Good teaching requires students to think, to develop in-depth understanding, and to apply academic learning to important, realistic problems. Good teaching boosts student achievement equitably for students of all social backgrounds, in elementary, middle, and high schools. According to a five-year study by UW–Madison Education Professors Fred Newmann, Gary Wehlage, and colleagues at the Center on Organization and Restructuring of Schools, all of these benefits result from a kind of teaching they call "authentic pedagogy."



Gary Wehlage (left) and Fred Newmann found that successful schools make time for working and learning more sustained than is typical.

Newmann and associates sum up their five-year study in the book *Authentic Achievement: Restructuring Schools for Intellectual Quality*. The research concludes that educators can strengthen the prospects for authentic pedagogy and help students generate authentic intellectual work—achievement that involves construction of knowledge, requires disciplined inquiry, and has value beyond school. Schools succeed in this goal to the degree that staff concentrate on certain cultural and structural features that support intellectual quality and professional community. (Table 1).

Cultural foundations

In schools that placed the intellectual quality of student learning at the center of their restructuring efforts, the language of student learning became the focus of daily discourse. Staff did not restrict aspirations for more ambitious learning to traditionally high-achieving students; their commitment extended to all students, based on the belief that all students can meet the higher standards. This commitment translated into teaching that contributed to higher levels of achievement for all students.

The cultures of successful schools include norms for professional conduct that increase students' chances for meeting expectations for higher achievement. But because research on teaching offers few clear directions for how to proceed with authentic pedagogy, staff must search continually for ideas and materials to improve their practice. They must test new possibilities through discussion, observation, and study. In successful schools, cultural norms support innovation and continued professional growth.

Structural foundations

Cultural norms require support from structural features. Successful schools find ways to make time for working and learning more sustained and continuous than is typical. Some schools in the study extended class periods beyond the common fifty-minute episode. Students were placed in groups for instruction or advising that continued for more than one year. Time for common planning among teachers was arranged during the school day and beyond. Staff development remained focused for a year or more on critical topics. To carry on the collaborative work critical to professional community, important decisions about instructional programs, hiring, and allocation of resources were often made in teaching teams or committees. These structures reinforced interdependence within the teaching staff. When combined with the cultural commitment to intellectual quality, these structural changes facilitated authentic pedagogy.

In schools that had significant autonomy from centralized bureaucratic constraints, faculties thrived when oriented clearly toward student learning of high intellectual quality and developing a strong professional community. The CORS study also found that smaller schools or instructional units organized to personalize teaching and learning offered striking support for building respect and trust between students and faculty, and support for professional community, which helps sustain each teacher's commitment to the difficult work of teaching.

Leadership: making it happen

School administrators and teachers play a critical role in helping to establish the cultural and structural conditions for successfully restructuring schools. The School Restructuring Study helped to specify some of the most significant of these characteristics and practices.

First, leaders in successful schools created a schoolwide collective focus on student learning of high intellectual quality. These leaders understood that promoting intellectual quality requires more than increasing the knowledge and skills of individual teachers; they also enhanced the capacity of the organization by placing issues of teaching and learning at the center of dialogue among the entire school community.

To nurture teachers' professional community, leaders helped to articulate the norms and values that give substance to a school's vision. For example, effective leaders in the participating schools

initiated conversations about the kinds of classroom experiences that promote students' intellectual development. They continually emphasized to staff the need to maintain high expectations for all students, and they encouraged staff to consider how they could best pursue the school's vision. For example, one principal described his responsibility as helping staff continually to clarify what the school's vision meant in practice. At other schools leaders regularly discussed the implications of the goal of helping students develop "habits of mind" that would make them critical thinkers.

To achieve the goal of promoting intellectual quality and professional community, teachers also need help from middle-level administrators, superintendents, and policymakers. Superintendents and policymakers can promote specific points such as school autonomy from regulatory constraints and sustained time for instruction, planning, staff development, and student advising. But systemic reform aimed at promoting intellectual quality and professional community must tie together the various cultural and structural foundations for authentic student achievement. For example, a school culture that supports innovation is likely to be stifled without adequate time and other resources for teachers to act on their commitments.

Superintendents can communicate with middle-level staff, principals, teachers, board members, the business community, and parents about the importance of the cultural and structural features of restructuring. Successful superintendents take the lead in establishing a districtwide vision for education that places priority on student achievement of high intellectual quality. District-sponsored meetings, planning activities, curriculum development, staff evaluation, and especially staff development, all aim at this central target. The superintendent can encourage schools to develop teaching teams and schedules that offer more time for planning and professional development. Superintendents can clear away bureaucratic constraints to innovation, encourage the development of small schools, and provide funds for school-based innovation and professional networks.

External support can help

Professional and political support from a variety of external agencies can help schools promote intellectual quality and professional community when schools are poised to take advantage of it. A school's access to such support depends on the actions of school leaders and their staff and on the priorities of the external groups themselves.

In the schools studied, professional support included staff development sessions to help the school advance its mission. One school developed a five-year relationship with a computer company. Some schools had opportunities to consider new standards for student performance proposed by professional organizations, state agencies, or independent developers. Political support came in the form of deregulation by the district and by the state. Deregulation enhanced schools' ability to establish programs, hire staff, and spend funds pursuant to goals that the school community supported.

For more information, see *Authentic Achievement: Restructuring Schools for Intellectual Quality*, by Fred M. Newmann and Associates, 1996 [Jossey-Bass Publishers, 350 Sansome St., San Francisco CA 94104 (800) 956–7739; http://www.josseybass.com].

JEFF MILLER

A teacher helps students develop habits of mind that make them critical thinkers.

Table 1

Cultural and structural foundations for authentic student achievement

Cultural foundations	Structural foundations
Primary concern for the intellectual quality of student learning	Sustained time for instruction, planning, staff development, and student advising
Commitment to maintain high expectations for all students, regardless of individual differences	Interdependent work structures for staff, especially teaching teams and committees for schoolwide decision making
Support for innovation, debate, inquiry, and seeking new professional knowledge	School autonomy from regulatory constraints
Ethos of caring, sharing, and mutual help among staff, and between staff and students, based on respect, trust, and shared power relations among staff	Small size for school and instructional units

Implementing site-based management

All students should be achieving at a level that only about 10 percent of students attain today. They should master the complex subject matter of mathematics, science, writing, history, geography and physics. Education reformers believe it could happen, but reaching that goal won't be easy.

Many aspects of current education structures will need to change, according to UW–Madison Education Professor Allan Odden and colleagues at the Consortium for Policy Research in Education (CPRE). Up to this point, they say, reform strategy has focused on curriculum and instruction changes, but revisions in management and organization also are needed.

For site-based management to work, people at the school site must have real authority over budget, personnel, and curriculum.

In most states, the education system is governed through a vertical system of management and organization. School board policy is implemented through the central office and a hierarchical system of control. This system worked well at one time, Odden says, but it is not adequate to meet the demands of delivering an increasingly ambitious curriculum to all students.

In standards-based systemic education reform, Odden suggests, the top of the education system would create goals and set curriculum standards, but accomplishment of these objectives would largely be decentralized to school sites. The latter step would require major changes in governance, management and finance of the education system, Odden says. Restructuring the education system toward implementing policy at the bottom of the hierarchy entails rethinking the roles, functions, and structures at all levels of the current education system—both the district and the site.

The need for SBM

Site-based management (SBM) has been proposed as a way to make schools produce high levels of student achievement effectively. It is a way to restructure site-district relationships in a manner that provides much more power, authority, and accountability to the school-site level. SBM provides the conditions for restructuring school and classroom organization. And, as importantly, it allows school faculties to allocate the money currently in the system, as well as target any new sources of funds, into productive uses. (For more about school restructuring, see story page 4).

To boost school results, an SBM structure must decentralize significant authority to the school site and implement high quality curriculum standards in a restructured school organization. Some districts and schools experience greater success than others in implementing SBM. While some schools use SBM to redesign the school organization to accomplish an educational vision, other school communities are stuck on power issues like who should have access to the copy machine and who should represent parents or teachers in the site council.

Finding high-performance schools

For five years, the CPRE researchers studied 44 schools in 12 school districts in the U.S., Canada, and Australia to determine what makes SBM work. Odden and colleagues interviewed more than 400 people—school board members, superintendents and associate superintendents in district offices, principals, teachers, parents, and students in local schools. All the schools studied had been operating under SBM for at least four years, although some had been working at it much longer.

Odden and colleagues defined high performance schools as those that were actively restructuring in the areas of curriculum and instruction. These were schools where SBM worked. The comparison groups were struggling schools; that is, schools that were active with SBM but less successful in making changes that affected curriculum and instruction. Odden and colleagues found that school-based management goes far beyond a change in governance. "For SBM to work," Odden says, "people at the school site must have real authority over budget, personnel, and curriculum. For SBM to be a vehicle for improved school performance, that authority must be exercised to introduce changes in school functioning that actually affect student learning."

The successful schools had dispersed power beyond the school council or the principal to council subcommittees and other teacher decision-making committees. CPRE research also found that shifting power to the school was not effective unless the school's strategy for using its new power was accompanied by strategies for developing three other essential commodities:

1. *Employees need knowledge and skills* to enact their new roles to achieve high student performance and continually improve outcomes. Teachers need interpersonal skills for working together effectively in a group setting and technical knowledge and skills for providing the service, i.e., new curriculum and instruction expertise.
2. *Teaching staff need information* about student performance, parent and community satisfaction, and school resources: district and site revenues, costs, cost structures, customer satisfaction, benchmarks with other schools, and data on the environment. "What distinguished the more effective SBM schools were the additional channels used to disseminate information," Odden says. "In these schools, information not only flowed down to the school, but also flowed through numerous mechanisms within the school, out to the community and out to the district." Particularly noteworthy were teacher work teams that collected and dispensed information within the school, and the constant effort to inform parents and the community.
3. *A reward system* is needed to acknowledge the extra effort SBM requires, as well as to recognize improvement, Odden says. High performance organizations shift from a seniority-based pay system to pay based on direct assessments of knowledge and skills. This method of compensation does not necessarily require more money; it involves a shift in how the salary dollars are provided.

For more information, contact CPRE at (608) 263–4260.

Odden says that accomplishing reform goals should be largely decentralized to school sites.

Adapted from "Key Issues in Effective Site-Based Management," *School Business Affairs*, Vol. 61 No. 5.

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understanding the purposes for model revision, and appreciating the value of multiple models of the same phenomenon.

Underlying the Lehrer/Schauble project is the view that teachers and students can develop and understand scientific models by using mathematical models. To explain the variation of plant growth in a field, for example, students use mathematical abilities such as:

- spatial visualization (how should the field be mapped or otherwise depicted?)
- measure (plant growth variation with respect to what?)
- data structure (how should we organize and relate observations?) and
- ideas about uncertainty (how should we represent variation?).

Lehrer and Schauble collaborate with teachers in five elementary grade levels in a local district. They began working on science and mathematics with a core group of teachers familiar with this form of teaching in number, geometry, and other math. The teachers share their resources, tools, and expertise with other teachers—in and beyond the district—through formal and informal teacher meetings and electronic conversations. For example, some teachers appropriated and revised a "Quilts" curriculum unit with accompanying computer software into what ultimately became a two-month unit about area and measure. The Quilts curriculum, originally designed by the Educational Development Corp., engages students in using squares of colorful material, each with an eye-catching geometric design. Pairs and triads of students study and discuss the geometric designs, compare them, reason with their teacher about their similarities and dissimilarities, and eventually construct large paper "quilts" for display.

Because teachers develop the contexts in which learning occurs, efforts to improve instruction need to assign teachers a primary role, Lehrer says. "Teachers should view themselves as professionals who diagnose and design learning environments," he says. Accordingly, the project encourages teachers to engage as coresearchers into students' thinking, to develop useful models of students' thinking, and to use those models to guide practices that help students develop their mathematical and scientific understanding. For example, young children tend to think that a good model of an elbow is one that looks like or otherwise preserves recognizable perceptual features of a real elbow. When such a model of student knowledge guides teaching, teachers can foresee the pitfalls and possibilities that await students in their learning, and plan activities accordingly.

"Many things happen in classrooms, and models of student thinking help guide teachers' attention toward portions of this variability that are educationally promising, and away from those that are 'noise,'" says Schauble.

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Mathematics reform

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(3) external forces that increase or inhibit the likelihood of each outcome.

Enlisting support for reform

Given this array of possible outcomes, implementing and sustaining the reform of school mathematics will require teachers' professional communities to orient their shared purpose and beliefs toward the quality of students' mathematics learning. Also, school leaders must help teachers manage the uncertainty caused by reform. Leaders may, for example, construct a less bureaucratic management structure with less rigidly defined roles. "If teachers who are changing their practices decide to try an alternative curriculum, observe another's teaching, or participate in a staff development activity," Secada says, "they need to have the time and resources to do so." Knowing the possible outcomes of reform efforts can guide a department or school in making plans.

Another key to successful reform is explaining the school's efforts and rounding up the support of external stakeholders, particularly students' parents. "Recruiting external support is not risk free," Secada says. "Opposition to change develops from symbolic politics as well as from a principled concern about the quality of students' education." Educators increase these concerns by using trendy labels or jargon to explain the program to parents, while ignoring sincere and legitimate requests for information or acting defensively. Parents and teachers sometimes engage in a power struggle over control of how students should be educated based on deeply conflicting values. "Parents had no input in the development of the NCTM *Standards*," says research team member Dominic Peressini, "and many of them, who went through the new math era, are concerned about how their own children's later-life opportunities will be affected by these changes." But parents often become the program's strongest supporters when a program is explained so that they can understand it or, better yet, experience what their children are experiencing. Parent supporters are often better able to explain the program or, in some cases, to defend it from potential detractors.

More information about supporting mathematics education reform, and about this study, can be found in: (1) Secada, W. G. & Adajian, L. B (in press), Mathematics teachers' change in the context of their professional communities. To appear in E. Fennema & B. S. Nelson (Eds.), *Teachers in transition: Mathematics and reform.* (2) Byrd (Adajian), L., Foster, S., Peressini, D., & Secada, W. G. (1994).