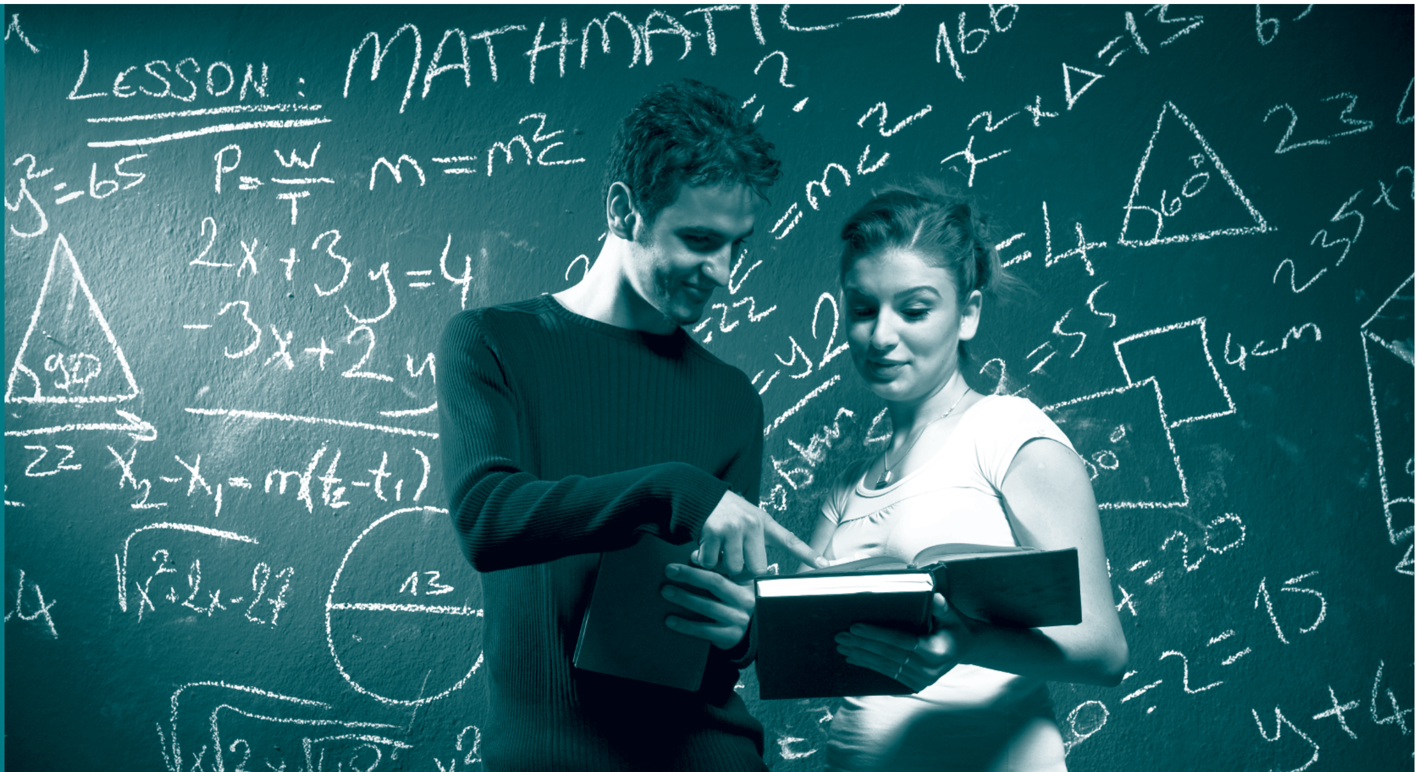

Rigor and Relevance:

A Model of Enhanced Math Learning in Career and Technical Education

University of Minnesota

NRC CTE

National Research Center for Career and Technical Education

RIGOR AND RELEVANCE: A MODEL OF ENHANCED MATH LEARNING IN CAREER AND TECHNICAL EDUCATION

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Executive Summary

Many high school students, particularly those enrolled in career and technical education (CTE) courses, do not have the math skills necessary for today's jobs or for college success. This report describes a research study designed to test a model for enhancing mathematics instruction in high school CTE courses. A seven-element pedagogy was designed to move CTE students gradually from a contextual understanding of mathematics to a more abstract understanding such as that required on many standardized tests.

Volunteer CTE teachers from five occupational areas were recruited and randomly assigned to an experimental or control group. In a series of professional development workshops, the experimental CTE teachers worked with math teachers to examine the CTE curricula and identify the embedded mathematical concepts. The teams then developed instructional activities that the CTE teachers used to enhance the teaching of math that already existed (but was previously not emphasized) in the CTE curricula.

During the 2004-2005 school year, the experimental group of CTE teachers taught the math-enhanced lessons. Teachers in the control condition were asked to teach their regular CTE curriculum with no changes. All participants received compensation for their participation.

After one year of exposure to the math-enhanced lessons, the students in the experimental classrooms performed significantly better on two of three tests of math ability. Furthermore, there were no differences in measures of occupational or technical knowledge, meaning that CTE students' math skills increased without detracting from the content skills learned in their CTE courses.

The improved math performance of the students in the experimental groups in this study was produced by assembling teams of teachers in five occupational areas and providing them with a process and a pedagogy through which they could successfully enhance the math in their own curricula. Essential to the model was the ongoing teamwork between CTE teachers and their math partners in an authentic community of practice. Based on this study, we determined that the following five core principles are necessary to replicate our results:

1. Develop and sustain a community of practice among the teachers.
2. Begin with the CTE curriculum, not the math curriculum.
3. Understand that math is an essential workplace skill.
4. Maximize the math in the CTE curriculum.
5. Recognize that CTE teachers are teachers of Math-in-CTE, not math teachers.

The report closes with a description of how technical assistance available from the National Research Center for Career and Technical Education can help other educators can achieve similar results.

RIGOR AND RELEVANCE:
A MODEL OF ENHANCED MATH LEARNING
IN CAREER AND TECHNICAL EDUCATION

This national study measured the effectiveness of a new pedagogical strategy designed to identify and teach mathematical concepts outside of traditional math classes. Many high school students, including many who are enrolled in career and technical education (CTE) courses in specific labor market preparation (SLMP) areas, do not have the math skills necessary for today's high-skill workplaces or to meet college entrance requirements. The purpose of the project was to help CTE teachers more explicitly present the mathematics concepts already embedded in the occupational curriculum as necessary tools for solving workplace problems. This approach was designed to have the dual benefit of improving students' mathematics problem-solving skills and reinforcing their general mathematics understanding.

Much of the mathematic knowledge required for both workplace success and entry into higher education is generally taught late in middle school or early in high school, with little follow-up or reinforcement for students who do not advance to courses in higher math. The study addressed how the math skills of these students could be refreshed and enhanced during their final years in high school without detracting from the CTE skill-building necessary to meet workplace demands. Based on considerable evidence regarding contextual learning, we hypothesized that high school students exposed to a math-enhanced CTE curriculum would develop a better understanding of mathematical concepts than students in a traditional CTE curriculum. Specifically, we asked the following research questions:

1. Does a math-enhanced CTE curriculum improve math performance as measured by traditional and applied tests of math knowledge?

2. Does enhancing a CTE curriculum reduce the acquisition of technical skills or knowledge?

This report describes the methods and findings of the research study conducted to test the Math-in-CTE model and describes how educators can achieve similar results in their own settings.

I. The Math-in-CTE Model

To provide CTE teachers with a means of enhancing the mathematics already present in their occupational curricula, we developed a new model that involves both a pedagogy and a process for professional development. The pedagogy, which is a practical application of mathematics instruction arising out of an authentic context, was designed by the research team and educational consultants and served to guide the teachers' development and instruction of math-enhanced CTE lesson plans. It consists of a three-step process that guides students to make links between math concepts and the task or problem at hand: solving a real, relevant problem; practicing on several similar examples; and applying the concept to a more abstract problem.

The Pedagogy: Seven Elements

We refer to our pedagogical model as the Seven Elements of a Math-Enhanced Lesson (see Figure 1). Using lesson plans developed around these seven elements, the teachers participating in the study introduced the CTE lesson and the math concepts in it and then assessed students' understanding of that math. The teachers then presented the math problems that were embedded in the CTE lesson. Critical to this instructional approach is that the math concepts are addressed when they arise naturally from the curriculum. The next steps involved working through that problem and similar problems in the CTE context and then moving to a more traditional, abstract problem using the same underlying mathematical concept(s). The lesson ends with a formal assessment of students' understanding. Figure 2 provides an example of a specific lesson using each element and Figure 3 presents a detailed description of each of the seven elements.

Figure 1. The Math-in-CTE Model: The Seven Elements of a Math-Enhanced Lesson.

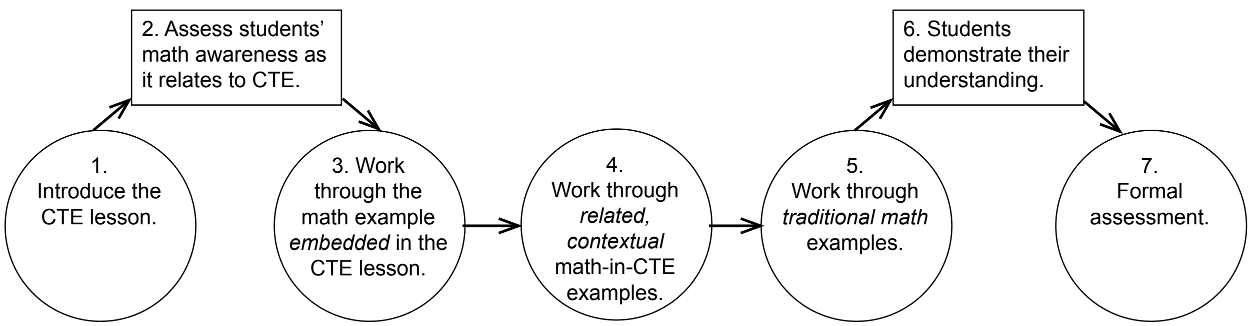


Figure 2. The Seven Elements: Components of a Math-Enhanced Lesson.

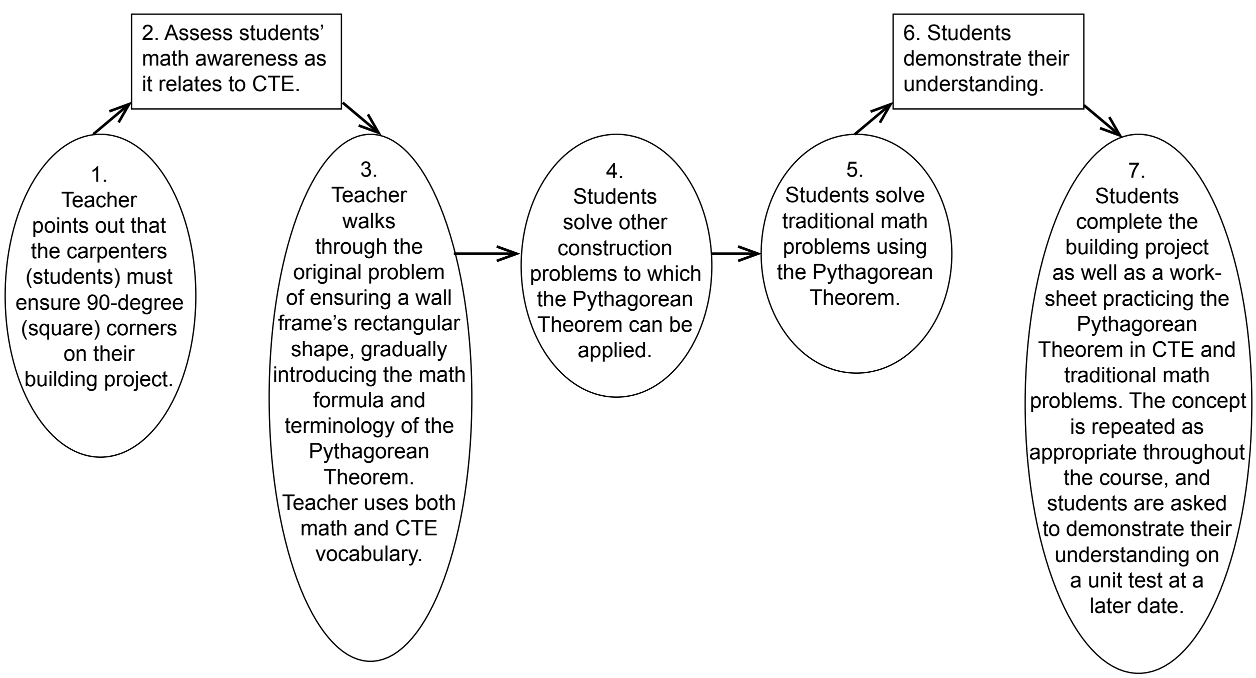


Figure 3. Sample Building Trades Math-Enhanced Lesson: Using the Pythagorean Theorem.

1. Introduce the CTE lesson.
   - Explain the CTE lesson.
   - Identify, discuss, point out, or pull out the math embedded in the CTE lesson.

2. Assess students' math awareness as it relates to the CTE lesson.
   - During assessment, introduce math vocabulary through the math example embedded in the CTE lesson.
   - Employ a variety of methods and techniques for assessing all students' awareness (e.g., questioning, worksheets, group learning activities).

3. Work through the math example embedded in the CTE lesson.
   - Work through the steps or processes of the embedded math example.
   - Bridge the CTE and math language. The transition from CTE to math vocabulary should be gradual throughout the lesson, being sure never to abandon either set of vocabulary completely once it is introduced.

4. Work through related, contextual math-in-CTE examples.
   Using the same math concept embedded in the CTE lesson,
   - Work through similar problems/examples in the same occupational context.
   - Use examples with varying levels of difficulty; order examples from basic to advanced.
   - Continue to bridge CTE and math vocabulary.
   - Check for understanding.

5. Work through traditional math examples.
   Using the same math concept as in the embedded example and the related, contextual examples,
   - Work through traditional math examples as they may appear on standardized tests.
   - Move from basic to advanced examples.
   - Continue to bridge CTE and math vocabulary.
   - Check for understanding.

6. Students demonstrate their understanding.
   - Provide students with opportunities for demonstrating their understanding of the math concepts embedded in the CTE lesson.
   - Relate the math examples back to the CTE content; conclude the lesson on the topic of CTE.

7. Formal assessment.
   - Incorporate math questions into formal assessments at the end of the CTE unit/course.

The Process: Professional Development with CTE/Math Teacher Teams

The development of the pedagogical framework (the seven elements) was only one aspect of the model. We also needed to provide professional development to the participating teachers so that they could learn to implement the pedagogy. Therefore, we required the teachers to attend a series of professional development workshops that were held at each of the five SLMP sites. Professional development took place over ten days: five in the summer before school began, two in late fall, two in early spring, and a final debriefing day at the end of the school year. The content of the workshops is described in the following section.

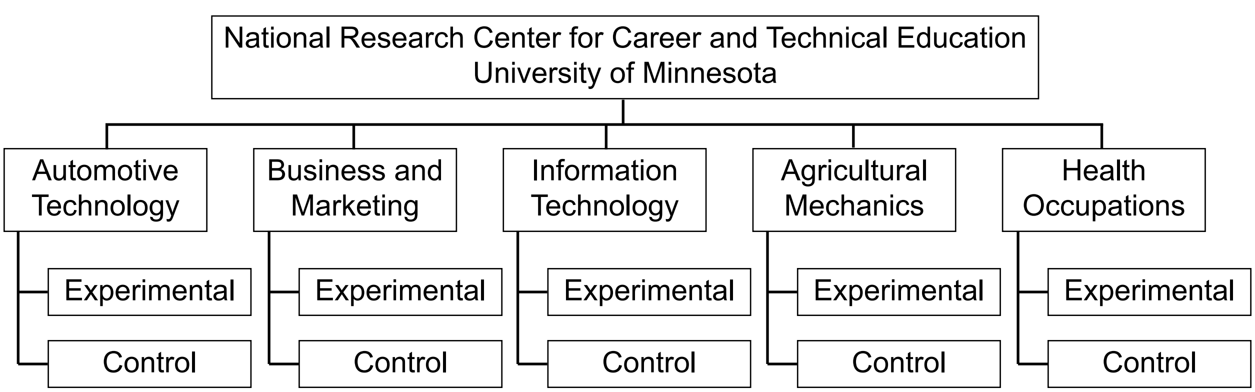
II. Study Method

We designed the study as a field experiment with a random assignment of teachers to experimental and control conditions. The rationale for this approach is that it randomly distributes any unmeasured factors that might affect performance on the outcome between the two groups, allowing for a more rigorous test of an educational intervention. When this method is used and a statistically significant difference is found between the groups, it can be attributed to the experimental intervention (Cook, 2002). The control condition permits the researcher to measure what would be expected if the students in the experimental classrooms had not received the intervention.

Participating CTE teachers from five SLMPs were assigned at random to an experimental or control group within each of the occupational areas (see Figure 4). We chose to study our model within more than one occupational area to test whether the results would be generalizable. In research, this is called a simultaneous replication.

The five SLMPs in our study, as shown in Figure 4, represented the breadth of CTE programming. We conducted the study in one program (business and marketing) that is essentially classroom-based, one (auto technology) that is heavily skill-oriented, two (health,

Figure 4. Experimental and Control Groups by SLMP.



information technology) identified as high-tech and high-growth fields, and one (agriculture) that has been historically associated with CTE. We recruited CTE teachers of these five areas from across the country, as we describe in the next section.

Recruitment of Participants

Recruiting participants for a study of this magnitude required the cooperation of national organizations involved in CTE, local and state level administrators, and university researchers. Initial recruitment of CTE and secondary math teachers willing to participate occurred with the assistance of mailing lists and advertising help from four principal sources: the Association for Career and Technical Education (ACTE), the National Council of Teachers of Mathematics (NCTM), the National Association for Tech Prep Leadership (NATPL), and various CTSO organizations (e.g., SkillsUSA, DECA).

We initially recruited a sample pool of at least 40 CTE teachers in four of the five SLMPs, who were randomly assigned to either the experimental or control condition (20 per group). The final sites and their participating teachers (136 teachers in all) were spread across the country: the business and marketing SLMP replication took place in a western state; the information technology and health occupations SLMP replications were located in mid-western states; the automotive technology SLMP replication took place in several eastern states; and the agricultural mechanics SLMP replication was done in a southern state. Each SLMP was located at a separate site; therefore the terms SLMP and site are used synonymously.

As an incentive to participate in the study, teachers in the experimental group (both CTE and math teachers) were offered a stipend for the school year, plus all costs for travel, food, and lodging to attend the workshops. For the workshops that took place during the school year, funds were provided to their schools to hire substitute teachers for their two-day absence. CTE teachers in the control group, who were asked to teach their curriculum as usual but to allow their students to be pretested and posttested, also received a stipend. At the end of the 2004-2005 school year, the control teachers were offered an opportunity to receive the professional development on math enhancement of their CTE curriculum.

Implementation of the Math-in-CTE Model

When CTE teachers applied to participate in the study, they were required to identify math teacher partners, preferably from their schools, who were willing to work with them during the study. The role of the math teacher partners was to help the CTE teachers identify the applied mathematics in their specific CTE courses, to assist the CTE teachers in developing math-enhanced CTE lessons, and to suggest instructional methods for highlighting the mathematics concepts. Recognizing that a majority of CTE teachers are not formally prepared to teach math, the pairing of CTE teachers with math teacher partners was a critical component of the NRCCTE model. Importantly, however, the role of the math partners was not to “team teach” or in any way teach the math for the CTE teacher, but instead to provide math support to the CTE teacher prior to and after they taught the math-enhanced CTE lessons.

Several steps were required to implement the Math-in-CTE Model in the participating classrooms before results could be measured.

1. Conducting Professional Development Workshops

Site facilitators with expertise in teacher training and curriculum integration were recruited and trained by the NRCCTE research team to conduct professional development workshops for the experimental teachers at each SLMP site (the sites worked separately in order to focus on their own occupational area). The site facilitators used several strategies, including a universal agenda template, to ensure that all experimental teachers received the same professional development. The professional development prepared the CTE/math teacher teams to function collaboratively in the experimental effort. Each team attended all workshops together and remained partners throughout the study.

2. Designing the Lessons

At their first professional development workshop, in the summer prior to the academic year in which implementation of the model was to occur, CTE/math teacher teams were given sample foundational curriculum maps as well as examples of contextualized math lessons gathered from multiple sources, including teacher resource Web sites. The curriculum maps aligned math concepts (from algebra, geometry, or trigonometry) with existing CTE curricula for the specific SLMP. For example, the use of proportions and ratios is critical to the preparation of medicines in health occupations. The curriculum maps were used as a basis for identifying the math concepts common to each of the CTE teachers' courses within the SLMP and for selecting the math concepts around which they would develop new, math-enhanced CTE lessons.

Facilitators for each of the SLMPs then introduced to their teacher teams the pedagogical framework—the seven elements—for developing math-enhanced CTE lessons. The teacher teams were instructed to include all seven elements in the lessons the group developed for their SLMP. Our major requirement was that the mathematics taught in CTE courses should arise directly out of occupational content, as it is this focus on making explicit the authentic mathematical concepts from the existing curriculum that differentiates our approach from others. Priority was given in the workshops to providing time and opportunities for CTE teachers to practice and observe others teaching the lessons. Final versions of the lessons they created were distributed within the SLMP at the conclusion of the workshop. The CTE teachers then used a scope and sequence chart to determine when the math-enhanced lessons would best fit into their instruction in the course.

In subsequent two-day workshops in the fall and spring, the CTE/math teams continued working together to refine the lessons for implementation based on feedback from those who had tried them in their classes. To provide additional support on math concepts throughout the year, regional math cluster meetings were conducted between each of these professional development sessions. Finally, a debriefing session was conducted in the summer after the study was concluded. During that summer, professional development workshops were also conducted for the control teachers to inform them about the pedagogy and lessons developed for the experiment.

Math concepts covered. By design, the development of math-enhanced lessons was unique to each SLMP, and therefore the number of lessons taught and the number of concepts within those lessons differed across SLMPs. Following the Math-in-CTE model, a math concept could also be addressed multiple times as it emerged in a given CTE curriculum.

All SLMPs placed a strong emphasis on number relations and computation, important foundational knowledge on which all mathematics content builds. Due to the nature of their occupational content, each SLMP's mathematics instruction tended to gravitate toward a small number of higher-level math areas. Table 1 presents an overview of concepts covered in each SLMP, which are not identified by occupational content area to ensure anonymity of responses.

Table 1: Math Concepts Addressed by Enhanced Lessons in Each SLMP

	Number of lessons addressing Math concept by SLMP				
Math Concept	SLMP A	SLMP B	SLMP C	SLMP D	SLMP E
Number and number relations	4	10	4	8	2
Computation and numerical estimation	6	12	7	8	12
Operation concepts	1	0	0	0	0
Measurement	3	0	7	5	12
Geometry and spatial sense	0	0	1	0	2
Data analysis, statistics, and probability	4	1	9	11	4
Patterns, functions, algebra	3	5	1	7	2
Trigonometry	0	0	0	0	2
Problem solving and reasoning	0	3	1	0	0
Communication	0	0	1	1	0

3. Teaching the Math-Enhanced Lessons

All teachers were expected to teach all the agreed-upon lessons created for their SLMP. We asked the teacher teams to confer with one another before the CTE teacher taught each math-enhanced lesson. Ahead of each lesson, the math teacher provided the CTE teacher with support by helping to plan the instruction, answering questions, assisting with problem-solving, and offering encouragement. To ensure the lesson had been taught, we asked the math teacher to submit a report on the meeting and the CTE teacher to submit a report on the class in which the lesson was taught.

Data Collection

Data collection occurred throughout the academic year and included observations of lessons, samples of students' work, and teacher surveys and focus groups. To assess students' mathematical performance before and after the intervention, three different commercially available math tests were used. All students took the same pretest, but to minimize both time requirements and the burden on participants while still providing a classroom-level average test score, only one-third of students in each classroom took each of the three posttests (rather than have every student take all three math tests). To ensure uniformity across all schools and SLMPs involved in the study, 40 minutes was established as a time limit for the administration of the math tests (pretest and posttests). This minimized the burden on students and teachers by keeping the testing time within one class period but was less time than may have been required or recommended by the test makers. The basic measure presented for all tests in this report is the%age of correct answers (correct answers divided by total number of test items). The time limit and scoring strategy were design compromises that make it impossible to compare our results to national norms.

Math Tests

As indicated, several tests were used to assess the mathematical skills of the students in the participating classrooms.

Pretest. The Mathematics section of the TerraNova CTBS Survey (CTB/McGraw-Hill, 1997b), a shorter form of the CTBS Basic Battery (CTB/McGraw-Hill, 1997a), was used as a pretest because it assesses multiple content areas and is a traditional, nationally normed, reliable cognitive test of math skills.

Posttests. We selected three tests rather than one because we anticipated that each might yield a different result. Each test maker employs its own conceptual framework for math, and we assumed each approached the construction of math questions around similar concepts in different ways. For the posttest measures, the students in each classroom were randomly assigned to one of three groups corresponding to the three math posttests:

1. The TerraNova CTBS Survey (CTB/McGraw-Hill, 1997a) is a traditional measure of mathematical ability. The test covers a broad range of mathematics concepts in the areas of arithmetic, geometry, statistics, algebra, and problem solving. Commonly used by secondary institutions as a measure of a student's mathematical aptitude, this test gave the research team a snapshot of the student's general mathematical abilities.

2. WorkKeys Applied Mathematics Assessment (ACT, 2005), a measure of mathematics often used in the workforce, served as our measure of mathematics skills in applied contexts. The mathematics in the exam include mostly remedial computation (arithmetic), but the exam offers the additional challenge of problem scenarios written in paragraph form.

3. The Accuplacer Elementary Algebra test (College Board, 1998), a standardized mathematics placement test used by many colleges and universities, was used as a measure of potential postsecondary remediation requirements.

Technical Skills Tests

All students also took a skills or content test for their occupational area at the end of the study, in order to ascertain whether the enhanced math lessons had detracted from the teaching of technical skills. For the health and IT classrooms, we used tests created for us by National Occupational Competency Testing Institute (NOCTI). We worked with the Automotive Youth Education Services (AYES) for the auto tech tests, and the curriculum consortium MarkED provided a test for the business and marketing courses. The agriculture test was a test required of all such programs by the agency that administers CTE in the state in which that site was located. Each technical skill or content knowledge test included, but was not limited to, the technical skills learned in the specific course included in the experiment. The occupational tests were given on a different day from the math tests, and students were allowed the regular length of time allotted by the makers of these tests because teachers and students wanted to use the scores for other purposes. The use of these tests allowed us to determine whether the experimental group experienced any loss of technical skill or content knowledge as a result of spending more class time specifically on mathematics.

III. Results

The purpose of the study was to determine whether the experimental intervention was sufficiently powerful to affect CTE students' performance on standardized tests of mathematical achievement. When combining all of the experimental and all of the control students across the five SLMPs, the two groups (experimental and control) had the same level of math skills at the beginning of the year (as measured with the pretest). After the intervention, which comprised an academic year of enhanced mathematics instruction in a single CTE class, three different measures were used to assess math performance, each with a third of the participating students. The final sample included 136 classrooms (57 experimental, 79 control), which represented 1598 students. We used classroom means (averages) as our unit of analysis. Three separate analyses were conducted, one for each of the math posttests, with statistical software designed to account for the fact that students were "nested" within different classrooms (Bryk & Raudenbush, 1992).

TerraNova Results

According to the first analysis, an average student from a control classroom would answer 45% of the items correctly on the TerraNova posttest. In contrast, a comparable student from the experimental group would answer about 49% correctly on the posttest, a statistically significant difference of 9% (see Figure 5). Another way to interpret the impact on test scores attributable to the Math-in-CTE intervention is *effect size*. Effect size can be thought of as the average percentile standing of the average treated (or experimental) participant relative to the average untreated (or control) participant. (Cohen, 1988). Here the average experimental class scored at the 71st percentile of the control classes.

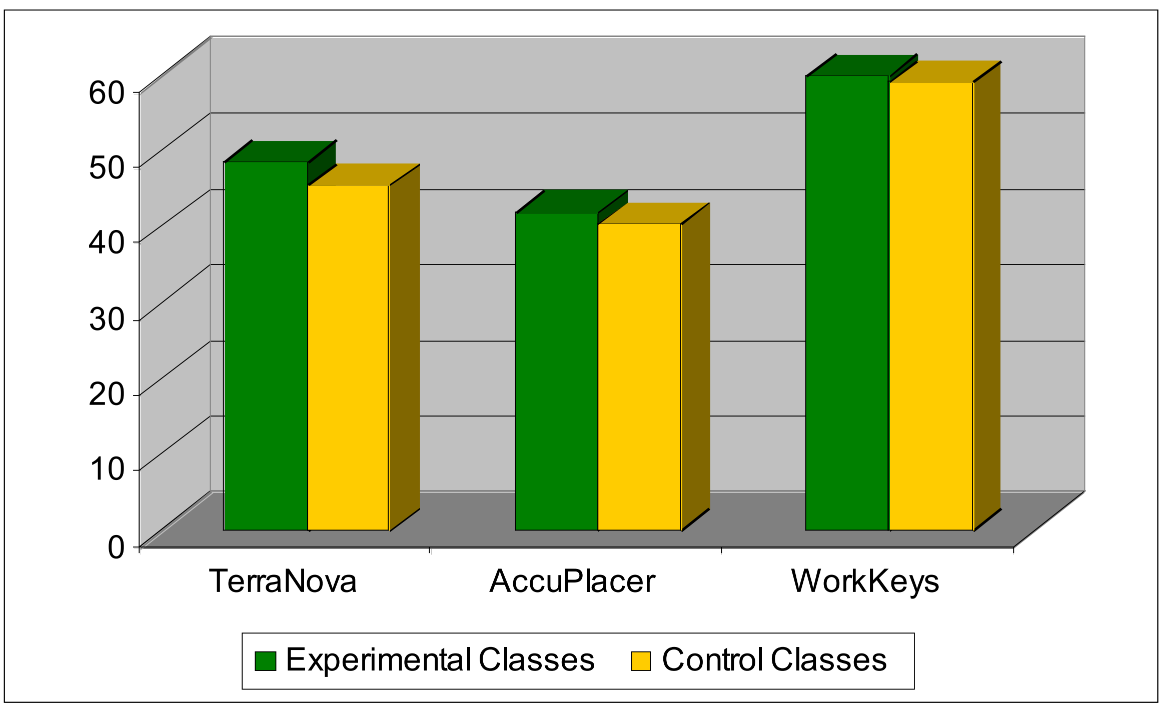
Accuplacer Results

According to the second analysis, an average student in the control group would have a mean Accuplacer posttest score of 39%. For a student in the experimental group, the predicted score would be about 42% correct or a statistically significant 8% increase. The effect measure for the average experimental class showed it scored at the 67th percentile of the control classes.

WorkKeys Results

Unlike the results for the other two tests, the WorkKeys scores did not vary significantly according to whether students were in the experimental or the control group. According to this analysis, a student in either type of classroom with an average pretest score would be expected to answer about 59% of the WorkKeys items correctly. While this is a higher%age of correct answers than was found for either the TerraNova or the Accuplacer, the difference between groups was not statistically significant. The inability of the WorkKeys test to detect an overall effect may be due to the level of math questions included, as indicated by the higher scores by both groups, or that the kind of math tested by WorkKeys was not addressed in all of the SLMP sites.

Figure 5. Average Post-Tests Percentage Correct for Experimental and Control Classes Controlling for Pre-Test Measures of Math Ability.



Technical Skills Results

Our final analysis addressed the third research question of this study: Does enhancing a CTE curriculum with additional mathematical instruction reduce the acquisition of technical skills and knowledge? Tests appropriate for each of the five occupational areas and provided by established test developers (NOCTI, AYES, and MarkED) were administered to the experimental and control students as part of the posttesting. Our data suggest that the intervention had no negative effect on the acquisition of technical skills or occupational content knowledge.

Conclusions

Based on these data, we conclude the following:

1. Students who participated in the math-enhanced CTE classes scored significantly higher than students in the control classes on a traditional measure of math achievement (TerraNova) and on a commonly used college placement exam (Accuplacer), though they scored about equally in a third test (WorkKeys).

2. Enhancing mathematics instruction in CTE classes can improve students' math understanding without any loss of technical or occupational knowledge.

IV. Beyond the Numbers: The Teachers' Experience with Math-in-CTE

Our qualitative results (from interviews and focus groups) suggest that, as a group, the CTE and math teachers described their participation in this study as a positive learning experience for themselves and their students. They commended the Math-in-CTE model as one that works—a model of "true integration," as one teacher put it:

> Ever since I have been in education, all I've heard is integration this, integration that. And I think, in this study, the math teachers and those of us in career and technical education realize this is true integration. None of us had seen it done [before].

While the teachers indicated that participating in the study was hard work and frequently frustrating, both the CTE and math teachers felt it was a worthwhile endeavor. The outcome was a model that CTE teachers found "do-able" and of observable benefit to their students. Many of the CTE teachers across the participating sites claimed that the model strengthened their overall teaching skills and the delivery of their CTE content, as described by this teacher:

> I got into the math thing to teach the math thing, but before long I realized that it was helping me teach what I had to teach. . . . Whenever I taught the math, it helped [the students] understand the technology better.

Teachers noted that participation in the study also opened opportunities for them to share the project with their peers and administrators, bringing positive attention to their programs.

CTE/Math Teacher Partnerships

The CTE and math teacher partnerships that were formed as part of this study were highly valued by the participants and considered essential to the success of the model. All agreed that the expertise of both the math and CTE teachers was needed to make this project work. Many of the teacher teams reported having to overcome some initial tensions and anxiety in working together, especially on the part of the CTE teachers, who often expressed a lack of confidence in mathematics. However, these fears dissipated and a mutual respect for each others' expertise emerged as they continued to work together.

Many of the math teachers described their participation as an "eye-opening experience" and valued learning about the CTE content and contextual learning. They also reported gaining real-world applications for their own instruction, along with an increased repertoire of answers for the students who ask, "Why do I need to learn this?" A number of the math teachers spoke of the burden they experience in preparing students for high-stakes math testing and expressed appreciation for their CTE teaching colleagues who now shared their concerns.

CTE teachers from all five SLMPs noted how essential the math teachers were to the success and credibility of the project in their schools. By the end of the full-year implementation, the teacher teams reported needing to meet less often because of the CTE teachers' increased confidence with the math and familiarity with the lessons, although they still expressed their need for the immediate and nearby support of the math teacher, especially to check the accuracy of their lessons or to get help in applying the math to the CTE.

Collaborative Engagement

The model used in this study emerged as a truly collaborative effort between the researchers and the teachers. As Louis and Jones (2001) argue, the involvement of teachers in the research process increases the chances of utilization of the research findings and increases the likelihood of future collaboration. Together, Center researchers and SLMP facilitators created a framework and facilitated a process that enabled CTE/math teacher teams to generate and implement the Math-in-CTE model. This level of engagement in the process created enthusiasm among the teachers; as one commented, "Just the fact that we were the ones heading this up, I think it made it kind of exciting to see what might happen with some of the things we had developed." Teachers reported that the structure of the professional development workshops and the pedagogical framework made it possible for them to work together effectively.

As the study progressed, the teacher teams and SLMP facilitators told the researchers that what they had gained from the Math-in-CTE model could not be reduced simply to a set of workshops and lesson plans, but that it was the process of working together that led to their positive results.

Teachers emphasized the need for those interested in implementing the model to be engaged in the "whole process from day one" with a math teacher partner and the full complement of professional development activities, including concept mapping. As one teacher observed, "The whole had become greater than its parts."

Others described looking forward to the collegiality of coming back together to share their ideas with and present their lessons to the whole group. One jokingly described it as "returning to the mother ship." The math teachers reported that they increasingly came to value sharing their math ideas with one another and the CTE teachers. A CTE teacher had a similar response:

> What was really interesting was when we began the professional development meetings, there were different math partners and we had all these minds thinking about these lessons. . . . The mixing of ideas as you're teaching the lesson is amazing—it's that diversity—it's coming back here every so many months and knowing how everyone else is doing.

The positive effects of this process of teacher teams joining with other teacher teams and developing collegial relationships while working with the lessons and math problems were neither planned nor anticipated when the study was initiated. Nevertheless, the emergence of these communities of practice was a welcome outcome with significant impact.

Success in the Classroom

The principle at the heart of this study was that the enhanced lessons should emerge from the math already embedded in existing CTE curricula. They were not intended as "add-ons" or special stand-alone lessons. Although the CTE teachers widely favored and supported the model, they often struggled to implement the lessons while still covering their established curriculum and fulfilling other responsibilities. While the participating CTE teachers were concerned about losing the integrity of the CTE content of their programs by adding too much math, they also believed that their students were benefiting from the experience, and for this reason, they did not give up on their efforts to enhance the math in their CTE courses.

The teacher teams felt ownership and pride in the lessons they produced for the study. Overall, the CTE teachers said that they enjoyed developing and teaching them. As one claimed, "Our lessons are absolutely awesome." A majority of the teachers reported they intended to use the lessons in the future, but planned to select those they use more carefully, customize others for a better fit with their curriculum, and even write new ones. The math teachers also planned to implement the examples and ideas they had gained into their own classrooms.

Both CTE and math teachers across the study sites shared many anecdotes of students who otherwise did not excel in math but were now "getting it" and even enjoying the lessons. One CTE teacher related one of her success stories:

> One day [a student] remarked that she was flunking math. I asked her why and what she was struggling with, because she did so well in the Math-in-CTE assignments. She said they were "different." I began helping her with her math assignments and related them back to what we had done in CTE. She started seeing the connections and now has an "A" in her math class.

The CTE teachers frequently reported initial resistance from students followed by breakthroughs in their learning, as this teacher described:

> Some of them moaned. But then later on they came to us and said, "Oh, thank you. We understand it now." . . . It made a huge difference to a lot of kids. Some of the kids in the beginning of the year said, "I can't do this, I can't do this." At the end of the year they said, "I get it!" That was great. I really liked that!

Challenges

While such success stories were widely reported, teachers also voiced a number of challenges and concerns. The CTE teachers continued to express their surprise at their students' lack of readiness in math. As lessons were being developed, NRCCTE researchers and SLMP facilitators stressed the importance of developing math-enhanced lessons at a level of Algebra I or higher. In practice, however, the teachers found that all too many students did not possess foundational math skills, such as measuring, multiplying, or understanding simple ratios/proportions. Teachers reported that they were not able to teach even the most basic algebraic concepts without remediation, which often made the lessons longer than planned and took time away from the CTE content.

At the end of the study, we asked the CTE and math teachers what they thought would be necessary for other teachers to successfully replicate the model in the future. Their most common response was that, as noted earlier, the model is a process, not just a package of lessons, and requires the engagement of the teachers. The model works, they reported, but it is hard work, and it will not work unless teachers want to participate.

The teachers stressed the importance of having dedicated time away from the demands of their school responsibilities in order to work together on the project. They observed that teachers, on the whole, feel overworked and are reluctant to leave their classrooms, so the effort to incorporate this new approach must be presented as something worth their time, both in terms of compensation and knowing that the effort will result in lasting and positive results for their students. The teachers also discouraged mixing teachers from different content areas in the workshops, indicating that "what worked" was a critical mass of CTE and math team teachers working together within the same SLMP. Teachers also pointed out that the partnerships worked best when the math teacher worked in close proximity to the CTE teacher, preferably in the same building, with common planning periods.

Most of all, both the CTE and the math teachers expressed a desire to see this effort continue. Having seen the benefits of the study for students and teachers alike, a math teacher reflected:

> I thoroughly enjoyed being a part of this process, and I feel very privileged that I was selected by my director and my CTE teacher to be a part of this. I made great friendships here. I've learned a lot, and I still have a lot to learn. I just think it's a wonderful thing. There's nobody that can convince me that this is not the way to go, because of seeing the results in my small little school.

A similar point was made by a CTE teacher:

> I have been in education for a few years and I've been involved in a lot of initiatives. This is the best one I've ever been involved in and the outcome has just been so positive. It's a great thing we did. But I get disillusioned with "this year's new thing and next year's new thing," you know what I mean? . . . It falls right through a hole. This is too good of a thing to let it just fall through a hole.

V. Moving Research to Practice

The newly passed Carl D. Perkins Career and Technical Education Act of 2006 continues to call for integrating academic and CTE curricula. In this study we sought to rigorously test the hypothesis that students enrolled in high school Career and Technical Education (CTE) courses who are more explicitly taught mathematics concepts already embedded in the CTE curriculum will develop a deeper and more sustained understanding of mathematical concepts than those students who participate in the traditional CTE curriculum. Our results supported our hypothesis: Using the Math-in-CTE approach for curriculum integration did in fact improve the performance of students on standardized measures of mathematical achievement, and it did so without negatively affecting the acquisition of occupational skills and knowledge.

Although we do not assert that this one modest intervention will result in students passing math exit exams or eliminate the need for remediation, the results do suggest that it is one way to help youth gain greater mastery of the math critical to their workplace success and post-high school education. While we believe that even greater benefits could be realized by adopting this approach within an entire CTE program of study rather than a single class, such a conclusion goes beyond the results of this study.

We also would like to note that the results presented in this report were achieved without the need for leadership or cultural change within the school, as opposed to what is commonly concluded from other school reform literature (e.g., Newmann, Secada, & Wehlage, 1995). Instead, the improved math performance of the students in the experimental groups was produced by assembling teams of teachers in an occupational area and providing them with a process and a pedagogy through which they could successfully enhance the math in their own curricula. Essential to the model was the ongoing teamwork between CTE teachers and their math partners in an authentic community of practice.

Implications for Practice

This curriculum/professional development approach holds great promise for substantially increasing the math skills of CTE students without negatively affecting their learning of occupational skills. To determine how to move the Math-in-CTE model from a successful experiment to common practice in CTE classrooms, we collected various kinds of data about the intervention in this study. The teachers who participated in the focus groups at the conclusion of the study were particularly helpful in identifying what worked and what did not. Drawing from multiple sources, we identified the following five core principles needed for successful adoption of the Math-in-CTE model, each of which will be discussed in turn:

1. Develop and sustain a community of practice among the teachers.
2. Begin with the CTE curriculum, not the math curriculum.
3. Understand that math is an essential workplace skill.
4. Maximize the math in the CTE curriculum.
5. Recognize that CTE teachers are teachers of Math-in-CTE, not math teachers.

1. Develop a Community of Practice

Obviously, teachers cannot teach what they do not know, and before working on these lessons few, if any, of the CTE teachers in the experimental group understood such mathematical concepts as order of operations, measures of central tendency, and using ratios to solve for unknowns well enough to explain them to their students. The professional development sessions provided both a structure and a supportive setting in which the CTE teachers could learn the math they would be teaching. This experiment demonstrated that a single CTE teacher working with a math colleague will be more effective than either teacher working alone, but if they can also interact with several others who are focused on the same objective, the effect is exponential. This is why communities of practice are critical to the success of the model.

Each of the teachers who participated in this experiment taught their CTE classes somewhat differently, and thus lengthy discussion, flexibility, and compromise were required to find common mathematical concepts that all teachers within a given SLMP could teach. But the teachers in this study were able to accomplish this, and the dialogue necessary to reach consensus as well as group support and critique produced a sense of ownership in the final set of lessons that emerged.

Obviously, if the math-in-CTE model is to be adopted, time must be provided for math and CTE teachers to engage in such a process, much like the Japanese practice of lesson study (Lewis, Perry, & Murata, 2006).

2. Begin with the CTE Curriculum

This study tested one of the primary claims of CTE: that relevance facilitates learning. However, in doing so, we also considered it essential to maintain the integrity of the CTE curriculum. Since its inception as a part of the high school curriculum, CTE has been linked to labor market needs. Relevance and links to the workplace are what attract many CTE students and provide the opportunity for engagement that they often find lacking in academic courses. For these reasons, we required that the math taught as part of the CTE courses should emerge from the existing curriculum, not be superimposed onto it.

Guided by the seven elements of our pedagogic model, each of the lessons developed for this study started with a specific occupational application and expanded to present the general mathematical concept inherent in that application. While the CTE teachers addressed math in depth, making its applications in CTE more explicit, they were still teaching CTE, not math lessons.

3. Understand Math as an Essential Workplace Skill

The most consistent message of the past two decades of educational reform is that high school students have not acquired the literacy and mathematical skills required for the United States to remain competitive in the world economy or, at a personal level, to qualify for a job with a family-supporting wage. Mathematics in such diverse applications as statistical quality control, computer spreadsheets, and global positioning technology (e.g., precision farming) has become a basic component of many jobs. Technological trends suggest that mathematics will become increasingly important to many occupations that require specialized preparation.

CTE courses have always included mathematics, but their teachers, who are not mathematics educators, often teach “tricks of the trade” without being explicit in addressing the math essential to the task. For example, students may learn the 3-4-5 rule to measure a square corner, but the source of this rule, the Pythagorean theorem, is not specifically mentioned. Such an approach addresses the immediate task but does not assist students in generalizing beyond the specific application. In contrast, the contextual approach that we tested with our Math-in-CTE model moves students successively from the specific to the general.

A mindset we sought to establish with CTE teachers who participated in the study is that math is a necessary tool in the workplace. Like any other tool, it has its place in the toolbox required to solve genuine workplace problems. The mechanic may reach for a wrench or Ohm’s Law to determine how to improve the performance of an automobile. For all CTE teachers, math is part of their curriculum because it is part of the workplace, a reality that they should share with their students. Students will need to understand mathematics in greater depth if they are to be prepared for the accelerating rate of change in jobs.

4. Maximize the Math

Understanding the CTE curriculum as rich with math, our fourth core principle is to encourage CTE teachers to maximize the math whenever the opportunity arises in the curriculum. We reasoned that the emerging communities of practice would increase the CTE teachers' understanding and comfort in teaching math. We encouraged them to go beyond these specific lessons and reinforce the concepts presented in them whenever they were teaching content that touched upon the underlying math. Maximizing the math also included constant and consistent bridging of the math and CTE vocabularies. The CTE teachers themselves identified the importance of moving back and forth from CTE to math terminology in modeling transfer and helping students make the link.

5. Train Teachers of Math-in-CTE

The Math-in-CTE model for curriculum integration does not attempt to make CTE teachers into math teachers, but it does yield expanded and improved instruction of mathematics in CTE courses. In our model, the role of the math teacher is to serve as a resource—a source of information and support. Discussions in the focus groups at each SLMP indicated that the process produced the intended result. Furthermore, several math teachers said that their participation in this study increased their understanding and respect for CTE.

The CTE teachers benefited from learning math in a collegial relationship. They were not "taught" math; instead they worked with an informed partner to improve their ability to teach math. They were motivated to learn this math because it was part of their curriculum.

Technical Assistance from NRCCTE

In response to the promising findings of the Math-in-CTE project*,* the NRCCTE has received multiple requests for assistance from those interested in learning more about this rigorously tested model of integration. Our intent is to make the Math-in-CTE model widely available for use in CTE classrooms across the country by providing technical assistance (TA) at the request of states or professional organizations.

This TA is grounded in the five core principles (described in the previous section) that emerged from the research study. Its overall goal is to implement the Math-in-CTE model in selected content areas, while building capacity in the state-level leadership team to carry on with future implementations. We hope to make state staff development integral to teacher professional development as an organic part of CTE improvement.

The NRCCTE provides a leadership team of facilitators, CTE and math teacher teams, and others who work together to deliver professional development. These TA teams are comprised of teachers and other seasoned educators who participated in the original research study. In addition to leading the workshops, the teams conduct meetings with state leaders to ensure that an infrastructure is in place to support full implementation of the model. For example, states or agencies are required to provide staff members who essentially serve as apprentices with the TA team for a minimal period of a year. In addition to learning the pedagogic model, these state/agency teams monitor and support the teachers through the year of implementation, oversee the testing of students, and collect data using scope and sequence charts and pre- and post-teaching reports.

In summary, the Math-in-CTE model is a sustained process of professional development that creates an environment of intellectual exchange among teachers. In order to ensure a vibrant and developing community of practice, states receiving TA are required to convene a critical mass of at least ten CTE/math teacher teams whose work is focused within the same CTE content area, such as construction, manufacturing, family and consumer science, business and marketing, health occupations, or automotive technology. Developing the ability of CTE teachers to implement the Math-in-CTE model in their classrooms requires a minimum of ten professional development days: five in the summer before school begins, two in late fall, two in early spring, and a final debriefing day at the end of the school year. This time allows for the development of curriculum maps, the creation of scope and sequence plans, the development and revision of enhanced lessons, and time for CTE teachers to practice teaching those lessons in front of their peers and their math teacher partners. Between the professional development workshops, the CTE/math teacher teams work together in their school settings, thus providing CTE teachers with continuous math support throughout the school year.

States or agencies are expected to cover the costs of the Math-in-CTE TA team (e.g., travel, stipends) as well as local costs associated with conducting the professional development. System-wide support for the teachers who will participate in the Math-in-CTE TA is imperative. Such support may include release time from school days, substitute pay, travel, and meal expense reimbursements. Contracting states/agencies are highly encouraged to provide incentives for participating teachers, such as college credit. In some states, local colleges or universities may be able to arrange this for participating teachers at low or no cost in partnership with the state department of education. States receiving Math-in-CTE TA are also encouraged to pre- and post-test students of participating teachers to measure the impact of the model in their schools. The NRCCTE is available to provide expertise in testing procedures and data analysis upon request.

NRCCTE researchers are also available to make presentations or conduct introductory-level workshops for policymakers, administrators, teachers, and others who are interested in learning more about the Math-in-CTE TA. These presentations and workshops are designed to provide a comprehensive overview of the model and generate awareness about the structural and procedural elements necessary to its implementation.

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