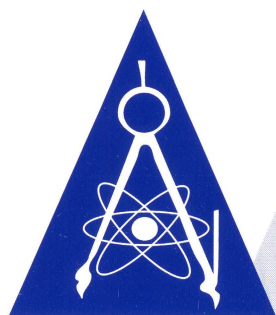


The Journal of Mathematics and Science:

COLLABORATIVE EXPLORATIONS

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Virginia Mathematics and Science Coalition

National Alliance of State Science and Mathematics Coalitions

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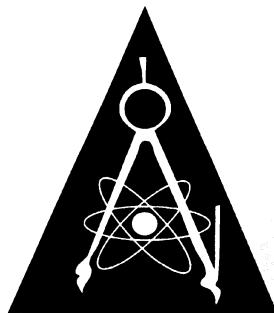
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ALGEBRA AND CALCULUS FOR ALL?

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Motivation for the paper

The motivation for this paper, "Algebra and Calculus for All?", comes from three different sources. The first is a longstanding belief that I have had, that not only do algebra and calculus play analogous roles in high school and college, but almost all the issues that apply to one also apply to the other.

The second source of the title came in June 1994, when I was asked to give a talk at a calculus conference in Ann Arbor, Michigan, sponsored by the Calculus Consortium centered at Harvard University. The rhetoric being used to discuss calculus reform at that conference was virtually identical to the rhetoric that we have been using in the University of Chicago School Mathematics Project (UCSMP) since its inception. I was struck by the similarity.

The third spur for this paper came in January of 1995, when Texas Instruments announced that, by the end of 1995, they would be selling a calculator that could do algebraic manipulation – dare I say "abstract" manipulation. The TI-92 does not only the manipulations one normally finds in algebra but also the manipulations found in calculus. There had been Hewlett-Packard calculators that did this. But the TI-92 is easier to use, and cheaper, though still not inexpensive.

This was not the first technology to make us wonder about the relationships between algebra and calculus. From the first function-graphing program there have been obvious questions of how much manipulation is necessary to graph a function, or to find its maxima or minima on an interval, two tasks that have been among the major reasons for studying calculus.

The Parallel Roles of Algebra and Calculus Courses

"Algebra" and "calculus" each have two meanings. Each is part of a large area of

mathematical thought - calculus is in the area of mathematics known to mathematicians as analysis, and algebra in schools is part of the field of mathematics that studies algebraic structures.

But these names also are strongly associated with specific courses, and I will first discuss the courses. These courses play parallel roles in high school and college in a large number of ways.

- a. They are fixtures of the curriculum; the first course; a sign of arrival.

Algebra is the first course in high school mathematics. If you take algebra before 9th grade, you are considered to be taking it early. If you do not take algebra in 9th grade, you are taking remedial mathematics. Calculus is the first course in college mathematics. If you take calculus before your freshman year of college, you are considered to be taking it early. If you do not take calculus as a freshman, you are taking remedial mathematics. Thus algebra and calculus are fixtures of the curriculum, fixed in time and place as the first year usually in a new school. They are a sign that you have arrived at a new level of schooling.

- b. They are prerequisites to a great deal of future work.

They are important fixtures. Algebra is the necessary precursor to the rest of high school mathematics. Whether or not you use much algebra in your geometry course, you must pass algebra to get into geometry. Calculus plays the same role for college level mathematics. You may not use much calculus in your abstract algebra course, but you won't be allowed in unless you have passed calculus.

- c. They are normally offered at a variety of levels of difficulty.

Not everyone goes on to take more mathematics beyond these courses. And so there have developed various levels. Honors level. Regular level. Basic level. Courses taught with rigor for the better students. Courses taught as drill and practice for the lower-performing students.

- d. They are filters.

If you are a student in the lowest of the levels, you are greatly handicapped if you wish to go on to take more mathematics. You do not have the prerequisites. If you do not perform well at the level you take, whether it be a high level course or a low level course, you will be

dropped a level. In these ways, both algebra and calculus act as filters. But they are different filters. No one wants algebra in high school to be a filter. On the other hand, calculus in college is used as a prerequisite to some majors simply to reduce the number of people who will take the major. Business majors in many places must take calculus, but many never encounter its uses while they are undergraduates even though calculus was required. Calculus is an overt filter; algebra is more covert.

e. It is normal for the courses to be taken one year earlier by the best students.

In 1955, the Advanced Placement program of the College Board began, and calculus began to be offered to the best students in 12th grade. At the very beginning, most schools tried to cram four years of high school mathematics into three so that they would have students ready for the AP exam, but after a while it became more popular to offer an 8th grade algebra course. Now the 8th grade algebra course for the best students is a fixture in most school systems. The latest evidence is that about 6% of students take a full calculus course in high school; about 20% of students are taking a year of algebra in 8th grade.

f. When given earlier, the course tends to be harder.

The AP Calculus course is not an easy calculus course. In many schools, the 8th grade algebra course is harder than the corresponding 9th grade course. There is a justifiable reason for this – the best students can handle such a course. But that means that many more students could take the course earlier if it were not made so difficult. We have ample evidence that average 8th graders can take algebra, and the best can do it at 7th grade. In some other countries, 7th graders normally study some algebra and 11th graders begin calculus. Although algebra in the 8th grade is being taken by an increasing number of students, it is still not standard practice. But it needs to become standard practice, because this is the only way that students have time to learn the statistics and discrete mathematics and other topics that they now should have before entering college.

g. Some people think that the ideas can be learned much earlier than this.

And there are those who believe even 7th grade is far too late. Henry Borenson touts his "Hands-On Equations" for 3rd, 4th, and 5th graders, the same grades in which Project SEED has been teaching algebra ideas for a couple of decades. And for many years I have had materials called "Calculus for Seven-Year-Olds", written by Don Cohen of Champaign,

Illinois. Thus, although the courses have fixed places in the traditional curriculum, there are many who believe that the ideas could be taught much earlier.

h. Hurdles are in place to discourage early work with the subject.

However, there are hurdles in place to discourage early work with the subject. When the student comes to a high school having had an algebra course, the student is examined closely. He or she is very likely to be given a difficult test with a good probability that the score will not be high enough to pass out of the algebra course. The school does not trust others to teach algebra. The school does not want to consider the fact that when you take a course from one teacher and then have to take a final exam months later written by someone else, you are unlikely to score as high as if you had taken the course from the exam-writer. The same situation applies in colleges. The colleges do not trust the high schools to teach calculus. A placement test is given that is not necessarily over the content of the courses students have had, and the results are used to justify not allowing the student to place out of a semester or two of calculus – and often used to put the student back a year or two.

The similarities I have mentioned between algebra and calculus have almost nothing to do with the content of the courses. Now let me move to the content, to the mathematics itself.

Parallel Views of the Content of Algebra and Calculus

We have been taught for all our lives, and our parents, and their parents were taught as well, two statements that we were to take as axioms about mathematics. The first was: *Mathematics is abstract*. And we have been taught that there are levels of abstraction. Algebra is more abstract than arithmetic. The concept of "variable" is viewed as a major step up from arithmetic, which is viewed as concrete. The concept of "limit" is viewed as a step up from algebra. Calculus is more abstract than algebra.

a. Algebra is more abstract than arithmetic; calculus is more abstract than algebra. This view of mathematics gives unsuccessful students an out. They can say that they learn concretely, that they are visual learners, that they need practical examples, and that mathematics just doesn't fit the bill. Because mathematics is abstract, we were also led to believe: *Mathematics is difficult*. And there are levels of difficulty.

b. Algebra is more difficult than arithmetic; calculus is more difficult than algebra.

The ideas about abstraction and difficulty are so ingrained in the psyche of many mathematicians and mathematics educators, that often when mathematics is not taught abstractly, or if it is taught so that students do not have difficulty, then it is not considered mathematics, or as good mathematics.

c. If algebra is not taught abstractly, then it is not good algebra; if calculus is not taught abstractly, then it is not good calculus.

d. If algebra is not difficult, then it is not good algebra; if calculus is not difficult, then it is not good calculus.

Those who are unsuccessful in mathematics can take refuge in their ignorance because mathematics is not supposed to be able to be learned by all. Those who are successful in mathematics bask in the glory of having succeeded where only a minority achieve success, wallow in the pride of having knowledge that only a few are granted the opportunity to acquire. Thus, as a consequence of this, society concludes:

e. Algebra is not for all students; calculus is for even fewer.

Because algebra is more abstract than arithmetic, many elementary school teachers avoid algebra entirely, and many high school teachers want it that way. They would prefer that a student come in without having had any algebra so that they can teach the student from the beginning. And so it is with calculus. The concept of infinite processes leading to limits is viewed by many calculus teachers as a very difficult idea. Calculus teachers are notorious for wanting high schools not to teach any calculus – not even introductions. And some high school teachers go along with this and do not introduce calculus ideas for fear of doing something wrong. A very common belief thus arises.

f. Introductory work in these areas without a full course is not wise except for the small percentage of very bright students.

An Alternate View of Algebra and Calculus

In 1623, Galileo wrote: "Philosophy is written in this grand book, the universe, which

stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth." (Galileo, *The Assayer*, 1623)

At the time of this quote, algebra was in its infancy, and analytic geometry had yet to be invented. There was no probability theory. The basic vocabulary and symbols of calculus would be first introduced about sixty years later by Newton and Leibniz. The $f(x)$ function notation, the symbol for π , and the abbreviations sin and cos would not come into the language until Euler over 100 years later. The invention of statistical displays – bar graphs, circle graphs, and the like – were even further in the future, and statistical theory was nonexistent.

The language Galileo wrote about was only a small piece of the edifice that today we call mathematics. The language available to Galileo described only part of the physical world. Today's mathematical language underlies financial dealings worldwide, describes a wealth of characteristics of all sorts of phenomena, is integral in high-speed communication through words and pictures, and models far more of the physical world than was available in Galileo's time.

All of my curriculum work, in which I first examined courses built around concepts of pure mathematics and mathematical systems, and later with applications of mathematics, has convinced me that mathematics is not inherently the most abstract of subjects, but made so; that it is no more abstract than English or any other language. It has also convinced me that mathematics is not inherently the most difficult of subjects, but made so; it is no more difficult than learning a new language. Furthermore, just as it is more difficult to learn a language when you are older, the very delays that we think make it more likely that children will succeed in learning algebra and later calculus make the subjects more difficult. But notice, and it is very significant, that the discussion now has turned from the *courses* of algebra and calculus to the *areas of mathematics* in which algebra and calculus are customarily the first courses.

What Have We Learned about Algebra?

Why do I feel as I do?

- a. Algebra starts earlier than its formal study, whether we want it to or not.

The equation $3 + \square = 7$ is algebra; the use of a square is no different than the use of a letter. So 1st or 2nd grade students do algebra problems, we just don't tell them—perhaps because we don't want to scare the teachers. For many decades, formulas like $I = prt$ or $A = \pi r^2$ have been studied prior to algebra. And now almost everyone introduces students to graphing, to equation-solving, to properties like the distributive property, before the formal course called algebra.

- b. The use of applications concretizes algebra, motivates it; makes it easier.

We know that algebra can be approached theoretically, such as through field properties, but this approach does not work with many students. On the other hand, we also know that we can approach algebra through formulas, and through generalizations of patterns, and that this approach does work. It isn't automatic, it doesn't come in one day. But situating the algebra in contexts which give reasons for studying the subject at the same time that they illustrate the concepts changes one's view of algebra forever. I know there are many here who could not return to the way they used to teach algebra.

- c. We have found no age cut-off with respect to the learning of variable.

We should not have been surprised. Variable is supposed to be an abstract concept, but variables are introduced quite early in some countries' curricula, such as Russia, and seem to be easier to learn early. Is the use of a letter such as A for area or x for an unknown any more abstract than the use of the symbol p for the sound "puh"? Surely there is an age cut-off; babies will not learn variables. But at the secondary level, from grade 6 or 7 up, it seems that the earlier the better.

- d. There *are* prerequisites to learning algebra.

I do not wish to be interpreted as believing that you can just go in and learn algebra. If a symbol is to stand for a number, as variables usually do, you have to know something about numbers. You have to know that a number can be represented in many ways, that 6 can be written as $\sqrt{36}$ and as $\frac{12}{2}$ and as 6.000, and that if $x = 6$, then x can be written in any of those ways, too. You need to know what it means for one number to be close to another

in value. If you have the expression $x + y$, you need to know what the $+$ sign means independently of what the numbers x and y are. We should work on these meanings before the concentrated study of algebra because such work is necessary for success in algebra.

e. The distinction between arithmetic and algebra is often hard to make.

Suppose you are working with a spreadsheet. You instruct the computer to take the numbers in cells A2 and B2 and put the sum in cell C2. So you write $=A2+B2$ in the cell C2. Are you doing arithmetic or algebra? Technology has blurred the distinction between the two. While working with spreadsheets and graphics technology, students use algebra without realizing it.

The distinction was blurred, however, well before there were computers. Consider any ABC. Is A a variable? It is in the sense that it may stand for any point. But we think of it as a specific point because it is such a familiar idea.

When I studied algebra, plotting points on the coordinate plane was considered algebra. So was any work with negative numbers. We never did one day of that work before algebra. Yet we have found graphing and negative numbers to be easy when it is contextualized, and so we are comfortable today not calling it algebra. Thus virtually all middle school or junior high school students are learning algebra today, whether or not they take a formal course with that name. Thus we must conclude:

f. Virtually all students can learn algebra.

Does What We Know about Algebra Apply to Calculus?

Do these statements and does this conclusion apply to calculus? Could we replace "algebra" with "calculus" in the statements above? True or false?

- Calculus starts earlier than its formal study, whether we want it to or not.
- The use of applications concretizes calculus, motivates it; makes it easier.
- We have found no age cut-off with respect to the learning of limits.
- There are prerequisites to learning calculus.
- The distinction between algebra and calculus is often hard to make.
- Virtually all students can learn calculus.

Let us take the statements one at a time.

The first introduction to limits that students see is certainly not in calculus. Infinite decimals involve limits. In geometry, students see limits of inscribed and circumscribed polygons for approximating π . For volumes, there is Cavalieri's principle which suggests the idea of finding volume by summing very thin slices. The volume of a sphere is the sum of the volumes of infinitely many pyramids. There are the successive approximations of solutions to equations, and of course there is rate of change. So the ideas of calculus start earlier than its formal study, whether or not we want that to be the case.

Most newer calculus projects make strong use of applications for exactly the same reasons that we use applications in all of our secondary school mathematics courses. The authors of these materials know that calculus can be approached theoretically such as through ϵ - δ definitions, but they also know that such an approach does not work with many if not most students. The use of applications does concretize calculus, motivate it, and make it easier to learn.

There are prerequisites to learning calculus. Students must be familiar with slope and rate of change from algebra; with area and volume formulas from geometry; with summation notation; with function notation. They must be able to chunk algebraic expressions so that they think of $f(x+h) - f(x)$ as a single number, and not as some undecipherable expression. And very importantly, they must learn to think of a function as a single object that can be represented in various ways, for instance, by a graph, by an equation, by a rule. They must be able to distinguish the function f from its values $f(x)$.

Technology has blurred the distinction between algebra and calculus. Suppose you are asked to determine the maximum point of the function V , where

$$V(x) = x(20 - 2x)(24 - 2x).$$

Some of you may find this function V to be familiar. It is the volume of the rectangular surface formed by cutting out squares of size x from a 20 X 24 rectangle, and then folding up the sides. If you use the trace function on an automatic grapher to estimate this maximum, are you doing arithmetic, algebra or calculus? There is an algebraic expression which is being evaluated, but the grapher is doing the calculation automatically, and all you see are the arithmetic values. Yet you are working on a calculus problem.

All algebra teachers in all algebra courses have students who solve algebra problems

without doing formal algebra. They use arithmetic. So it should not surprise you that calculus problems can be solved without formal calculus.

In the algebra of even a decade ago, we might have multiplied the three factors of $V(x)$ to represent $V(x)$ as a polynomial so that we could differentiate V with respect to x more easily. But if we can find the answers to max-min problems without formal differentiation, we don't need that manipulation. Even before the existence of a symbol manipulator, the technology took away our motivation to do some of the manipulation in algebra.

But you do not need to be using computers to not know whether you are doing calculus or some other subject. When calculus ideas are used in geometry, or infinite sums are shown for an infinite decimal, the ideas of calculus lurk but few students realize it. And we have found no age cutoff with respect to those learnings.

Can all students learn calculus? It is hard to believe they can't, if the approach is reasonable. Should all students take the course called calculus? That is a different question, one beyond the scope of this talk.

Algebra/Calculus K-12 and the Question of Integrated Curricula

Today, as soon as one mentions the algebra *course* to some people, they cringe. Mathematics knows no strict boundaries, they say. There should not be a full year devoted to algebra. People have said this about calculus, too.

As many of you know, I have either authored, co-authored, or actively edited virtually every page of the UCSMP texts and teacher editions. Before UCSMP began, I had authored or co-authored four texts for each of the years of high school. All these courses tended to integrate areas of mathematics that were previously often separated: the integration of transformations and matrices into algebra and geometry; the integration of applications into all courses; the consideration of both algebra and geometry in the first four UCSMP courses; the combining of functions and statistics in *Functions, Statistics and Trigonometry*; the interplay of the discrete and the continuous in *Precalculus and Discrete Mathematics*.

Yet I have been uneasy with those who believe that our curriculum should be

decompartmentalized. One reason I have been uneasy is that I believe the courses I have worked on to be more integrated than many of the curricula that other people call integrated, including the curricula of Japan or Russia or the curricula written to follow the New York State Regents exams. To me, an integrated curriculum must have connections not only within lessons and chapters and units, but also between and among the units. One of the major developments in mathematics early in this century was the demonstration that all mathematics, from arithmetic to geometry, from sets to calculus, could be considered as part of one logical system. Consequently, covering a bunch of unrelated mathematics topics in a given year without relating them is not integration, but disintegration. It destroys one of the most basic principles underlying the field of mathematics.

Still, there is an important reason for not having the traditional one-year algebra course. The most powerful argument against the *traditional* year course in algebra is that only the best students really understood what they were doing when they finished. Almost no country in the world tried to do what we tried with first-year algebra; that is, to take students from a position of almost no familiarity with the subject to become familiar with some of the most complicated aspects of manipulation of the symbols – all in a single year. This practice does result in failure for a significant number of students. But we have learned how to avoid most of the failures:

- (1) Introduce students to the main ideas of algebra well before making them central in a course.
- (2) Develop algebraic ideas in context, not as symbols without meaning.
- (3) While concentrating on algebra, involve all other mathematics both as motivation for doing the algebra and as avenues for application.
- (4) Do not expect the most difficult ideas to be learned in one year but return to them again and again as often as needed.

The first three of these were not characteristics of the traditional way in which we approached algebra. And, in many schools, these principles are still not followed. If you have that traditional view of how algebra is taught, you are correct to want to change it. In our work with UCSMP we have tried to follow all four principles.

And, in the UCSMP curriculum, we have applied these principles to calculus. The main ideas of calculus are introduced over six years. Some of the other new curricula are beginning

to do the same. The following concepts are those which need to be done over a minimum of three years:

Idea

Inequality

Distance with coordinates

Area

Rate

Infinity

Rate of change

Sequence

Function

Limit

Areas on coordinate systems

max-min

Σ

And these two topics should be introduced at least once before the study of a formal calculus.

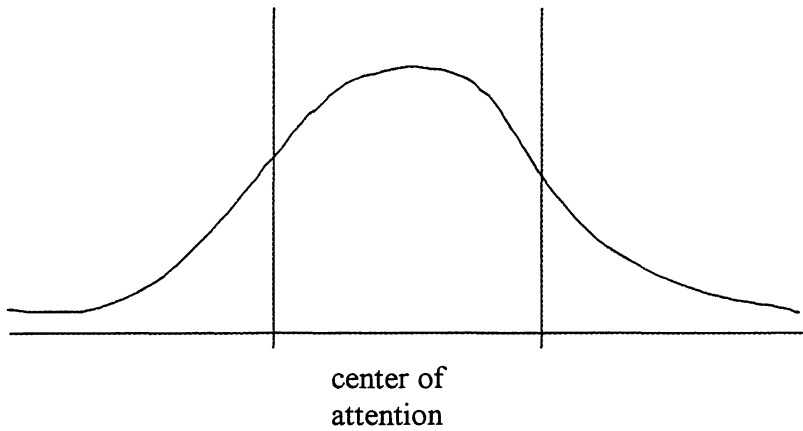
They are too important to delay:

derivatives

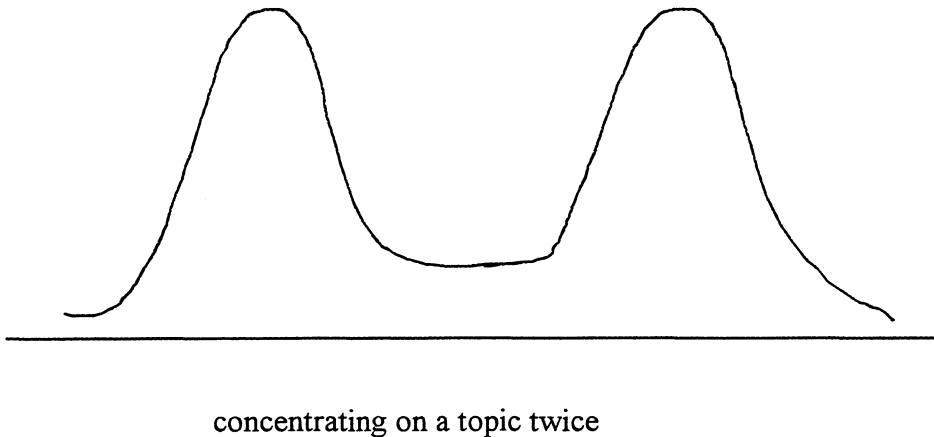
integrals

Virtually all of these ideas should be developed in context, and except for the derivative and integral they should be developed more than once before the student studies a formal calculus course. I think this is an optimal way to approach to prepare students for calculus.

In general, one might say that the normal approach is the best approach for studying an area of mathematics. The area should have a time when it is the center of attention, but both before and after that it should be examined, too.



There is a moral to this for calculus. The present-day year-long or 1.5-year-long calculus course is unwise if students have none of the course before. But, if attention is given to the major concepts in many of the preceding years, then it is a good idea to put all those ideas together, synthesize them, show how they are all related.



Algebra is so important that it is customary to concentrate on it twice, in a first year

course with major thought to variables in expressions, and in a second year course with more attention to expressions in functions. A bimodal normal curve represents this approach. In this approach, we don't give up algebra in between the modes, or before or after the years in which there is concentration. I think that some of the newest integrated curricula agree with this idea, but want many more modes – perhaps one mode for algebra each year. Maybe calculus should be done that way, too. The jury is out on this.

Regardless of your view about integrated curricula, the best approach is to develop an area over many years. Then, when the time is ready, the area should be studied in some detail so that all of those ideas that were done separately over the years can be seen as related to each other, so that logical connections can be made, so that students can see what is known and what is not known about the area, what problems are simple, and what problems are quite difficult. While this is being done, other areas should not be neglected. Calculus and geometry and probability and statistics are passengers on the algebra train, but when the calculus train comes, it needs its own passengers – some algebra, geometry, probability, and statistics from earlier years, but also differential equations, complex variables, algebraic structures that students might encounter in later years. Students' lack of early exposure to these later topics in early undergraduate mathematics is surely one of the reasons for student difficulty with them in later undergraduate mathematics.

As an aside, all of this applies to geometry. To introduce geometry with a full-year course is silly. It takes a while to learn concepts like measurement, similarity, congruence, and transformations. That is why a good curriculum pays strong attention to geometry both before and after the one year in which geometry is the centerpiece. That attention is absolutely necessary if you wish students to perform well.

The Question of Manipulative Skill

So far, this analysis of algebra and calculus has dealt primarily with the properties, uses, and representation dimensions of understanding mathematics, what some people have called the conceptual understandings of mathematics. Now let us turn to the question of manipulative skill.

We cannot ignore the availability of symbol manipulators. To do so is like ignoring

available paper-and-pencil algorithms. By a symbol manipulator, what I mean is technology in which you can input $ax = b$ without specific values for a and b , and get $x = b/a$ as output; in which you can put two rational expressions to be added, subtracted, multiplied, or divided, and get the sum, difference, product, or quotient in lowest terms as output; in which you can input a polynomial of virtually any degree and get its factored form either over the rationals, reals, or complex numbers as output; in which you can input an equation for a function and get its derivative as output; in which you can input a definite integral and obtain its value or input an indefinite integral and obtain an expression for it. Symbol manipulators were available on large mainframes even 20 years ago; they became available for smaller machines in the early 1980s; they became available in user-unfriendly form on calculators at least a half-dozen years ago; and now they have become available in user friendly form.

Many of the skills in algebra are important regardless of the later mathematics one wishes to study. Squares and square roots are found in geometry and statistics and physics. Linear and exponential equations and functions are found here, there, and everywhere, as the song goes. Applications can be found for polynomials, too, and we have them in our books. And there are applications of rational expressions and rational functions, but not as many of these, and they are not so elementary, so we should not teach them in first or second year algebra but delay them until the year before calculus. But much of the manipulation that has been in traditional algebra courses has nothing to do with these kinds of situations; it is manipulation contrived so that the student can do the further contrived manipulations that will be encountered in calculus. As an example, consider this question from a traditional algebra course:

$$\text{Simplify } \frac{x^2 - 5x + 4}{3x^2 - 13x + 4}$$

Why was it in traditional courses? Mostly because years later students might encounter the following question in a calculus course:

$$\text{Find } \lim_{(x \rightarrow 4)} \frac{x^2 - 5x + 4}{3x^2 - 13x + 4}$$

At the time of calculus we might argue that a student ought to be able to factor a quadratic by hand, but that does not give much reason for doing it in first-year algebra. When we built our curriculum we could not justify this kind of manipulation until the pre-calculus course.

When studying rational functions, there is for the first time more than a contrived reason for having such manipulation.

But it's not clear to me that students of the future need to be able even to do this kind of manipulation by hand. The purpose of the calculus exercise is not to factor the numerator and denominator; it is to notice that there are ways to analyze limits even when both numerator and denominator of a fraction are 0 at the limit. Once we know that, we can ask technology to do the factoring. The advantage of asking technology to do the factoring is that we concentrate on the idea rather than on the technique, on the end rather than the means. Without the technology, we may feel limited in the types of expressions that can be dealt with by this technique. The technology shows us the power of the technique.

One of the interesting things that technology does is make us aware of techniques that we may have not have ever been taught, or if taught, we may not have mastered. We can obtain partial fractions with ease whenever we wish and now ask the important question: why do we want partial fractions? Many students learn to separate out a rational expression into partial fractions, but have no idea why they are doing that. It is no different than a student who struggles with long division and then, after mastering the algorithm, is not able to recognize the situations in which division is needed. No student should leave an algebra course without being able to recognize situations in which algebra is appropriate. An adult of the future might ask: Why did *I* take algebra? But no adult should ever ask what algebra is good for.

The appearance of inexpensive technology that does algebra – and we do expect that the technology will become cheaper – will enable us to concentrate even more on the whys of mathematics. We will be able to teach students why algebra is important and why calculus is important without being burdened by the need to teach them how to deal with every expression or function. And we will no longer have to say that you have to learn this or that paper-and-pencil skill because it is needed for calculus.

We must not forget that to the general populace today, complicated algebra and even easy calculus are viewed as the province of an elite minority of society. Will you tell your friends that you went to a conference to learn about the teaching of algebra, geometry, statistics, and calculus? You know what many of your friends think. Either they view you as a genius or

they view you as weird. Take heart in that this is the way that people who knew arithmetic were viewed 500 years ago. The technology algorithms make algebra and calculus automatic just as our long multiplication and long division algorithms have made arithmetic automatic, and they will in the long run cause algebra and calculus to be available to all, and much less threatening.

Messages

What are the messages for the algebra student and the algebra teacher of today? The first is that algebra is a language with a set of skills, properties, uses, and representations that is not learned in a single year or two. Like other languages, it takes many years to become fluent in it, and even students who have studied it for four or five years may not achieve that fluency. Learning the language should start in elementary school, even by 6th grade you are still at the early stages, in *Algebra* you first visit the country in which this language is native, in *Geometry* you apply that language, in a second year of algebra you revisit the country, and then in pre-calculus and statistics and discrete mathematics and throughout your study of mathematics and its applications you use this language, continually learning more about it through your use.

The second message is that when you concretize algebra, when you and your students discuss its applications, when you discuss it at all, you are transporting your students into the land of algebra in order to make them more fluent in the language. But if you just treat the subject abstractly, without context, then you are acting as if algebra is a dead language, and then there is no land to which you can now transport your students.

The third message is that students must learn how to use today's technology, just as they learned how to use yesterday's. Yesterday's technology included the use of tables for squares and square roots, logarithms, and trigonometric functions, and all sorts of algorithms for rewriting expressions and solving equations and inequalities. Today's technology incorporates the tables and has new algorithms. Yesterday's technology is much more difficult to use than today's, but today's is not trivial. It too has to be taught.

Today's symbol manipulator technology acts like a dictionary for the language. It tells which expressions mean the same thing. It indicates synonyms for complicated expressions,

and because we are dealing with mathematics, you have the opportunity to show how one creates synonyms. Learning a foreign language is very difficult if you have no dictionary because people keep using words you do not understand and because you are always unsure of how certain words are spelled. In an analogous way, the technology will help students learn algebra. The interesting outcome from having so much technology around is that our courses become simultaneously both more conceptual *and* more applied.

There will be teachers who don't want their students to have the technology. They will say that the student no longer has to work, that the student no longer has to think. They do not understand that, like any language, algebra exists for many reasons, and the purpose of teaching algebra is so that students can communicate, reason, and problem-solve in the language, not so that they can find synonyms or learn to spell. Obviously students should not have to look up every word in the dictionary, but they must learn how to use the dictionary.

The fourth message is that the previous messages also apply to the learning of calculus. When we teach inequalities, distance, area, rate, infinite decimals, slope, sequences, functions, limits, summation notation, maximum or minimum problems, we are engaged in the first stages of the learning of calculus. We should not shy away from making the connections, because the learning of calculus also requires many years for its fluency. And we must use the technology.

The fifth and last message is that, with these new developments, for the first time it is reasonable to believe that the ideas of algebra and calculus *can* be learned by virtually all students. But no person will believe that these ideas *should* be learned by all students unless he or she is convinced that the subject is important enough to warrant such a hallowed position in the schooling of students. Both the natural universe and that part that has been made by humankind may be written in the language of mathematics, but if we mathematics teachers do not teach the connections to that universe, we cannot expect others to do it for us. The developments of the last generation are a challenge to all of us, but they make the teaching of mathematics in this generation as exciting as it ever has been, and for the first time they have made the important ideas of algebra and calculus accessible to all. ■

An earlier version of this paper was presented at a talk with the same title given at the annual meeting of the National Council of Teachers of Mathematics in Minneapolis, April 19, 1997.

SHAPING THE FUTURE OF TEACHER PREPARATION IN SCIENCE AND MATHEMATICS

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Recently, I spent an exciting hour with a group of elementary teachers who had won national awards for excellence in teaching science and mathematics. It was energizing to visit with them about their work - and it was very reassuring to know that they are out there in those classrooms getting young people excited.

I was there to make a brief presentation about the National Science Foundation (NSF) report on undergraduate education in science, mathematics, engineering, and technology (SME&T), *Shaping the Future* [1], developed by an NSF review committee that I chaired. In particular, I asked for their suggestions about how to improve undergraduate programs for prospective teachers. A major emphasis of the report is on teacher preparation, and, in the months since the report was issued, I've become even more persuaded that teacher preparation is a vitally significant aspect of undergraduate education that is too often treated as a stepchild by institutions of higher education. So, I sought the advice and suggestions of these excellent elementary teachers.

They responded with enthusiasm, and with considerable criticism of the usual teacher education programs. One of their major messages was that prospective teachers must get out into real classrooms, with real master teachers, much earlier and much more often than is normally the case. They essentially said that being taught in college classrooms how to teach children was not effective. I wish I had been able to have the benefit of their experience and to have similar encounters with other fine K-12 teachers during the months that *Shaping the Future* was being drafted, as the report would doubtless have been even stronger and clearer about changes that must come in the preparation of those who teach science and mathematics to our young people.

Charge to the Committee

The first NSF report on undergraduate science, mathematics, and engineering, issued in 1986, (the "Neal Report," named for Homer Neal, the chair of the committee responsible for the report) was directed almost exclusively to the program for preparation of majors, particularly those who were heading for graduate school and eventually a PhD in a SME&T discipline. When Luther Williams, Assistant Director of the NSF for Education and Human Resources, initiated the review that led to *Shaping the Future*, he was explicit about our charge. The purpose of the review was to "consider the needs of all undergraduates attending all types of two- and four-year colleges and universities," addressing "issues of preparation of K-12 teachers in these fields, the needs of persons going into the technical work force, the preparation of majors in these areas, and the issue of science literacy for all."

In the process of developing *Shaping the Future*, the review committee solicited written opinions from some 150 faculty, administrators, professional society officers, and corporate executives about the state of undergraduate SME&T education in the mid-1990's. We also had oral testimony provided by panels of faculty from the various disciplines, of college and university administrators, and of employers (including one school superintendent who employs hundreds of new teachers every year). The opinions of the SME&T community about teacher preparation in these fields are reflected in *Shaping the Future*, which summarizes them as follows: "Many faculty in SME&T at the postsecondary level continue to blame the schools for sending underprepared students to them. But, increasingly, the higher education community has come to recognize the fact that teachers and principals in the K-12 system are all people who have been educated at the undergraduate level, mostly in situations in which SME&T programs have not taken seriously enough their vital part of the responsibility for the quality of America's teachers. The Neal Report devoted one brief sentence to teacher preparation, for example (though much more to teacher enhancement). But, virtually every participant in the review work of this committee has expressed concern over the way the undergraduate SME&T education community is working in the preparation of teachers."

Teacher Preparation

It seems obvious to me that the undergraduate community should be concerned about the effectiveness of its teacher preparation programs as an important part of its responsibility to the general society it serves. But I also believe that higher education has an inherent

self-interest in the quality of K-12 education. As our report points out: "With a more intensive and effective commitment on the part of institutions to the preparation of K-12 teachers, colleges and universities can raise their expectations about the preparedness of entering students. One way to do that might be for institutions to enter into "treaties" with the secondary schools providing that, after a certain date, credit will not be given at the collegiate level for remediation in SME&T."

SME&T departments have in the past usually played a more active role in the enhancement of teachers already out in the field than in teacher preparation programs for current undergraduate students. This generalization is doubtless too broad, as most generalizations are. But NSF summer institutes for teachers and other programs, such as MAT graduate programs, have been important means by which SME&T faculty and departments have become involved in K-12 education. Such enhancement programs will continue to be important means of helping teachers learn new content materials, curriculum ideas, and pedagogical methods. Professional development for teachers will continue to be of great importance in maintaining and strengthening quality elementary and secondary education.

But my colleagues and I on the review committee for *Shaping the Future* were persuaded that unless increased attention is paid to the quality of the undergraduate program for prospective teachers, we will never hope to be able to mount a sufficiently comprehensive enhancement program to keep up with the need. That is, we must do more to "turn out" a quality product at the beginning - and then we can do what is needed to help those quality teachers stay current, excited, and growing in knowledge and ability.

Key Recommendation

The overarching recommendation of *Shaping the Future* is key to thoughtful examination of teacher preparation programs in particular. That recommendation is that:

All students have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and all students learn these subjects by direct experience with the methods and processes of inquiry.

We must examine each of the two phrases in this central recommendation. The first calls for education that is both excellent and supportive. For my view one of the best validated pieces of educational research is that students tend to learn at the level they are expected to learn. There have been many experiments demonstrating the "Cinderella effect", that if teachers believe that their students are capable of learning and convey that expectation to the students, presenting challenging material to them, the students will generally learn more than if they are taught in the context of lower expectations. Not only does the kind of preparation students need for life in the 21st century require excellence of education; the expectation that students will excel is likely to result in increased learning as well.

But SME&T education must also be supportive. *Shaping the Future* includes lots of feedback from students and others about the intimidating nature of instruction in most SME&T courses. Most of us recognize that too many SME&T departments take pride in how many students fail their courses, in how "tough" those courses are. It is almost as though many faculty believe that high expectations are incompatible with caring, nurturing, and supporting the learning of students. I disagree. Science and mathematics are hard, and students come into college courses in these fields with a lot of baggage of past bad experiences, failures, and fears. Those faculty who teach these courses should recognize these concerns and do everything possible to meet the students where they are, without lowering reasonably high expectations.

Our central recommendation has a second part that is also important. I introduce this topic with a story. I once attended a meeting in Minneapolis with Bruce Alberts, President of the National Academy of Sciences. At the meeting were several teachers and administrators from public schools, present to discuss science and mathematics education in K-12. One of the major topics was the need to incorporate inquiry and discovery into science and mathematics. One kindergarten teacher remarked that she had been teaching kindergarten for 25 years and had used "hands-on" methods in her teaching for the last several of those years. "But it was not until last summer," she continued, "when I had an opportunity to work for several weeks in a faculty laboratory at the University of Minnesota that I ever understood what 'inquiry' meant."

It is a major failing of our SME&T education system, I believe, that students are not

generally led to understand that doing science and mathematics involves asking questions. SME&T is more than giving answers to already-researched questions. As a result, most people in society have little idea what is involved in research and do not understand what a scientist means when she says something is "true". There is little appreciation that advances in science and mathematics are in large measure cumulative, so that results that seem "useless" at the time may be vital links in finding a very practical application at some point in the future. Several years ago, for example, coral reefs were being decimated by an invasion of the crown of thorns starfish, leading to very deleterious effects on various fish populations. Scientists at the time knew very little about this starfish and so were not able to suggest effective means of control. I wondered at the time what people would think about a grant from the NSF to a biologist to study the sex life of the starfish; yet, the knowledge gained from such a study might have been of great utility to the fishing industry.

Shaping the Future notes that there has apparently been a decline in the offering of laboratory-based courses at the undergraduate level, probably as a result of departmental decisions about budget reductions in the face of financial constraints. But our recommendation about the necessity to incorporate the "methods and processes of inquiry" into our courses is not the same as recommending more laboratory courses. Far too many of our laboratories are of the cookbook variety, in which students follow step-by-step instructions designed to reproduce a long-understood phenomenon. In too few cases are students given the opportunity to formulate questions and construct experiments in order to examine possible answers to those questions. As a mathematician, I particularly regret that almost never in courses before the graduate level are mathematics students given an opportunity to create conjectures and try to decide if they are actually provable theorems.

All you have to do is to think about how many people misunderstand the word "theory" - as in "Theory of Evolution" - in order to see how we have failed, as educators in science and mathematics, to help people learn what our disciplines are really about, what scientists do and how they do it. It is far more important for the non-specialist to understand the methods - and limitations - of science and mathematics, the nature of scientific "truth", and how to interpret scientific claims in daily life than it is to have memorized the periodic table of elements or to have learned all the vocabulary in an introductory college text in chemistry.

This major recommendation of *Shaping the Future* - that all students have excellent and supportive educational programs that incorporate the methods and processes of science - has a lot of implications for teacher preparation. First, courses taken by the prospective teachers themselves (who are certainly included in "all students") should have these characteristics. One of the most important things for SME&T faculty to keep in mind is that future teachers of science may be more likely to teach science in the same way they were taught than they are to teach in accord with the pedagogical principles they were taught. For instance, to have a course in methods that stresses inquiry learning in biology may not overcome the influence of several courses in the biology department that were taught in a lecture mode, with emphasis on memorization and incorporating routine follow-the-instructions laboratories. SME&T faculty should be aware, as they teach many introductory courses, that potential teachers of their field are learning from them, not only disciplinary content facts, but also how to teach.

But in addition to influencing the courses for prospective teachers, the *Shaping the Future* recommendation must also apply to what prospective teachers are taught about their role as educators. Their preparation should help them in very practical ways understand how to nurture inquiry and discovery in children without sacrificing rigor or content. It should make them as ready to excite students about science learning as to solve the quadratic equation. We who are in SME&T fields likely got here because we found our field exciting; perhaps some particular teacher or teachers led us to delight in this kind of learning and discovery. We, in turn, should help all our students - and especially those who are going on to teach others - rekindle that sense of delight. *Shaping the Future*, quotes a columnist in The Washington Post, Steve Twomey, writing about the first birthday of his son, Nick. "My son tries to pick up holes ... He tries to pick up shadows, too. There is nothing he won't try to pick up, because there is no such thing as an uninteresting object, and I'm really kind of jealous. Nick has a full sense of wonder, and I don't anymore." I believe that we must nurture that innate sense of wonder as we prepare teachers of science and mathematics.

Other Recommendations

Shaping the Future contains many more specific suggestions for improving teacher preparation programs as well. These include:

To state governments and statewide higher education boards

Collaborate with external accrediting agencies to make strengthened science, mathematics, and technology standards for K-12 the norm in accrediting teacher education programs.

Teacher education programs must prepare prospective teachers to use, comfortably and effectively, national and state standards in science and mathematics. This means that faculty in higher education must be familiar with the standards in their fields and incorporate them into their courses as appropriate.

To college and university governing boards and administrators

Create or strengthen an institution-wide commitment to the preparation of K-12 teachers and principals, bringing together departments of education, SME&T and other departments, K-12 staff, and employers of teachers to design and implement teacher preparation programs having substantial SME&T content and stressing rigorous standards, along with emphasis on engaging students in learning.

There is a lot here I want to comment on. First is the stress on teacher preparation as an institutional priority. On too many campuses, such programs are viewed as the responsibility of the department or school of education, usually on the periphery of institutional awareness and having low prestige and priority. But the preparation of teachers involves - among others - departments of mathematics, chemistry, English, and history. To help a person become a teacher of content who can excite and nurture a young mind and who is committed to human development as a high calling seems to me a very interdisciplinary undertaking, eminently worthy of institutional commitment at the highest levels. Think what it would do for teacher preparation programs to have the governing board and the president lift up this area as a major responsibility of the entire university, a central aspect of the institution's service to society.

Second, note that we include principals as well as teachers. I believe that the principal in a school sets a tone that is very important in determining the amount of learning that goes on. We need to help prospective (and in-service) principals understand how to create the kind of climate that empowers teachers and nurtures students.

Third, note the emphasis on "bringing together." There is, on nearly every campus, far too little meaningful conversation between SME&T departments and those in education. There is seldom any joint discussion of what prospective teachers need, how to make content and pedagogical principles work together, and how to assess the readiness of students to be good teachers. Even beyond this kind of faculty and departmental collaboration, K-12 teachers must also be part of these conversations and centrally involved in the design of teacher education programs. This was the point stressed by the award-winning elementary teachers mentioned at the beginning of this article. I believe it is an even more important point than is reflected in *Shaping the Future*. Our master teachers have much to offer beginners in the way of experience and encouragement. In addition, however, the most important message a big city school superintendent gave our review committee was that the new teachers he hires have little understanding of who the students are, the kinds of home environments from which they come, and the kinds of attitudes and backgrounds they bring with them to the classroom. Now one may wish that today's students were just like we were, but the fact is, they are not. The superintendent's point was that the teacher preparation programs his new teachers come from did not adequately help the students learn about the kinds of students they will actually have in their classes. To do that seems obviously to require that prospective teachers spend more time in school classrooms with real students, seeing good teachers who teach content while they handle problems of motivation and discipline and deal with a diversity of languages, cultures, and learning styles.

To SME&T Faculty

Develop partnerships and collaborations with colleagues in education, in the K-12 sector, and in the business world, to improve the preparation of teachers and principals.

I recently invited a group of young faculty in science and mathematics to think of things they could do to foster such collaborations. Knowing the kind of pressure these young faculty are already under, I asked them to restrict their attention to ideas that would not take more than 3 hours of time or cost more than \$10. Some of the ideas were predictable but no less valuable - such as inviting a colleague in education to lunch; learning which students in a course are prospective teachers and meeting privately with them to encourage and recognize them as well as to ask for suggestions on making the course more relevant to their particular interests. One of the group said that he is a department chair and has a faculty member in his

department who is the official "liaison" with the education department; but the chair had never talked with that faculty member about this role - what the faculty member actually did as liaison and how the chair could help. The chair said he would correct that immediately upon his return home.

To The National Science Foundation

Expand support of K-12 teacher preparation programs - especially through the NSF Collaboratives for Excellence in Teacher Preparation program, where we would recommend funding only projects that clearly incorporate the principles of effective SME&T education (as identified in *Shaping the Future*) and show promise of reaching a larger fraction of those entering the profession.

The National Science Foundation plays a significant leverage role in teacher preparation, through funding of grants and contracts. It must apply that leverage carefully, so as to reinforce the kind of excellent but supportive programs that we recommend - programs that bring together all the important players in the preparation of teachers and that include the methods and processes of inquiry.

Conclusion

The review committee for *Shaping the Future* was persuaded that we in higher education cannot criticize the K-12 sector without pointing the finger at ourselves for not taking as seriously as we should teacher preparation as part of our task. What more important activity is there than participating in the development and maturation of a young person, and what more important educational activity can there be than preparing undergraduate students to do that well? We salute our colleagues who are devoted to this task and call on the rest of us - faculty and administrators alike - to join them in this cause. ■

Reference

- [1] *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139), National Science Foundation, Arlington, VA 22230, 1996.

STUDENT DISCOVERY AND LEARNING THROUGH PRECALCULUS CBL PROJECTS

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In the precalculus course which is being piloted at Virginia Commonwealth University we have interwoven four student CBL (Calculator-Based Laboratory) projects throughout the semester to foster student participation and discovery through supervised group work. These activities are scheduled on specific class laboratory days throughout the semester and are coordinated with topics as they are developed in the text. These topics range from an introduction to functions to specific applications of functions including the quadratic exponential, and trigonometric functions. For each experiment, the apparatus, including appropriately programmed CBL's, is set up in the classroom by the instructor and assistants at two to four stations. Students are then organized into groups of five or six and conduct their experiments at the established stations. A written description of the experiment (including goals and expectations, step-by step process instructions, and hints for making the desired mathematical connections) has been given to each student at the prior class meeting. Following a brief overview of the current experiment by the instructor, the student groups perform the experiment and transfer the data collected by the CBL to their own TI-83 or TI-82 calculators for interactive study and analysis. The class instructor and a student assistant (undergraduate or graduate) assist groups throughout the process as needed. The general group task in each of these experiments is to analyze the functional data points collected by the CBL and stored and graphed under the STAT PLOT procedure on their TI-83 or TI-82 calculator; to use algebraic techniques to find an appropriate mathematical function (quadratic, exponential, trigonometric etc.) which will closely model the situation depicted by the data points; to graph the function (entered as Y_1 in their TI-83 calculator) simultaneously with the STAT PLOT of the data points; and to refine their function rule until their graph closely fits the graphed data points.

In addition to leading the students to actively discover the specific characteristics and controlling features of these mathematical functions, the knowledge of use of which are critical to the impending study of calculus, we believe that this student work provides invaluable insight into how scientists use mathematics to determine functions which model physical situations. For example, when the student encounters a textbook exercise like “If a certain bacteria grows according to the functional rule $f(x) = 1000 e^{3062x}$ where the time x is measured in minutes, when will the population reach one million?”, some insight will already have been instilled as to how such a function was determined. The instructor can remind the class that they, in fact, have similarly determined function rules from collected data. In contrast to receiving on “faith” a general answer like “Those functions are statistically determined by scientists after many experimental trials” which still gives little insight into the mechanisms for determining the function rule, the students can now relate to their own experience in modeling data with function rules. The students should also have a better feel for what the variables x and $f(x)$ represent.

The CBL laboratory experiment also provides a natural opportunity for students to describe their mathematical discoveries and observations in a written report form. Guided by the written expectations and grading criteria provided, each student is required to synthesize the group findings and analysis to an extent that he/she can accurately describe the goals, processes, and results in a written form which their peers can expect to comprehend.

Our preliminary evaluation of these CBL laboratory experiments in pilot sections of the precalculus course show a very positive effect in generating student interest and in their ability to make mathematical connections to real world physical situations. Instructors agree that the students’ written reports are generally very good, although wide variations exist in the effort and creativity which student writers show in striving to generate reader interest in their reports. Preliminary analysis of performance on test questions directly keyed to the analysis of laboratory projects indicate student achievement comparable to that on other questions. In the first pilot sections, written student reports were required on all of the laboratory projects. Constraints due to the magnitude of grading have led us to explore a balance between written report grades and specific test question analysis to provide evaluation of student learning from the CBL

laboratories. Additional evaluation of the impact of CBL activities is planned during the next course offerings.

We will give a sample student instructional handout along with a possible set of reportable analyses for one of our four CBL laboratory experiments. Similar descriptions of the other three laboratories will be available commercially.

Before we present the “Pendulum” experiment which motivates the modeling of periodic phenomena with sine and cosine functions, we will give some tips for the experimental set-up which, based on our experiences, should be helpful. First, since the CBL motion detector measures distance from an origin on a horizontal line, we found it necessary to swing a large object in order for the detector to retain horizontal visual contact as the object swung in its arc. Old basketballs proved to work very well when hung from a ceiling on a six to eight foot length of monofilament fishing line. Since the basketballs do not need to maintain firm inflation, they can usually be obtained at minimal costs from flea markets or thrift stores. Also, a small nail inserted into the valve stem of the ball provides a convenient means to tie the ball to the monofilament line. Thus, except for the cost of the CBLs and motion detectors, several experimental stations can be set up with very little cost. Two stations proved ample to serve six groups of five or six students during a fifty minute laboratory session, even when some repetitions were needed by several groups. We found that nice graphical results could be obtained with three or four pendulum swings with minimal observed damping results. Other self explanatory tips are interspersed in the description which follows.

Student Laboratory Description – Pendulum

I. Background

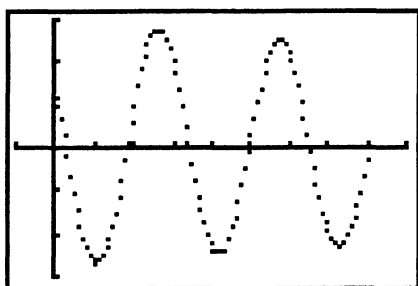
When a pendulum swings back and forth its horizontal motion can be described by a periodic function. In this lab we will use the CBL to measure the horizontal distance of a swinging basketball from the “center”. We will call the spot where the pendulum hangs at rest the “center”. The CBL will take measurements every tenth of a second. The data curve will actually be damped (its amplitude will decrease as the pendulum arc decreases) because of air resistance, etc., but we will find a good approximation of the motion using the basic trigonometric functions cosine and sine.

II. Lab

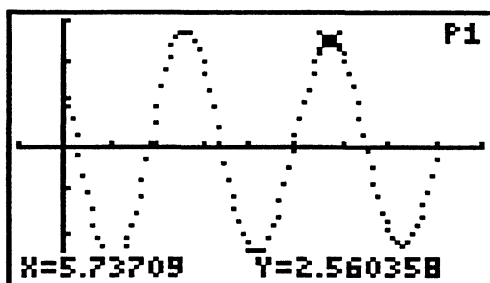
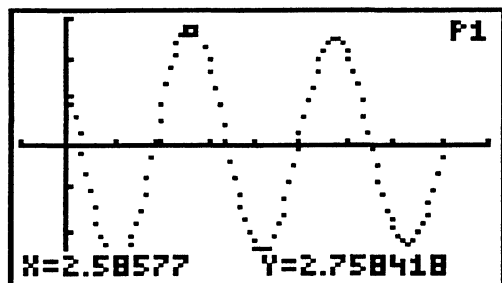
- Step 1.** The classroom calculator will have the program SWING installed. Clear out any functions that may have been stored in the calculator, especially under Y_1 .
- Step 2.** The pendulum will be set up with motion detector and CBL unit ready to go. Make sure the class calculator, with the program SWING installed, is connected to the CBL unit using the link provided.
- Step 3.** Turn the CBL unit on by hitting the red **ON** button. Turn your calculator on and hit the **PRGM** button. Use the arrow keys to scroll down to the program called **SWING** and hit the **ENTER** button twice.
- You will see the introductory screen. Hit **ENTER** and then hit **ENTER** again to collect the data.
- Step 4.** Let the ball hang at rest and hit **ENTER**, making sure the ball is still. This center point of the swing will serve as the point from which the horizontal distance of the ball will be measured.
- Step 5.** Hold the ball out (no closer than 14 in. from motion detector, keeping the string taut, but not stretched, and keeping the ball aligned with the motion detector). Hit **ENTER**.
- Step 6.** Have one student count down and hit **ENTER**, starting the program at the same time that another student releases the ball. Be sure to let go, without giving the ball a push.
- Step 7.** You should now have a plot (graph) of data on the calculator, the x-axis scale representing time and the y-axis scale the horizontal distance of the ball from the center. Does it look like a cosine curve? If not return to the program and repeat the experiment. Keep trying until you get a nice cosine curve.
- Step 8.** Disconnect your calculator from the CBL unit. Transfer the data to your own calculators (TI-82 or TI-83).

Sample Experiment Responses:

After completing step 8 of part “II. Lab” the student has a calculator with the following sample graph.



Trace to find the extrema of your data curve. What are the coordinates of two consecutive local maximum points?



Since the motion of the ball is periodic, trigonometric functions might help to describe its motion. We will first attempt to describe the horizontal position of the ball using a function of the form $y = A \cos(bx)$. Using the y-values of these points you can decide what your amplitude should be. What value do you want to use for your amplitude, A?

I chose $A = 2.6$ because it was between the two local maximum y-values.

Using the x-values of these points you can decide what your period of your pendulum should be. What is the period?

$5.73709 - 2.58577 = 3.15132$, so I wanted my period to be about 3.15132.

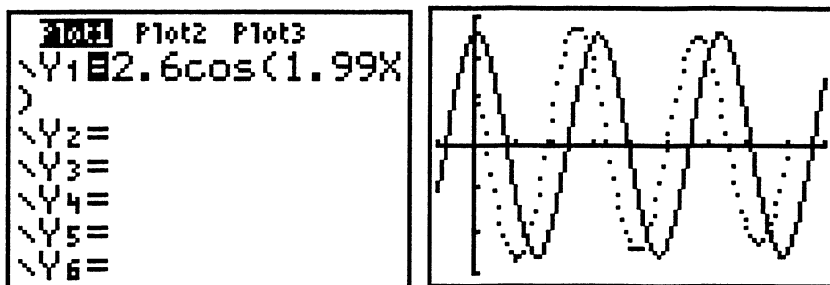
Knowing the period, what value do you want to use for your b ?

$$b = (2\pi)/\text{period} \sim (2\pi)/3.15132 \sim 1.99$$

Putting in your values for A and b , what is your equation?

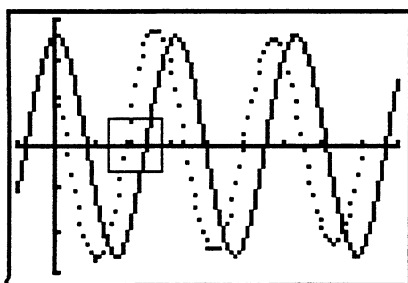
$$y = 2.6 \cos(1.99x)$$

Graph this equation in Y1. Does it match the data well? Should you adjust your amplitude or period? Do so if necessary.



It matches pretty well. The period and amplitude look fine, but it seems offset on the x -axis a little bit.

Shift your graph if necessary. Hint: Trace to find the difference in the x -values of an x -intercept on the data curve and the corresponding point on the curve obtained from your equation. Remember to add the distance c to your original x to obtain $y = A\cos[b(x+c)]$ for a left shift and to subtract the distance for a right shift. What is your equation now?



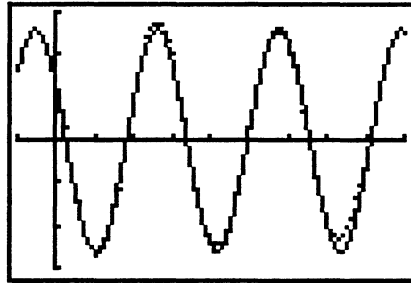
Distance between data curve and curve from the equation is .56.

Since $c = .56$, my new equation was $y = 2.6 \cos(1.99x(x + .56))$.

```

21031 Plot2 Plot3
\Y1=2.6cos(1.99(
X+.56))
\Y2=
\Y3=
\Y4=
\Y5=
\Y6=

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Now rewrite the equation in the form $Y = A \sin[b(x + c)]$. What do you have to do to the equation above to get it in this form? Recall that the “general sine function” $y = A \sin[b(x + c)]$ must be shifted to the left by one fourth of a period to coincide with the “general cosine function” $y = A \cos[b(x + c)]$.

I needed to shift to the right $(3.15132)/4 = .78783$

This gave me the equation $y = 2.6 \sin\{1.99[(x - .78783) + .56]\}$

So, my final equation was $y = 2.6 \sin[1.99(x - .22783)]$

■

REFORM OF PRESERVICE SCIENCE EDUCATION: AN EXAMPLE FROM A STATE-SUPPORTED UNIVERSITY

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The ongoing movement to reform the teaching and learning of mathematics and science began as an effort targeting grades K-12. This movement, however, also has significant implications for institutions of higher education, especially in the area of teacher preparation. Northeast Louisiana University has utilized an extensive system of support, including vital National Science Foundation funding, to redesign its science curriculum for elementary education majors. Four courses featuring the content areas of biology, chemistry, geosciences, and physics and integrated with respect to content and methodology were collaboratively developed by education and science faculty and were approved as requirements for all preservice majors. Preliminary evaluation results with respect to students' content knowledge and attitude are favorable. Ongoing efforts include the development of activities designed to further integrate the courses with respect to content and the execution of focused evaluative studies to reflect the degree of implementation of the reform practices that have been modeled by the university faculty.

Introduction and Background

The last ten years have witnessed some monumental changes in science and mathematics teaching at the university and precollege level [1]. These modifications have been directed by landmark efforts such as *Science for All Americans* [2], *Professional Standards for Teaching Mathematics* [3], *Benchmarks for Science Literacy* [4], and the *National Science Education Standards* [5]. Changes also have been guided by reform projects in specific disciplines such as *Earth Science Education for the 21st Century: A Planning Guide* [6] and *Earth Science Content Guidelines Grades K-12* [7] in the geosciences [8][9]. Other disciplines in the sciences, such as biology, chemistry, and physics also have developed similar reform-based standards at various levels.

The *National Science Education Standards* and other reform projects were initially

developed with the intent of reforming the teaching and learning of science at the K-12 level. However, these documents also have significant implications for higher education, especially in the area of teacher preparation. This study investigates the response of Northeast Louisiana University (NLU) to reform initiatives and documents the nature, extent, and impact of the reform efforts in preservice education.

Northeast Louisiana University is a state-assisted, multipurpose, senior institution of higher education. It is located in Monroe, Louisiana, and serves a geographic region consisting of 13 parishes, the largest such region served by any institution of higher learning in Louisiana. Included in this region are 187 public schools and 20 non-public schools. They serve a student population of 173,000 with 4,000 teachers; the student population is composed of 47% minority and 53% non-minority. From this student population NLU draws 64% of its 11,000 students. The primary purposes of NLU are instruction, research, and service, the most compelling of which is instruction. Degree programs are offered in business administration, education, liberal arts, pharmacy and health sciences, and pure and applied sciences.

University Response to Reform-based Initiatives

Systemic reform in K-12 science will be inefficient and possibly even futile if not accompanied by simultaneous reform in teacher education. Northeast Louisiana University has been one of the leaders in Louisiana in developing, teaching, and implementing reform-based instruction at the university and precollege levels. Oliver and Loftin [10] found in a statewide study of the National Science Foundation's Collaboratives for Excellence in Teacher Preparation (CETP) program in Louisiana that "the progress of collaboration for reform has been most successful" at NLU and that by far "the most successful collaboration between the disciplines and education" was at NLU. Contributing factors to the success of NLU's systemic reform efforts were noted as joint appointments between the science disciplines and education and the consistent support of administration at all levels. Northeast presently has two joint appointments between the College of Pure and Applied Sciences and the College of Education (one in the geosciences and one in mathematics).

Major systemic reform endeavors in science and mathematics at NLU have been funded primarily by external grants which have totaled over \$2.5 million in the last five years.

Principal funding agencies for the reform projects include the National Science Foundation (NSF), the Louisiana Systemic Initiatives Program (LaSIP), the Louisiana Collaborative for Excellence in the Preparation of Teachers (LaCEPT), the Louisiana Networking Infrastructure for Education (LaNIE), the Riverwood Educational Challenge Fund, and the Louisiana Applied Oil Spill Research and Development Program. A key to the systemic reform of the teacher preparation programs at NLU has been the diversity and extent of the projects. These projects have had a tremendous impact on restructuring science and mathematics instruction both at the university and at the precollege level.

The major impetus for reform in teacher education at the university level in Louisiana was the National Science Foundation's CETP. In 1993 the state of Louisiana, through its Board of Regents, the statewide coordinating board for higher education, received one of three CETP awards in its first cycle of funding. The state project is called the Louisiana Collaborative for Excellence in the Preparation of Teachers or LaCEPT. The purposes of the program are described in the NSF program solicitation and include making all students scientifically literate in a technological society, reforming the content and delivery of K-12 mathematics and science, preparing new teachers to meet the challenges of reform-based education, and engaging in collaborative efforts in order to bring about the desired changes.

The five-year award from the National Science Foundation is \$4.5 million, and the state provides a matching \$2.75 million over five years. All Louisiana public and independent colleges that prepare mathematics and science teachers are eligible to submit a proposal for a Campus Renewal Project (CRP). Through these proposals faculty and administrators evaluate the current status of reform on individual campuses, indicate their long-range vision to cultivate and institutionalize reforms, develop project activities to achieve the vision, and indicate plans for evaluation and dissemination of project work. Project proposers are encouraged to collaborate with other universities and to utilize other funding programs that can interface with the Campus Renewal Projects. Intracampus collaboration is required as is collaboration with local education agencies.

Emphasis on science reform actually occurred during the second phase of the NLU Campus Renewal Project. The initial target for reform in preservice education was the mathematical preparation of elementary education majors. Using the standards documents of the National Council of Teachers of Mathematics and The Mathematical Association of

America, mathematics and education faculty developed reform-based approaches for teaching existing courses required of preservice majors. Even though the second and third years of CRP funding witnessed the shifting of emphasis to science reform, preservice course offerings in mathematics continued to evolve. In Louisiana, state requirements declare that majors in elementary education must take 12 hours of mathematics as part of their course of study, but it is left to individual institutions of higher education to establish the content of their course offerings. During the 1997-1998 academic year, the mathematics course offerings and requirements for NLU elementary education majors were redesigned to include two new courses specifically designed for elementary education majors. Combined with an existing geometry course for preservice majors, the mathematics department now offers nine hours of courses tailored to the needs of future elementary teachers; the fourth course requirement is an introductory offering required of majors in various fields of study.

Revision of Preservice Education in the Sciences

In order to accomplish the objectives of national science standards in teacher preparation, there is a need for a broad background in the biological, physical, chemical, and geological sciences for K-8 teachers. To achieve this base of understanding, preservice teachers should understand the nature, role, skills, and processes of scientific inquiry as well as understand the essential concepts in the major science disciplines. Additionally, teachers need to understand and make conceptual connections in science and mathematics and utilize science in societal issues [5].

A 1994 study of preservice majors at NLU indicated that they were not receiving the necessary background in the sciences. In fact, records indicated that during the spring of 1994 53% of preservice majors were enrolled in a biology course, 36% in a geosciences course, 11% in a physical science course (primarily physics and astronomy), and 0% in a chemistry course. These figures were representative of the fact that for their required 15 hours in science most elementary education majors selected courses from the areas of biology and geosciences and excluded physics and chemistry courses.

The integrated science curriculum was designed and implemented at NLU to assist preservice teachers in achieving the "base of understanding that all teachers should have" according to the *National Science Education Standards* [5]. The development team for the

courses consisted of faculty from each of the specific science content disciplines (biology, chemistry, geosciences, physics) as well as science and mathematics educators representing elementary and secondary education. Fortunately, there were several faculty members who had been involved in reform-based programs in the sciences and mathematics. These individuals were eager to be a part of the reform process and assumed leadership roles in the project. There were not, however, similarly-experienced faculty in all science disciplines. In order to field a complete team, faculty representing some of the content areas had to be recruited into service and trained in reform-based strategies. Only with broad-based administrative support was this feat achieved. Faculty training and support activities included renowned guest speakers such as John Carpenter in earth science and Lillian McDermott in physics education, workshops related to reform-based classroom strategies such as the use of technology and alternative assessment, travel to appropriate conferences, and team discussion of pertinent journal articles related to the reform movement.

Weekly sessions in which the framework for the integrated science curriculum was collaboratively formulated were conducted during the fall semester of 1994 and the spring semester of 1995. The four courses, each a three-hour credit course meeting 150 minutes per week, received the approval of all university curriculum committees and were included in the university catalog as requirements for incoming freshmen preservice majors in the fall of 1995. The reform-based experience of the faculty involved in developing the integrated courses determined the order in which they were field tested. Faculty from the departments of physics and geosciences had directed reform-based projects for area teachers, so their courses were selected as the initial offerings for NLU students. The integrated physics and geosciences courses were taught in the fall of 1995, and the integrated biology and chemistry courses were offered the following spring.

Essential concepts and fundamental knowledge provide the basis for the integrated science curriculum for preservice teachers. Scientific inquiry through a variety of instructional methods is emphasized. Deliberate connections to mathematics and environmental issues are incorporated into all of the courses through the commonly shared themes of science, technology, and society. The following is a brief description of the integrated science courses:

- Integrated Biological Sciences emphasizes basic concepts and principles of the biological

sciences. These concepts and principles include the history and methods of biological science, basic chemistry and physiology of living systems, ecological principles and related environmental issues, and biodiversity.

- Integrated Chemistry emphasizes fundamental concepts of chemistry with an emphasis on the interdisciplinary nature of the concepts introduced. These concepts include atomic structure, elements and the periodic table, compounds and chemical change, water and solutions, organic chemistry, and nuclear reactions.
- Integrated Geosciences emphasizes an integrated approach to essential concepts in introductory geology (physical and historical geology), astronomy (from an earth science perspective), and weather to make clear personal applications of science, process skills, problem solving, and inquiry learning.
- Integrated Physics emphasizes the basic concepts and principles of physics, including force, motion, energy, light, heat, electricity, and magnetism. Personal applications of science, process skills, problem solving, and inquiry learning are also emphasized.

The major topics for the integrated science courses were chosen using several criteria. Since the audience for the integrated courses was perspective elementary teachers, the standards from various K-12 science reform projects were carefully studied and scrutinized. Other considerations which were significant in the development of the integrated science courses included precollege textbooks, college textbooks, and interviews with faculty who taught introductory courses in the various science disciplines.

Accompanying the need for reform in content and methods of instructional delivery is the need for reform in assessment. Since new instructional techniques are often utilized in the integrated science courses, alternative methods of assessment are used to support and complement traditional grading methods. Authentic assessment (evaluation that truly matches the concepts that are learned and the method in which they were learned) is incorporated into the traditional grading techniques. Examples of alternative methods of assessing students include the use of concept maps, student demonstrations, and group and individual projects.

Another significant feature of the integrated science courses is the limited number of students who are admitted to each class section. In an effort to provide the best setting for preservice students to experience reform-based teaching and learning, class size for the integrated science courses has been restricted to a maximum of 30 students. This size favorably compares to that of an elementary classroom. Such a commitment of instructional resources is a further witness of the support offered by the administration of NLU for the reform and improvement of preservice teacher preparation.

It should be noted that the term “integrated sciences” has several meanings at NLU. First, the courses are integrated in that scientific content and pedagogical methodologies are taught and modeled in the four-course sequence. This addresses a major theme of the *National Science Education Standards* [5] which state, “Teachers need to be taught science in college in the same way they themselves will teach it in school.” Second, the integrated courses often cover and investigate topics from several different existing courses. For example, the integrated geosciences course includes concepts from physical geology, historical geology, planetary geology, oceanography, and atmospheric science. However, each course is offered through and taught in the science department whose name the course bears. That is, the integrated chemistry course is taught in the chemistry department; the biology course is taught in the biology department, etc. In addition, the laboratory component of the courses is integrated with the lecture component. Laboratory experiences in which students actively engage in hands-on/minds-on activities are conducted in conjunction with the other instructional techniques utilized to convey to students the concepts and principles included in the integrated courses. Finally, the integrated science courses are connected by a common theme of science, technology, and society.

Impact of the Reform of the Preservice Science Offerings

At this stage of development and evaluation, the comprehensive impact of the integrated science courses is not clear. However, preliminary results look very promising. For example, attitude surveys administered in the integrated geosciences course since the fall of 1995 have averaged 1.6 on a scale ranging from -2 to +2 with -2 being the most negative response and +2 being the most positive. Students scores on pre- and post-tests based on concepts and principles taken from major science reform efforts have shown an average increase of 49% from pretest to posttest results. Further, posttest scores by students in traditional courses

were 40 percentage points less than those of students in the reform-based course. Additional studies and interviews with inservice teachers who participated in the four-course sequence will more clearly reveal the degree of success that can be claimed.

Ongoing Improvements

Course developers felt great satisfaction with the adoption of the integrated science courses as requirements for all preservice elementary education majors. The institutionalization of the courses by the university signaled the accomplishment of a significant milestone for proponents of reform-based teaching in the realm of higher education. It was the case, however, that the faculty involved in the development and teaching of the curriculum wanted to improve the courses and offer the preservice students an insight into the integration of the scientific content areas. That is, they wanted to model for the students examples of the connections between chemistry and physics or chemistry and biology or biology and geosciences. This desire led to the development of multidisciplinary experiments which focus on one scientific content area but feature the connections among other areas. For example, one of the experiments is, "What in the World is an Otolith and How is it Used in Paleontology?" This experiment has as its primary content area geosciences, but it includes exercises that make deliberate connections to chemistry and biology. Another experiment, "Pond in a Jar," is based on biology content but includes chemistry, geosciences, and physics. The intent of those developing the experiments was to make them ongoing throughout the four-course sequence and to emphasize in a specific course the content that is pertinent to that course. In addition, the experiments will be revisited, and further societal and personal implications will be emphasized when, as seniors, the students take their education methods courses. Following the successful completion of their methods courses, the preservice teachers will enter the classroom as student teachers. Since the experiments have been developed around essential scientific concepts that are appropriate for the K-8 classroom, the opportunity to review and expand upon applications of the experiments will be of great benefit to these soon-to-be classroom teachers.

Conclusions and Recommendations

A key component in determining the success of the newly-developed curriculum is the degree of dissemination of the concepts and the methods taught in the integrated science courses. That is, are those beginning teachers who were impacted by the new curriculum

implementing reform-based strategies in their classrooms? Further, how much support do these novice teachers need to be able to implement reform methodologies? Finally, how can improvements be made to better prepare current preservice teachers in reform-based instruction? Studies are being planned to answer the above-mentioned questions. Information about the degree of implementation and attitude toward teaching science using reform strategies will be collected in the form of surveys and interviews. Plans are underway to offer assistance and additional ideas to beginning teachers through a web site supported by a network consisting of university faculty and experienced inservice teachers who were participants in an NLU-directed and NSF-funded program. Requests for assistance will offer insight to university faculty regarding areas of strength and weakness and will provide guidance for further improvements in the teacher preparation program.

National Science Foundation funding is scheduled to terminate at the end of 1998. That will not, however, signal the termination of the work described in this article. True systemic reform can be achieved only through the collaborative efforts of all involved. Administrative support, university-wide collaboration, and excellent relationships with local education agencies are well-established factors that have contributed to the degree of success attained thus far. These, too, are the factors that will sustain and nurture the ongoing efforts to improve the teaching and learning of science from kindergarten through higher education. ■

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DEMONSTRATIONS FOR CHILDREN OF ALL AGES - THE CORK CANNON

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Demonstrations are one of the most useful techniques for teaching science to anyone, regardless of age. Demonstrations attract attention and normally make the observer want to learn more about what is happening. This paper reports on *The Cork Cannon*, one of the favorite demonstrations done in the demonstration road show, *Phun Physics*, that travels to schools within about 60 miles of Charlottesville. The Department of Physics and the Center for Science, Mathematics, and Engineering Education sponsor this demonstration show, which was seen by about 8000 persons during the last school year. Although quite simple, the Cork Cannon demonstration is rich in pedagogy and can be used to illuminate several ideas, including temperature, pressure, phase change, heat conduction, water vapor, humidity, projectile motion, air resistance, atmosphere, and kinetic theory.

Performing demonstrations with liquid nitrogen is one of the most exciting activities for children of all ages, from 6 to 60. College and university instructors use it in introductory physics and chemistry courses to demonstrate a multitude of concepts. Of course, it also helps that using liquid nitrogen is fun and attracts the students' attention. I use the *cork cannon* at the beginning of most demonstrations that use liquid nitrogen, whether it is in an introductory college physics class, an inservice class for K-12 teachers, or a demonstration show for children. The demonstration is lively, gets attention, and has lots of different principles that can be discussed, depending on the level of the audience.

In essence the cork cannon consists of a metal pipe, closed at one end, into which liquid nitrogen is poured and a cork is inserted into the open end (Figure 1). As the liquid nitrogen boils, pressure builds up until the cork pops off. I first saw such a device demonstrated by Gerald Royce of Purdue University at an American Association of Physics Teachers meeting/workshop a few years ago. The first one I built is shown in the photo.

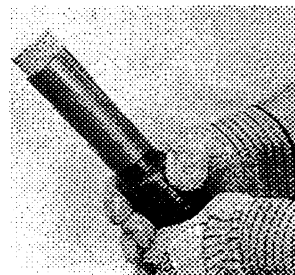


Figure 1. The Cork Cannon

Safety is the key in both constructing and using the cork cannon. Liquid nitrogen can seriously burn, and any projectile, the cork in this case, can cause damage. I started off by deciding that I wanted to use large corks for two reasons: 1) a student would be more likely to catch or deflect a large cork than a small one, and 2) a larger cork would slow down more than a smaller one due to air resistance. Corks are light objects and can easily be caught in a parabolic flight. Also, the corks do not become very cold in the process.

CONSTRUCTION

I started out by going to the physics stockroom to see what size corks we had. I liked the #20 and #22 corks and decided on #20 when I looked up the price of the larger corks. Large corks are very expensive. I eventually had to purchase additional corks and paid \$94 to buy a hundred #20 corks from Fisher Scientific. As a result we always try to reclaim the corks after a demonstration and use them over and over. Thus far, corks are not a collectible item for students, and we easily retrieve them. Next I found a suitable brass pipe that the cork would fit. The inside and outside diameters of the brass pipe are 3.84 cm and 4.66 cm, respectively. Its length is 27 cm. We inserted a copper plug into one end of the pipe and welded it to seal that end. Over half of the brass pipe is covered with pipe insulation that was obtained at a building supply company. This was then wrapped with black plastic electrical tape. We always wear gloves when handling the cork cannon for demos and have never felt uncomfortably cold. The demo is short, and the pipe insulation works very well.

CANNON USE AND SAFETY

I can attest by personal use that it is absolutely essential to become familiar with the use of the cork cannon before demonstrating it in a class with students. One holds the cannon (brass pipe) in one hand and, with the other, pours liquid nitrogen from a small (1 L) dewar into the pipe. The liquid boils away quite rapidly at first, and the pipe does not want to be completely filled. Almost invariably it will be difficult to place a cork into the pipe during the first few seconds, because of the rapid boil off of nitrogen. The placement of the cork into the pipe takes practice. If the cork is fit too loosely into the pipe, it simply falls out to the laughter of the students. If one uses a rubber mallet to place the cork securely into the pipe, normally one of two things happens. Corks are not perfect solids, and sometimes the nitrogen gas can find a way to escape around the fringes, because of cavities in the cork. One is then faced with the problem of getting the cork out; that generally must wait until all the nitrogen

has boiled away and a sharp instrument like a knife is inserted into the cork to pry it out. The spontaneity of the demonstration is lost. The other thing that can happen is that the cork will suddenly shoot out at tremendous speed - usually at an awkward moment and hitting something you don't want to hit. During my second use of the cork cannon (and the last time I ever used a rubber mallet!), the cork popped out, went up at about a 70° angle, hit and busted a fluorescent light bulb in the ceiling. Fortunately no one was hurt, and the fluorescent bulb fixture should have been covered, but it was not.

I tell you this unfortunate story so that you will be careful to pay attention to safety concerns and to practice their use. Gloves and safety glasses must always be worn when using the cork cannon. Never point the cannon at the audience. Some demonstrators never shoot the corks towards an audience, but I like shooting them well over the heads of the students who love to catch the corks. The students, of course, like it when we shoot the corks in a high arc towards their teacher. One has to be careful. This demonstration is best done in a large room or auditorium. In a small room, it is possible for the cork to bounce off the ceiling or a wall. The best advice is to not do the demonstration in a small classroom and always to point the cannon in a safe direction.

By practicing a few times with the cork cannon one learns just how hard to insert the corks into the cannon. We normally place the cork into the pipe with our fingers and then bang the cork with our palm while wearing gloves. I am now fairly consistent with the palm bang and can shoot the corks a distance of 6-10 m with ease and regularity. We find that, after the first couple of corks are launched, we have to shake the cannon a little to help the nitrogen boil off. One needs to be careful during this shaking in order not to move the cannon inadvertently in an unsafe direction, because the corks shoot out unpredictably. We normally shoot 5 or so corks out with one filling of liquid nitrogen, and we don't repeat the demonstration. The point is made with one filling of liquid nitrogen.

DISCUSSIONS

There are many science discussions that can go along with the cork cannon depending on the audience. For college classes we talk about phase change from liquid to gas. We always ask if anyone knows the temperature of liquid nitrogen. Then we go into a discussion of temperature scales: fahrenheit, celsius, and kelvin. With small children, we ask what is the

coldest thing they know. They invariably say ice or snow, and usually someone knows that their temperature is 32°F , and we mention the temperature in celsius. They are surprised to learn that liquid nitrogen boils at an approximate temperature of -300°F . They cannot imagine such a cold temperature and this naturally leads to a discussion of temperature ranges. We talk about pressure and how atoms and molecules bouncing around inside the container cause pressure. Atoms move slowly when colder, but speed up considerably when warmer.

We may start an interesting discussion by asking is what is the white cloud that we see when we are pouring the liquid nitrogen into the pipe. Sometimes we have to remind them by safely pouring out some liquid nitrogen and letting them observe the white cloud again. We find that we almost always get the answer that the white cloud is nitrogen gas. Then we go through the discussion of what is in the Earth's atmosphere. They eventually relearn that nitrogen is a colorless gas and can't be the white cloud. Then we proceed to discuss water vapor in air and how it is condensed into small water droplets by the extreme cold of liquid nitrogen. We remind them that this is similar to fog seen on cold mornings or to the white cloud observed when they breathe out when it is very cold. This is a favorite lesson.

I have built a second cork cannon that is about 6 cm longer than the first, but I have found that it did not operate appreciably better. I had hoped that we could shoot more corks from one filling of liquid nitrogen, but there was no consistent difference. ■

A SUMMER ACADEMY PROGRAM FOR PROSPECTIVE TEACHERS: MODEL TEACHING EXPERIENCES

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This article describes the project, **A Summer Academy Program for Prospective Teachers: Model Teaching Experiences**, of the Oklahoma Teacher Education Collaborative (O-TEC), one of the nation's Collaboratives for Excellence in Teacher Preparation (CETP). To recruit highly qualified teachers in science and mathematics, O-TEC institutions promote a program of summer academies that provide prospective teachers with opportunities to become familiar with effective teaching methods. During the academy, high school juniors and seniors explore inquiry-based teaching strategies, exemplary curricula, science and math content, and state and national standards in math and science education—all under the tutelage of mentor teachers, a Master-Teacher-in-Residence, and university faculty. The prospective teachers have opportunities to put into practice what they learn about effective teaching. For two weeks, the prospective teachers experience teaching science lessons to elementary children from neighboring school systems. These experiences help the prospective teachers perceive the challenges and rewards of teaching at a pivotal time in their lives.

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Introduction

Emphases of Teacher Preparation Reform

Universities across the nation are participating in reform initiatives to improve teacher preparation programs. The focus of reform is on the art of teaching [1] and the goal of teaching, i.e., learning. Learning is considered a criterion and product of effective instruction. Effective teaching requires focusing on both content and the process of learning [2].

Collaboratives for Excellence in Teacher Preparation

Reforming science and mathematics teacher education requires change in teacher practices at all levels [3] [4]. The **Oklahoma Teacher Education Collaborative (O-TEC)** is participating in the National Science Foundation's **Collaboratives for Excellence in Teacher Preparation (CETP)** program with a goal of reforming mathematics and science education. This reform effort recognizes that preservice teachers need opportunities to develop theoretical and practical understanding, not just technical skills [3] [4]. The reform emphasizes inquiry-based instruction for all teacher preparation programs.

The intent is to shift the focus of teaching from traditional methods of instruction that emphasize memorization of facts and procedures toward inquiry-oriented methods that facilitate the development of conceptual understanding [3] [4] [5]. The use of hands-on instruction designed to promote students' conceptual knowledge by building on prior understandings, active engagement with the content, and application to real-world situations are all critical components in all O-TEC programs [3] [4] [5].

The O-TEC collaborative is pursuing systemic reform of teacher education by three methods:

- recruiting high ability prospective teachers interested in math and science through summer academies;
- revising undergraduate curricula for science and mathematics education majors;
- providing support through teacher institutes and networks to retain entry-level teachers who have one to three years of teaching experience.

Literature Review of Effective Teaching

Teaching Science as Inquiry

What is the best way to teach science in the elementary school? Studies show that effective teachers have teaching methods that use inquiry to promote student discovery and concept constructions [3] [6]. Science as inquiry, modeled on the scientist's method of discovery, focuses on asking questions, investigating, considering explanations, and weighing evidence [6] [3]. According to the National Science Education Standards published by the National Academy of Science [3]:

Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning and conducting investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating results.

Inquiry-based teaching guides students to construct their understanding of fundamental scientific ideas through direct experience with materials, technological resources, experts, and by conducting investigations [3][6][7]. Through debate, students communicate their ideas and refine their explanations. Science as inquiry includes high expectations for students to acquire knowledge; each student constructs knowledge through the interplay of prior learning and newer learning [8]. The new vision of science as inquiry recommends that students combine processes and knowledge as they use scientific reasoning and critical thinking to develop their understanding of science [3]. This type of teaching creates opportunities for students to take responsibility for their own learning, individually, and as members of groups.

The Constructivist Learning Cycle Model

The constructivist learning cycle model serves as a learning and teaching method [9]. The learning cycle is anchored in an understanding of the development of cognitive reasoning abilities [10]. The phases of the learning cycle provide the structure for planning an effective science activity. Once the concept is identified, the teacher structures the learning activity to incorporate exploration, concept invention, application, and evaluation. The cycle provides a dynamic planning system that balances student-centered exploration with teacher-guided conceptual construction.

The exploration phase is student-centered and affords students with concrete materials and direct experiences to promote the concept construction [6]. Students are more receptive to understanding a concept if they have engaged directly in a concrete experience which has raised a question in their minds. Data collection prepares the students for the next phase of the learning cycle.

The concrete experience provided in the exploration phase is used as a basis for generalizing the concept in the concept invention phase. The teacher's responsibility is to lead the students through discussions so that they "invent" the concept independently [3][6]. The teacher facilitates the students by introducing specialized vocabulary and concept labels. In

this phase, the students restore mental equilibrium through accommodation as supported in the developmental learning theories of Piaget [10]. When the students “invent” the concept, it is more likely remembered.

The application phase affords each student an opportunity to directly apply the concept to everyday science experiences. This phase provides additional time for accommodation required by students needing more time for equilibration [10] [3]. Application nurtures understanding as the new dimensions of science learning are internalized.

The purpose of the evaluation phase is to assess student outcomes including hands-on performances. The evaluation phase assesses beyond standard forms of testing [11]. The phase focuses on a holistic evaluation of the students’ learning including process skills checklists (Table 1, opposite), systematic observations, reflective questioning, interviews, pictorial assessment, hands-on performances, and journals. Evaluation occurs at any point in the activity, and consistent evaluations reveal misconceptions before they become deeply rooted.

Exemplary Inquiry-Based Curricula

Science and Technology for Children (STC) is an exemplary science curriculum developed by the National Science Resources Center [12]. The STC curriculum is a comprehensive, inquiry-based science curriculum that has mathematics content embedded in the investigations. The exemplary science curriculum is:

- Research-based;
- Developed collaboratively by master teachers, educators, scientists, and engineers;
- Nationally field-tested with diverse classrooms in rural, urban, and suburban schools.

A research and development process insures that STC modules are scientifically accurate and pedagogically appropriate for all students including students with ethnically diverse backgrounds.

Research Supports the Use of Activity-Based Science Programs

Research on the effectiveness of activity-based science programs has examined different measures of student performance. Results of research to determine the effectiveness of activity-based programs have been statistically significant [13] [14] [15]. Using research

literature and data aggregation procedures, Shymansky, Kyle, and Alport [7] conducted a meta-analysis of activity-based programs, within the elementary, junior high, and high school curricula. The analysis on 18 different measures of student performance showed the greatest gains in achievement and process skill development for students who received instruction from activity-based programs.

Observation	<ul style="list-style-type: none"> • Describes attributes of objects. • Describes changes in terms of actions.
Classification	<ul style="list-style-type: none"> • Creates groups using a single attribute to express linear relationships. • Creates groups using several attributes to express symmetrical relationships.
Prediction	<ul style="list-style-type: none"> • Guesses based on limited observable facts. • Guesses based on an accurate understanding of cause-and-effect relationships.
Controlling Variables	<ul style="list-style-type: none"> • One manipulative variable and without holding others constant. • Several manipulative variables and holds at least one variable constant.
Inferring	<ul style="list-style-type: none"> • Explains using observable data. • Explains using quantifiable observable data.
Defining Operationally	<ul style="list-style-type: none"> • States relationships between observed actions to explain phenomena. • Explains relationships by generalizing to other events not observed.
Hypothesizing	<ul style="list-style-type: none"> • Statement based on simple sensory observations without explanations. • Statements used to create concepts through explanations

In 1986, these results were reanalyzed using refined statistical procedures [7]. Data from the reanalysis showed that students in hands-on programs outperformed their traditional

elementary school counterparts by 9 percentile points on a composite performance measure. From the data, it was concluded that the new elementary science programs were more effective in enhancing student achievement and problem-solving skills than traditional programs [7]. The *Science and Technology for Children* module, *Electric Circuits*, used in the Summer Academy of 1997 is one of the new elementary science programs supported by this research.

Effective Questioning Techniques

Research verifies that teachers use questions more than any other teaching method. Teachers ask about 93 percent of all questions and allow students little wait time to respond or opportunity to ask their own questions [11]. The questions teachers generally ask require factual answers and low levels of thinking. Questions that require application, analysis, synthesis, or evaluative thinking are very seldom used [11]. Bredderman [16] discovered that the questions teachers used influenced the students' level of response.

Bredderman [16] reported a direct relationship between the level of questioning and the level of response. Increased use of higher-level questions may be a significant difference between activity-based science learning and traditional teaching. The effect of raising the cognitive level of classroom discussions could result in increased achievement [16] [17]. The general conclusion is that the prospective teachers began to perceive this effect in their model teaching experiences. They discovered that using more advanced questions could result in more analytical thinking.

The Roles of the Teacher and Students

Research of the teacher's and the students' roles reveals that the constructivist teacher assumes many roles but largely functions as a facilitator of knowledge construction. The constructivist model is based on the proposition that knowledge is not transmitted directly from one person to another but is actively constructed by the learner [18] [10] [11]. Constructivist theory focuses on the mental activity of the learner as he/she assimilates new ideas, tries to resolve the cognitive conflict created during the process of fitting the new ideas into existing concepts, and restores mental equilibrium through assimilation and accommodation [18] [10] [11].

Learning Styles

Despite research that attempts to identify common elements of learning, educators contend that everyone learns differently. According to Reiff [3], although each person is born with certain tendencies toward particular learning styles, inherited characteristics are influenced

by culture, personal experience, maturation, and development. A learning style is described as a set of factors, behaviors, and attitudes that facilitate learning [19] [20] [21]. Learning style is the manner in which various elements in one's environment affect learning.

Because there appears to be a relationship between culture and learning style [22] [23], teachers should provide students with a variety of ways to learn. Learners that come from cultures that exercise authoritative control and/or lack good nutrition tend to be field-dependent learners. Students who exhibit this learning style prefer group interaction with the teacher, need explicit instruction, and require praise for motivation [3] [21]. Students from societies that depend on unspoken observations for survival are visual learners [21] [20]. Preferring to learn from the written word are students from contemporary, literate societies; whereas, students from traditional, preliterate cultures prefer to learn from direct experience [22] [21].

The Study

This article describes the development, operation, and evaluation of the project, *A Summer Academy Program for Prospective Teachers: Model Teaching Experiences*, conducted at one of the nine higher education institutions participating in the *Oklahoma Teacher Education Collaborative (O-TEC)*.

The Focus of the Summer Academy

The summer academy is the mechanism to recruit high ability juniors and seniors interested in science and mathematics to participate in a four-week program that introduces them to teaching as a career. The summer academy incorporates state and national standards adopted for student learning in grades K - 12 in order to provide the prospective teachers with opportunities to strengthen their skills in science and to experience the rewards and challenges of teaching. Academic and practical experiences are provided to encourage a long-lasting interest in mathematics and science. The summer academy creates a supportive climate that promotes high expectations; builds inquiry; fosters communication skills; and encourages critical thinking.

Targeted Population

Recruitment targets minorities and historically underserved student populations. Teaming with the Teacher Cadet program directed by the Oklahoma Minority Teacher Recruitment Center of the Oklahoma Board of Regents for Higher Education provides a network for minority recruitment. High school juniors and seniors who are Native Americans, African Americans, and Spanish-speaking Americans attending schools in rural areas were encouraged

to participate.

Selection of Participants

Twenty-four juniors and seniors from high schools in western Oklahoma were selected as prospective-teacher participants. Twenty-five percent of the participants were represented by minorities with Native Americans representing the majority. The participants were selected according to the following criteria: (a) high school junior or senior from a rural school, (b) personal interest in learning about the teaching profession, (c) some practical experience working with young students, and (d) recommendation by school personnel familiar with student's academic and interpersonal skills. The prospective teachers' working experience with elementary children ranged from actively participating in the Teacher Cadet program to baby-sitting their neighbors' children.

The Design of the Program

The four-week program focused on the development, operation, and evaluation of a summer academy for prospective teachers using model inquiry-based teaching experiences. During the first week of the academy, twenty-four high school juniors and seniors actively explored inquiry-based teaching strategies, exemplary curricula, science and math content, and the state and national standards in mathematics and science education--all under the tutelage of mentor teachers, the Master-Teacher-in-Residence, and university faculty. In the following weeks, the prospective teachers put into practice what they had learned about effective teaching. The prospective teachers presented sixteen science activities from the *Electric Circuits* module to elementary school children. During the final week, the University involved the prospective teachers in a geology field excursion, career day, and a culminating activity. A summary of the summer academy activities is shown in Figure 1, opposite.

University Faculty and Master-Teacher-in-Residence

The university faculty was represented by two university professors of science education, one professor of mathematics, and the Master-Teacher-in-Residence. A Master-Teacher-in-Residence (MTIR), added to the university professional education team, assists in the planning, developing, implementing, and monitoring of the summer academy. The MTIR position is funded by NSF (with an overhead match by the institution) to aid each site in completing the following specified tasks:

- Redesigning curricula in selected science, mathematics, and education course;
- Encouraging greater use of technology, interdisciplinary, and inquiry-based approaches;
- Developing increased levels of communication with teachers in public schools;

- Establishing a series of summer academies;
- Disseminating best practices developed by the O-TEC collaborative;
- Monitoring key factors in order to evaluate the program; and
- Facilitating continuing dialogue, planning, and participation among O-TEC participants.

		Activities
<i>Week 1</i>	Morning	Learning Theories Science Process Skills The Learning Cycle Questioning Strategies Critical thinking Skills
	Afternoon	Electricity Labs Content Sessions Teaching Preparations Reflection
<i>Weeks 2 & 3</i>	Morning	Exploration Activity with Elementary Students Concept Invention Phase Application/Extension Phase Assessment/Journal Writing by Elementary Children
	Afternoon	Journal Writing Small Group Sessions on Morning Sessions Debriefing Sessions on Successes, Challenges, and Problems Large Group Sessions on Teaching Strategies Teaching Preparations
<i>Week 4</i>	Morning/ Afternoon	Self-Reflection Activities Field Experience Career Day Evaluation Banquet

Figure 1. Schedule of Activities for the Summer Academy for Prospective Teachers

Using Mentor Teachers with the Prospective Teachers

Four master teachers of mathematics and science in the public schools served as mentors for the twenty-four prospective teachers. Both academic and pedagogical support was provided during the summer academy. The mentors helped the prospective teachers with daily

problems that they encountered as they participated as learners and practicing teachers. The prospective teachers observed how the mentors worked with them during the first week of the academy. The mentors served as role models as they:

- Exhibited patience;
- Adjusted teaching demeanor to a student's action;
- Experimented with numerous instructional and evaluation strategies; and
- Challenged students with math and science content [2].

The STC Module: *Electric Circuits*

The STC module, *Electric Circuits*, was used by the prospective teachers when they experienced teaching with the elementary children. The inquiry-based activities focused on the properties and uses of electricity. The elementary children, under the prospective teachers' guidance, constructed circuit testers, investigated conductivity, made glowing filaments, built switches, created their own flashlights, created models of series and parallel circuits, and discovered the properties of diodes. The challenging activity involved the elementary children with the tasks of designing, constructing, and wiring a cardboard-box "house." First, the elementary children learned how to draw detailed plans for wiring a house. Using D-cell batteries, insulated wires, single-pole and double-pole switches, and series and parallel circuits, the elementary students wired their four-room cardboard box "house." This activity provided opportunities for the elementary children to perceive the interconnectedness of math, science, and engineering.

Planning Week : Sessions Involving Mentor Teachers and University Faculty

During the planning week, the mentor teachers and university faculty discussed pedagogy, reviewed the learning cycle, discussed concepts of electricity, and investigated labs on the uses and properties of electricity. They planned activities from the *Electric Circuits* module to be presented as model lessons in laboratory settings with the prospective teachers. The mentor teachers discussed the objectives of the state and national standards for mathematics and science education and planned the integration of the standards with the content. Evaluative methods including reflection and journal writing instruments were developed (Figures 1-4).

Week One: Prospective Teachers' Training

The first week of the academy involved 24 high school students participating in morning

and afternoon sessions. Early morning sessions directed by the university faculty and the MTIR included *Learning Theories*, *Science Process Skills*, *The Learning Cycle*, *Effective Questioning Strategies*, and *Critical Thinking Skills*. Sessions facilitated by the mentor teachers focused on *Exemplary Curricula*, *Electric Circuit Activities*, *Cooperative Learning*, and *Journal Writing*. All staff members presented the afternoon sessions which centered on *Electricity Labs*, *Content Sessions*, *Reflection*, and *Teaching Preparations*.

Weeks Two and Three: Model Teaching Experiences

The second and third weeks provided the prospective teachers with opportunities to involve elementary children in the science activities that they had prepared and practiced. During these two weeks, the Master-Teacher-in-Residence and mentor teachers monitored the activities as the prospective teachers presented their lessons. Using their acquired effective instructional strategies, the prospective teachers engaged the elementary children in the *Electric Circuits* activities. The *Electric Circuits'* manual provided suggestions for using problem-solving skills with the activities that were selected. The culminating activity of the module involved teams of elementary children. Each team constructed a four-room house out of a cardboard box, designed a detailed plan for wiring the "house," and then used insulated wire, bulbs, single-and-double poled switches, and D-cell batteries to install the wiring in their "houses." A performance assessment was the finale of the week when the elementary children demonstrated the open and closed circuits in their cardboard box "houses."

Week Four: Field Experiences, Career Day, Reflection, and Culminating Activity

The fourth week involved the prospective teachers in a earth science field excursion, career day, reflection, and a banquet. The one-day field excursion included a historical and geological tour of the Roman Nose Canyon and three natural springs. A retired science education professor served as a guide for the excursion and emphasized the historical and cultural aspects of the canyon. The Native American, Chief Roman Nose of the Southern Cheyenne, settled this area in the 1800s. This experience helped the prospective teachers understand the interconnectedness of science and social studies.

A career day was sponsored by the School of Education and the Science Education Section of the Department of Chemistry. A variety of careers for math and science teachers were featured by several of the faculty members of the School of Education. The Elementary and

Secondary Undergraduate Education programs were described, and a question-and-answer session was provided. The prospective teachers were invited and encouraged to visit the campus during the following school year.

Journal writing was emphasized as a tool for continual reflection. Over the four-week academy, the prospective teachers participated in daily journal writing for reflection. Each afternoon, the prospective teachers were provided sufficient time to write in their journals. This reflection helped them capture their teaching, analyze their progress, and identify needs for further learning (Figures 2 and 3, below).

1. What activities did you do in the sessions today?
2. What did you learn in the content and investigation sessions today?
3. Were you puzzled about the concepts or activities in today's presentation?
4. Describe your enjoyments and/or dislikes in the sessions today.
5. Describe your accomplishments today.
6. In what ways can you describe your performance today?

Figure 2. Journal Format for Prospective Teachers for Week One.

1. Describe the elementary students in your group and how they responded to the activities.
2. How do you feel about this morning's teaching?
3. What did you do well during your teaching sessions?
4. If you were going to teach this lesson again, what would you do differently next time?
5. Please write additional thoughts or comments about today's teaching experience.

Figure 3. Journal Format for Prospective Teachers for Weeks Two and Three.

An evening banquet honored the prospective teachers and their parents. The evening's program included speeches by the site director and university faculty and the presentation of certificates by the Dean of the School of Arts and Sciences.

Data Collection and Outcomes

Data collected from the project, *A Summer Academy Program for Prospective Teachers:*

Model Teaching Experiences, included daily journals, collegial reflection, an evaluation instrument, *Perceptions of the Summer Academy*, and a follow-up questionnaire (Figures 2 - 4). Journal writing facilitated the prospective teachers in capturing their learning and

<p>1. Now that you have completed your participation in the A Summer Academy for Prospective Teachers: Model Teaching Experiences, what do you perceive as positive aspects of teaching as a <i>career</i>?</p> <p>2. What do you perceive as negative aspects of teaching as a <i>career</i>?</p> <p>3. How likely is it that you will choose teaching as a <i>career</i>? Please circle the number that matches your response.</p> <p style="text-align: center;">1 _____ 2 _____ 3 _____ 4 _____ 5</p> <p style="text-align: center;"><i>I will not be a teacher.</i> <i>I will be a teacher.</i></p> <p>4. If you are not planning to become a teacher, what other <i>career(s)</i> are you considering?</p>
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Figure 4. Follow-up Questionnaire for the Prospective Teachers

teaching, analyzing their progress, and identifying their needs for further learning and teaching (Figures 2 and 3).

Journal Writing from Week One: Capturing Their Learning

The prospective teachers responded to the question "What did you accomplish in the sessions today?" (Figure 2). The prospective teachers' responses reflected realistic aspects of teaching; i.e., how to:

- *Ask questions.*
- *Teach to the point that it is effective.*
- *Have patience and work together.*
- *Make science fun and easier.*
- *Effectively communicate.*
- *Write complete lesson plans and what to put in them.*

The prospective teachers identified some concepts that they learned from the lab and content sessions (Figure 2). Some of the described accomplishments were:

- *The ability to turn on a bulb with a battery and wire.*
- *I have the parallel and series circuits down.*

- *How to build a flashlight.*
- *I wired a cardboard box house and found that very rewarding.*
- *A broader understanding of electricity.*

Journals : Capturing Their Teaching and Analyzing Their Progress

Self-assessments are an important part of the authenticity established in constructivist teaching. A journal, a self-assessment tool, assists the reflective process when teachers record what they have done and what they have learned (Figure 3). The prospective teachers described their thoughts about their teaching experiences with the elementary children.

- *The children's performance was good; they participated well.*
- *My kids were great, and I can't wait until tomorrow.*
- *I was able to do better today than yesterday.*
- *I found that my performance gets better every day.*
- *Dealing with different personalities helps a teacher become strong and more open to new ideas and viewpoints.*

The prospective teachers' responses in their journals revealed that they analyzed their progress by assessing their performance (Figure 3).

- *My performance was good because everyone remembers what they learned.*
- *I was not as clear yesterday as I thought.*
- *My students seemed a little bored. I could have done better.*
- *I feel that I did very well relating to the students today.*
- *First, I thought I wasn't doing anything right, but after I saw the students understand what they were doing, I felt better.*

Journal Writings: Assertions

Analysis of the journal writings yielded two assertions (See Figure 3). The assertions focused on active participation and concrete experiences with science phenomena.

Assertion 1. Science learning is a process which requires active participation on the part of both the learner and the teacher.

- *That it depends on the way you ask questions to get the different answers.*
- *I learned to learn right along with them and have fun while learning.*
- *I taught about how things relate to the real world and got them thinking about*

conductors in their houses and around them.

Assertion 2. Engaging in concrete activities stimulates curiosity and promotes further investigation.

- *Today I learned that the kids learn by experimenting. Just by letting them experiment and then answer their questions.*
- *I learned that kids like to experiment and take their time.*
- *I learned that most kids enjoy science or should I say hands-on activities.*
- *I learned that the students have to touch everything no matter what.*

Collegial Reflection: Expressing Their Thoughts and Revising Their Beliefs

The afternoon debriefing sessions which were moderated by a panel including mentor teachers, the Master-Teacher-in-Residence, and university faculty, provided the prospective teachers with opportunities to share successes, challenges, and problems that they had encountered during that day of teaching (Figure 1). The exchange of ideas and the subsequent teaching suggestions provided support for their activities scheduled for the following day. From their comments, the prospective teachers appeared to be acquiring an appreciation of the nature of effective science teaching.

Perceptions of the Summer Academy

The evaluation instrument assessed the prospective teachers' perceptions of the design of the program and the individual benefits (Table 2, next page). The prospective teachers perceived that the hands-on activities were useful and that they became more comfortable using them. Seventy-five percent of the prospective teachers thought that the summer academy's experiences had improved their teaching ability. They identified working with the elementary children as a most valuable experience. Many of the prospective teachers stated that the *hands-on* time with the elementary children made the "things said during lecture make sense."

Item	No opinion (%)	Agree (%)	Strongly Agree (%)
Was interesting.	4	29	67
Hands-on useful.	0	25	75
Was worth the time.	4	29	67
Academy was fun.	0	21	79
More comfortable with hands-on.	4	33	63
Improved my teaching ability.	0	25	75
Program was excellent.	0	17	83

Comments:

Most valuable experience

- Teaching the elementary students.
- Being able to apply what we had learned when teaching the elementary students.
- The hands-on experience with the children.
- Getting to work with the children and the mentor teachers; also the friendships made.
- Helping students further their interest in math and science.
- Getting to work with the students really gave it a real life meaning and was enjoyable.
- Being able to teach using hands-on teaching methods.
- Hands-on time with the children; it made the things said during lecture make sense.
- Working with the kids in a classroom atmosphere.
- Learning teaching strategies and the hands-on.

Follow-Up Questionnaire

A major question on the survey was "How likely is it that you will choose teaching as a career?" Of the fourteen respondents, 49 percent responded that they plan to choose teaching as a career. Seven percent believe that they will not enter the teaching profession, and 36 percent are still unsure of a career choice (Table 3, opposite).

Conclusion

Based on the data collected, it was determined that the prospective teachers perceived the importance of hands-on activities, the roles of the learner and teacher, and effective questioning strategies. The prospective teachers' responses showed that 75 percent perceived

Table 3.	Follow-up Questionnaire: How likely is it that you will choose teaching as a career? (n=14)				
	<i>Will not be a teacher.</i>		Unsure	<i>Will be a teacher.</i>	
	1	2	3	4	5
Responses	1	1	5	4	3
Percent	7	7	36	28	21
<p>Comments:</p> <p>Positive aspects of teaching career:</p> <ul style="list-style-type: none"> • Sense of accomplishment. • Helping children. • Meeting new people. • Academy confirmed my ambition to become a teacher. • Summers off. <p>Negative aspects of teaching career:</p> <ul style="list-style-type: none"> • Challenge of children with special needs. • Frustrating sometimes. • Time required for planning. • Difficult profession. • Children not enjoying learning. • If kids don't learn. • Amount of patience needed. 					

the usefulness of hands-on activities and 63 percent replied that they were more comfortable teaching using activity-based science lessons (Table 2). In their journals, the prospective teachers described how the roles of the learner and teacher play an important part in the learning process (Figure 3). The general conclusion is that the prospective teachers began to perceive the importance of questioning in their teaching experiences. They discovered that using more advanced questions could result in more analytical thinking (Figure 3).

This program of summer academies to recruit potential teachers interested in mathematics and science is a step toward strengthening our educational system. The Third International Mathematics and Science Study [24] shows that “what we teach and how we teach” is what determines students’ achievement. During the academy these prospective teachers had access to outstanding teachers, exemplary curricula, and inquiry-based instruction. They had a glimpse of the need for teachers to be prepared to teach effectively. The prospective teachers learned, from practical experience with the elementary students, the importance of high expectations. The TIMSS [24] report shows a link between having higher expectations for students and getting better results.

A team of professors in the Department of Psychology at the University of Tulsa, the lead O-TEC institution, is tracking all prospective teachers who participate in O-TEC summer academies. Each O-TEC institution will be able to determine the number of prospective teachers who follow through with their interest in teaching as a career. The prospective teachers who attend O-TEC higher education institutions will be supported during their undergraduate programs. ■

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AN UNDERGRADUATE INTERN MODEL FOR MATHEMATICS TEACHER PREPARATION

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Introduction

Efforts to improve mathematics and science education are an important issue for our nations' schools. There has been an increased awareness of the need to do this with the release of the Third International Mathematics and Science Study (TIMSS) [1]. An important component of this effort is the corresponding updating of science and mathematics teacher preparation programs. The National Science Foundation has invested significant resources to stimulate the progress of reform in science and mathematics teacher preparation through several programs including Course and Curriculum Development, Undergraduate Faculty Enhancement, the Collaboratives for Excellence in Teacher Preparation and others. California State University, Chico, with NSF support (DUE-9354776), has developed and institutionalized a promising new teacher preparation model for middle and high mathematics teachers. This article contains a full description of the Chico model together with some preliminary findings on its impacts.

The traditional model for obtaining a teaching credential in California normally consists of content coursework for the first four years culminating in a Bachelor's Degree, followed by a "fifth year" certification program that includes student teaching. Those who are planning to teach at the middle or high school level usually get an undergraduate degree in their specific discipline. Hence, future middle and high school teachers of mathematics in the State of California generally obtain an undergraduate degree in mathematics and then go on to earn a single subject credential. This credential allows them to teach mathematics at both middle and high school levels. At this time California does not have a statewide program that certifies teachers to teach only at the middle school level as some states do.

The Chico model we will describe is one that is embedded into the undergraduate mathematics degree within the mathematics education option (the one for prospective mathematics teachers). The model consists of three new mathematics education courses together with a teaching internship for the prospective mathematics teachers, two new courses in developmental entry level mathematics based on proven secondary reform curriculum for entering freshman with mathematics deficiencies, and a faculty development program designed to attract and educate traditional mathematics faculty in reform pedagogy and curriculum. Following the new undergraduate experience, the preparing teachers still must complete the usual "fifth year" program. Initial assessment of this model provided through exterior consultants supported through the grant and through DUE's own "External Evaluation of NSF Undergraduate Course and Curriculum Development Program" are quite positive and support the need for additional research into the effects of the program. The primary groups effected by this reform initiative include university undergraduates in need of mathematics remediation, preservice mathematics education majors, and regular mathematics faculty.

The new preservice courses provide understanding of the philosophies, beliefs, objectives, methods, and pedagogy underlying current mathematics education thinking. These courses provide specific experiences facilitating lessons using various new reformed mathematics curricula at the middle and high school levels. Subsequent to their coursework, the preservice teachers are provided a highly structured field experience based on these ideas as they actually teach (under the supervision of mathematics education faculty), two new developmental courses. Coupled with this internship is a seminar conducted by the supervising faculty member. The materials used in the developmental courses are college versions of the Interactive Mathematics Program (IMP), a reformed secondary curriculum developed through NSF support at the Lawrence Hall of Science, UC Berkeley and San Francisco State University. The developmental audience is college students with entry-level mathematics deficiencies. Participating mathematics education instructors go through a comprehensive faculty development program consisting of in-depth teaching experiences with the IMP materials, team teaching new preservice courses together with experienced mentor faculty, and participation in seminars associated with the field experience for the preservice undergraduates.

Other Existing Programs

The NCTM Curriculum and Evaluation Standards [2] represent the first time that virtually all professional mathematics organizations have endorsed a set of national standards; middle and secondary level curriculum designed to meet these standards is only now becoming available. Consequently there is no history of preservice programs based on the new curriculum. That is not to say that there have been no projects that have attempted to implement mathematics education reforms as called for by NCTM. Of those projects that have been funded, most deal with in-service training rather than preservice. "Integrated Pedagogy and Content in Preservice Mathematics Teacher Education" (University of Georgia), "Improving Teacher Preparation in the Natural Sciences and Mathematics at Allegheny College", "Bridging the Gap Between Theory and Practice in Teaching Elementary School Mathematics: Using Research and Teaching in Reform Teacher Education" (Vanderbilt), and "Preparing Teachers to Teach Mathematics: A Problem Solving Focus" (Indiana University) are examples of recently funded NSF projects targeting training and curriculum development for reform mathematics. Perhaps the project that is most similar to the Chico model is the "Middle School Science and Mathematics Teacher Preparation Project" at Northern Arizona University. They have developed a five year model for the preparation of middle-school science and mathematics teachers. Academic abilities and teaching skills are developed followed by a "capstone" experience wherein students teach a summer camp under the direct supervision of master teachers and university professors.

We expect the number of teacher preparation projects integrating NCTM recommendations to grow as there is a general recognition within the mathematics community that teacher preparation and preservice programs are in need of improvement in light of the significant advancements in mathematics education methods and pedagogy. However, after thorough searching, the authors have found no ongoing projects like the Chico project that significantly integrate a year of undergraduate level content and methods instruction with extensive and well supervised field service experiences as recommended by NCTM, MAA and AMS. Further, none have attempted to look at reform ideas as they apply to remediation at the same time as they have developed programs for preservice teachers.

The Need for Reformed Teacher Preparation

There is a major component that is conspicuously absent in the implementation of

mathematics reform ideas into our schools; not so much a “knowledge gap” but more of a gap in the conceptual flow in the reform effort—the transition of effective strategies from the inservice to preservice levels. Teacher preparation programs have not themselves incorporated the advocated methods and content of the reform.

"Too few mathematics teachers are prepared to teach the mathematics their students need." [3]

The U.S. Department of Education recently funded researchers to observe and interview graduates of teacher preparation programs for a three year period. Known as the "Salish" study, researchers chose nine institutions that are members of the Salish consortium, a group of over 50 institutions interested in reform of preservice programs in science and mathematics education. One of the results of this study was that few new teachers were prepared to teach conceptual (constructivist) mathematics or make mathematics relevant to students' lives, as recommended in the NCTM Standards [3].

While all the "methods" courses in the Salish study emphasized conceptual mathematics and science, the preservice students' mathematics and science courses primarily relied upon traditional instruction. Because there were no opportunities for preservice teachers to practice the reform pedagogies they learned in their "method" courses, teachers ultimately tended to instruct mathematics in the more traditional ways they experienced in their college mathematics and science courses. A further deterrent to incorporating reform pedagogies in their practice was the generally conservative pedagogical environment found in most high school mathematics departments [4].

Thus, even for those leading universities that do have valuable experiences for preservice teachers using cooperative groups, embedded assessment ideas, higher level thinking skills, learning from a constructivist's viewpoint, etc., there is a serious problem in providing field experiences that continue to develop these ideas. If a student is exposed to excellent preservice coursework and becomes knowledgeable about these reform ideas, but then goes on to student teach or intern in a "traditional classroom" rather than a "reform classroom", then that student will likely interpret what took place at the university as “ivory tower ideals”. Rather than confirming the claims of current methods and curriculum, any suspicions that

classroom theories learned at the university may not really work at the practical level of middle and secondary teaching will be supported by their observations in the traditional setting. A traditional master teacher, uninformed in reform ideas, will further reinforce these suspicions. Hence, the transition to new mathematical ideas is stalled--or at the very least severely impeded. We need to train future teachers effectively so that they can (and WILL) immediately teach consistently with the goals and expectations put forth in the NCTM Standards. The NCTM *Professional Standards for Teaching Mathematics* [5] recognizes this and identifies the need for preservice teachers to be actively involved in learning environments that use our current knowledge base of mathematical learning during their teacher preparation. In addition, the Mathematical Association of America's Committee on the Mathematics Education of Teachers wrote:

"To change the teaching and learning of mathematics in the nation's schools, the preparation of teachers must also include developing an understanding of students as learners of mathematics, obtaining appropriate background in mathematical pedagogy, and constructing suitable classroom environments to foster learning by all students." [6]

Model Description

Curriculum for Preservice Undergraduates

A series of three new mathematics education courses is now being field tested and refined at California State University, Chico. The targeted audience is mathematics majors who are interested in teaching as a career. These courses are available early in the college experience of these students, normally in their sophomore or junior year. The prerequisite is successful completion of the first full year of calculus. The first two courses carry three semester units and the third carries four units.

The primary objective of the first of these newly developed courses is to provide the undergraduate students with the overall background of current mathematics education ideas as expressed in such documents as the TIMSS [1] report, and the NCTM Standards [2]. An expected outcome of this course is that students will obtain the necessary theoretical constructs that form the foundation for reform curriculum. To deliver these ideas, similar methodologies as used by the already proven California Mathematics Projects at CSU, Chico

for *in-service* training of veteran teachers is applied. This course (as well as the second and third) is based on a constructivist theory of teaching and learning and incorporates extensive use of cooperative groups, active use of manipulatives, and real applications of technology (in particular, graphing calculators). The first course is a blend of both mathematics content and pedagogy and has the theme of learning to think mathematically. The current course outline includes: mathematical problem solving, nature of mathematics, and conceptual understanding of mathematical ideas through manipulative approaches.

The second course takes the preservice students carefully through many examples of reform curriculum including the College Preparatory Mathematics Program, Core Plus, Connected Mathematics, Mathematics in Context, University of Chicago School Mathematics Project, Shell Centre materials and the Interactive Mathematics Program. The materials chosen serve the triple purposes of reinforcing middle and high school mathematics topics, illustrating new activities and approaches to classroom instruction and providing students experience employing reform methods and pedagogy. It is these same kinds of materials that will be delivered by the preservice students during the field service component of the program. The current course outline breaks reform curriculum into several units: elements of reform, learning theory and constructivism, collaborative learning and orchestrating discourse, and alternative assessment. A typical experience includes a student or pair of students delivering a short lesson taken from one of the materials cited above. Following the mathematics lesson, the class engages in discussion and analysis of the lesson in terms of the specific elements of reform incorporated into the lesson.

At the same time as students are enrolled in their preservice coursework, they become eligible to serve as “tutors” helping the current interns (see below). Typically two students are assigned to each internship class and allocated three hours of tutor time per week. The tutors are paid around \$6.50 per hour. The tutors are expected to spend at least two hours per week in the interns’ developmental class simply observing and helping with group activities. The tutors also help with grading and usually are provided opportunities near the end of the semester to develop and lead a lesson. This tutoring element of the preservice coursework is not required, but has proven to be a major advantage for those who can fit it into their schedule. Since the program is growing at a slow but steady pace there has been enough tutor positions to accommodate over 80% of the preservice students.

The Internship

In order to develop future mathematics teachers who can teach effectively with new curriculum, they must be confident and adept at using the methodologies that these curricula employ. Curriculum developers are very much aware of this as all of them either require, or strongly encourage, substantial inservice programs for teachers wishing to adopt their materials. At Chico, we accomplish this goal by *employing* those preservice students to teach a college adaptation of the IMP materials to college students who have entry level deficiencies. This preservice *internship* is structured using a collaborative team approach and is supervised by mathematics faculty who have IMP training and experience.

In addition to this *paid* teaching, interns enroll concurrently in the third course of the new program, a "de-briefing" four unit seminar that meets for a week prior to the beginning of the semester and then twice a week throughout the term. The seminar is conducted by a faculty member who also supervises the interns. The supervising faculty visits each remediation class two hours per week and shares the observations at the twice-weekly seminars. There is time designed into the seminar sessions for peer coaching, curriculum modification, discussion and implementation of alternative assessment ideas, performance outcomes, and other topics held to be essential elements of a truly professional teacher preparation program.

Developmental Curriculum

The Interactive Mathematics Project curriculum, developed through Eisenhower and NSF funding, is a well-defined, exciting four-year high school math program. The University of California has endorsed this mathematics program as meeting their A-F requirements for admission. Chico State faculty together with the IMP authors have developed and field tested a "college version" of these materials for use by community colleges and universities to help students who do not yet meet the entry level requirements to begin normal college level coursework. The high school version of these materials is now available through Key Curriculum Press. The importance of these materials to the preservice program is that they represent a model of reform oriented curriculum for the preservice interns to implement. What makes the IMP materials more attractive for our program than other reform curriculum (which may be pedagogically similar) are the comprehensive lesson plans that guide the teacher step-by-step through the new reform oriented classroom discussions and activities. These comprehensive lesson plans have proven to be of tremendous importance to both the

novice interns and the supervising faculty.

Faculty Development and Program Load Allocations

The new model also calls for significant faculty development. Initially, two faculty members attended IMP inservice sessions held at the Lawrence Hall of Science in Berkeley where they received the same type of training in using the IMP materials as provided secondary instructors who adopt the program. These two faculty members then taught the college version of the IMP materials to developmental students and incorporated the IMP training into the preservice curriculum. Once the program was established, other faculty who expressed openness to the ideas of reform were invited to go to Berkeley to learn about the IMP materials. Currently additional faculty who express interest in becoming involved in the program attend 24 hours of IMP training held over three or four days the week before school. The sessions are lead by our own experienced faculty mentors. These sessions are held the week before each semester and have elements of the IMP training built in; they are also required for the interns scheduled to teach in that semester. The new faculty then teach a section of the same developmental course as taught by the interns. The new faculty also participate as do the interns in the debriefing seminars. Subsequent to this experience, the training faculty member team-teaches the preservice courses with a mentor instructor who has completed the full training. At this point the newly-trained faculty member is ready to supervise the interns, orchestrate the debriefing seminars concurrent with the internship, and facilitate the preservice coursework as the lead mentor faculty who may or may not have a team teacher "mentor-in-training".

The NSF grant provided initial support for the training of the first generation of faculty to deliver the new model. In the future these costs will need to be absorbed by the campus. These faculty training costs are largely offset by the positive economics of remediation by undergraduates. (See "Program Economics" below). Faculty load allocations for trained faculty have followed somewhat of a "trial and error" process through the first years of the project. Load allocation to faculty for the first two preservice courses is standard, with three units allocated to each. The supervising faculty is allocated three units of teaching load to run the seminar and approximately one unit of load for each developmental course taught by interns that is supervised. At Chico State, a team of four faculty members currently runs the program. The typical pattern is for faculty member A to teach the first preservice course in

the Fall, faculty member B teaches the second preservice course in the Spring. Faculty member C, having taught the Fall preservice course the year before supervises and runs the debriefing seminars in the Fall for those interns who completed the coursework the year before. Faculty member D, having taught the Spring course the year before, supervises and runs the seminars for those conducting their internships in the Spring. In this way, each faculty member follows a "class" of preservice undergraduates for two years, with preservice teaching or supervision responsibilities every other semester.

Program Economics

During the Fall semester of 1995 nine interns and one graduate student who interned the prior year taught five remediation courses using college versions of the IMP curriculum. Each intern was paid \$1,000 and the graduate student was paid \$2,400. The college version of the IMP materials involves two semesters of work meeting five days a week. The interns taught four first-semester courses in teams of two or three and the graduate student taught one second-semester course alone. A total of 162 remediation students were served five contact hours per week at a total instructional cost of \$11,400. The cost of the tutorial aides mentioned before amounted to about \$500 per class (\$2,500 total). These same five classes, if taught by part time faculty, would cost approximately \$25,000. In years 1996-97 and 1997-98, a total of 21 developmental classes were taught by interns and tutors at an instructional cost of approximately \$56,000. This compares to part time costs without tutors or graders of approximately \$105,000. Although these low internship costs are a tremendous savings to the University and lower than all but a few community colleges, more importantly, the interns and tutors received the educational benefit of a rich field service experience under the direct supervision of University mathematics faculty. As pointed out above, these savings can be used to help justify the cost of future faculty training and recruitment.

Preliminary Results

Effects on Preservice Undergraduates

The initial NSF support for development of the reformed model included a modest budget for project assessment. Several assessment instruments designed to measure the impacts of the program on the preservice teachers were developed locally. Some of the measures are provided in the appendix. The primary questions addressed included the following:

- *How does the preservice experience affect the knowledge and attitudes of preservice teachers toward teaching in a reform environment?*
- *What effect does this preservice undergraduate experience have on the overall quality of preservice teachers once they enter the student teaching program?*
- *What effect does this preservice undergraduate experience have on the career objectives of the participants?*

Dr. Lily Roberts developed instrumentation to provide data revealing the answers to the above questions. The initial funding was not sufficient to conduct a significant longitudinal study to definitively answer most of these questions. Despite this, initial results have been quite positive and provide a strong case for continuing and expanding the study. In addition, we have received anecdotal information from the interns themselves, university faculty who have supervisory duties in the fifth year program, and master middle and secondary teachers in the field leading us to believe the program is having an extraordinary impact on some of the participants. Below is one of our favorite anecdotes:

One of our first interns to earn a credential recently accepted a teaching job at a high school in the Bay Area. For several days running, the Vice-Principal for Instruction would walk by and peer in at her class through a window in the door to her classroom. After several days of this, the Vice-Principal brought the Principal into her class and announced --"I wanted the Principal to see how mathematics should be taught!"

NSF provided another unexpected resource through their self-assessment process. The National Center for Improving Science Education (NCISE) had been contracted by NSF to assess the overall effectiveness of NSF-EHR-CCD funding. Chico was selected by NSF for exterior review by NCISE. At the annual Association of Mathematics Teacher Educators (AMTE) conference held in February 1997 in Washington, D.C., Dr. Ted Britton reported on the preliminary NCISE findings concerning the Chico project. Many of those findings affirmed that something new and successful was being developed.

"The mathematics students glowingly praised the experience for giving them an early opportunity to experience teaching. One of the most enthusiastic instructors

said: 'I can't imagine NOT doing this; I'd do it without pay.' While they found the learning difficulties and low motivation of some remedial students frustrating, it did not dissuade any of the fifteen undergraduate instructors we interviewed from wanting to become teachers." [7]

The preliminary anecdotal feedback and the findings of Dr. Roberts and NCISE indicate that such a reformed model may represent a major advancement in the preservice training of mathematics teachers.

Effects on Remediation Students:

Probably the single most important question related to the sustainability and replicability of the intern model like that at Chico is the effectiveness of the use of new reform curriculum by undergraduate preservice interns in terms of the success of the remediation students. In the initial NSF funding, the assessment component addressed the following questions:

- *What effect does having developmental mathematics curriculum based upon reform mathematics have on the overall success of the remedial student?*
- *How do the mathematical capabilities and attitudes of students remediated by preservice teachers compare to those taught by university faculty?*

To study these questions the principal investigators began tracking the mathematics histories of developmental students dating back to 1991. The earlier cohorts were taught by university faculty with traditional elementary and intermediate algebra materials. Developmental students are required to pass intermediate algebra or its equivalent prior to taking a university approved general education mathematics class. The number of students who had passed their general education mathematics class was tracked for each cohort. It was soon discovered that many developmental students deferred taking any math class for several semesters, despite passing the prerequisite developmental course. It was learned that six to eight semesters of history for each cohort must be studied before a true picture of the passing patterns emerges. The histories of the more recent cohorts of developmental students who have been remediated by the preservice interns are still in their early stages and will require several more semesters of study before comparisons can be made to earlier cohorts. A simple chart illustrating this information is provided in the appendix II. These initial findings indicate

no significant changes, positive or negative, from traditional remediation by regular faculty.

Impacts of Faculty Development on Teaching and Learning

The Chico preservice model incorporates an aggressive pursuit of faculty to get involved with mathematics teacher education. Five faculty members at Chico have completed this process in the past three years. One recently retired leaving the four who currently run the program. It appears that significant pressure for more faculty to become involved is building as the program grows. A new faculty member has just been hired and will begin their teaching assignment at Chico State by team-teaching the new courses described above with experienced faculty. Even though there is much anecdotal documentation about the strengths and effectiveness of the professional growth of the participating faculty, this does not come without some increased fears. The model has faculty working heavily in what may be considered non-traditional areas for mathematicians to be involved in, the teaching and learning of mathematics. Evaluators found concerns expressed:

"Some of the interviewed faculty and the department chair felt that these negative faculty members could put an assistant professor's tenure at risk if he/she placed any emphasis on education ahead of mathematics. One faculty member felt that one of these critics had 'placed fabricated damnations in the tenure file of a mathematics educator.' " [7]

It will be important for this model to continue to bridge the gap between traditional research oriented mathematicians and mathematics educators. Recommendations from the American Mathematics Society call for precisely this to happen. Having a program that has so many faculty and students directly effected may be the answer to make this tie become a reality.

Needed Additional Research

Longitudinal Assessment of Teacher Performance

If this preservice program represents a substantive improvement in teacher preparation, it must be well documented for policy makers and administrators to be persuaded to pilot such a program. In addition to the original research questions addressed through the NSF grant

the following questions should be addressed through a future longitudinal study of sufficient duration:

- *What effect does this reformed preservice undergraduate experience have on the overall quality of preservice teachers once they enter the workforce?*
- *To what extent are the preservice graduates ready to teach IMP or other reform curricula in the schools?*
- *Can the preservice graduates assume the leadership roles required to influence the adoption of reform in their schools?*

To get at these questions, it will be important to track graduates of the program in their early teaching years to answer questions such as:

- *How do mentor teachers supervising student teachers view/rank the level of preparation of those who experience the preservice program compared to those who don't?*
- *How do department chairs, principals, and other teacher supervisors view/rank the level of preparation of those who experience a reformed preservice program compared to those who don't?*
- *How do the mathematics students of new teachers view/rank the effectiveness of those who experience a reformed preservice program compared to those who don't?*
- *To what extent do those who experience the preservice program feel well-prepared to teach as they begin their careers?*
- *To what extent do those who experience the preservice program feel they are effective teachers early in their careers compared to other new teachers?*
- *To what extent do the preservice program graduates go on to become teachers who create student centered classrooms?*
- *To what extent do the preservice program graduates go on to become agents of mathematics education change in their schools?*

Can Remediation Drive Teacher Preparation Reform

The second critical need is the knowledge of the *effects of this teacher preparation program on college remediation efforts* when those efforts form the basis of the hands-on field experience. Knowledge that the preservice interns are obtaining major benefits from the reformed preparation program alone will not be enough to persuade policy and high level

decision makers to adopt the model if it comes at the expense of the remedial students. On the other hand, if additional research indicates equal or better learning taking place in the remedial classroom, strong incentives (educational AND financial) could begin to drive this reform effort on a systemic scale. The California State University System administers an Entry Level Mathematics exam to new students. The administrations in May [8], July [9], and October [10] of 1996 showed that 21,029 of 25,503 taking the exam (82.5%) statewide failed and therefore required some form of remediation. Nationwide, 60 percent of college mathematics enrollments are in courses ordinarily taught in high school. Perhaps this need will eventually be eliminated when national standards and higher expectations are in place in our nation's schools, but right now we have a severe problem. The California State University Trustees are searching desperately for cost-effective solutions to this remediation need. The Chico model provides remediation as a by-product of the internship component of the teacher preparation program at a fraction of the cost of remediation by regular faculty. In light of this tremendous need for remediation, the associated economic pressures represent a major force that could be harnessed to drive reform in teacher preparation if the reform in preservice teacher preparation can be shown to result in effective remediation.

The Link to Faculty Development

A third need for additional study relates to *faculty development in reform mathematics*. The following important questions have yet to be addressed.

- *When faculty receive special training and then deliver a reformed teacher preparation program, what impacts or changes are transmitted to their regular mathematics courses?*
- *What is the impact on the knowledge, attitudes, and beliefs regarding teaching and learning of faculty who experience the Chico faculty development program?*
- *To what extent do the ideas, methods, and pedagogy of reform transmit or diffuse from a reform teacher preparation program to the general mathematics faculty as a whole?*
- *How can other teacher preparation programs link with faculty development?*
- *How can incentives and rewards be structured within institutions to encourage growth in the number of faculty who participate actively in teacher education while developing an understanding and habit of practice of reform methodology and*

pedagogy?

Summary

In contrast to other modern teacher preparation programs, the Chico preservice model described above provides substantial opportunities for prospective teachers to not only learn about, but also practice employing reform pedagogies to teach mathematics. The new courses add a significant improvement to the overall education of future mathematics teachers, while the immediate transfer of those ideas to team-teaching intern experiences makes that knowledge concrete. The accompanying seminar that has all interns discussing their experiences and learning more about pedagogical ideas is the enhancement that is needed to create successful future mathematics teachers. One of the outcomes of this program is to create a teacher who views teaching as a professional endeavor and who discusses their teaching with other teachers and who views teaching as a lifelong learning experience.

At the same time we have created a more economical solution to mathematics remediation. Not only are the costs less than traditional approaches, the developmental students are given a different mathematical experience that is more useful to them in their future. Currently at Chico it is the case that developmental students who go through our developmental program are more successful than those students who test out of the program and can immediately take their General Education class. This fact may have nothing to do with our developmental program, but it may show that a modern approach to mathematics gives developmental students a better disposition to do mathematics.

Finally, the Chico model creates faculty who are much more concerned about the teaching and learning process. They have become more active professionally and report that their involvement in the teacher preparation program has positively influenced their mathematics instruction. ■

Appendix I**SAMPLE INSTRUMENTATION****Attitude Survey**

Every teacher has strengths and weaknesses, such as activities that s/he feels more confident about than others. For each instructional activity identified below, please check the box in the column that best indicates how confident you feel about your ability to carry out the activity successfully. If there is an activity listed that you do not use, please respond how confident you would feel in using that activity, but indicate that you don't use it currently by also checking the last column.

Instructional Activities	Very confident	Somewhat confident	Somewhat uncertain, but willing to try	Very uncertain, would like more preparation before trying	Don't use this activity currently, but indicated level of confidence
Lecture to students.					
Listen to students.					
Provide opportunities to do hands-on activities.					
Demonstrate hands-on activities with manipulatives.					
Have class discuss material related to math content with you and each other.					
Have students work in small groups.					
Facilitate group discussion or group processing.					
Encourage students to work with others regardless of ability level.					
Give students real-world problems to solve.					
Adopt new materials or otherwise revise curriculum as needed.					
Adopt new materials or otherwise revise curriculum based on student input.					
Encourage students to help others.					
Have students share responsibility for each other's learning.					
Use alternative forms of assessment (e.g., explorations, performance tasks, portfolio).					
Other, Please specify:					

Performance Tasks Inventory

Scenario 1: Pythagorean Theorem

You are going to teach the Pythagorean theorem. Describe how you will do this, including what you will consider before, during, and after you teach this class.

Scenario 2: Factoring Polynomials

You have several students in your class who complain that they just don't understand how to factor polynomials. Describe what you will do to address their complaints.

Scenario 3: Slope of Lines

You have to assess you students on their understanding of slope of lines. What are three possible assessment strategies that you might use and why would you use them?

Scenario 4: Teaching Philosophy

You are preparing your notes for Back-to-School Night. Describe the three most important points about your philosophy of teaching mathematics that you want to convey to parents.

Each task had its own 4 point scale and rubric. All intern papers were scored by the faculty in the program separately and differences in scores were mediated. The tasks were given as both pre and post measures. General characteristics of the rubrics included these ideas:

score	
4	describes at least one student activity in detail, including a description of why the activity works, or provides several such activities in less detail; an appropriate activity will clearly help students construct meaning
3	clearly a constructivist approach, but not exceptional
2	predominantly constructivist ideas, but a weak/minimal presentation or justification; possibly with a failure to address specifics of the scenario
1	may hint that learning is something done by students but doesn't go beyond that . . . or . . . totally teacher-centered . . . or . . . the respondent may lack necessary mathematical knowledge
0	doesn't address the scenario; little or no productive ideas

A typical response to a scenario can be characterized as either student-centered or teacher-centered. In broad terms, a student-centered approach provides opportunities for students to construct meaning while a teacher-centered approach focuses on feeding students information. A particular teacher-centered response might qualify as an excellent example of the use of non-constructive techniques of instruction, but it does not merit a high score in this rubric. One of the things this NSF grant was trying to measure was the increase in undergraduates understandings of teaching and learning from a student's perspective.

Open-ended Question Survey

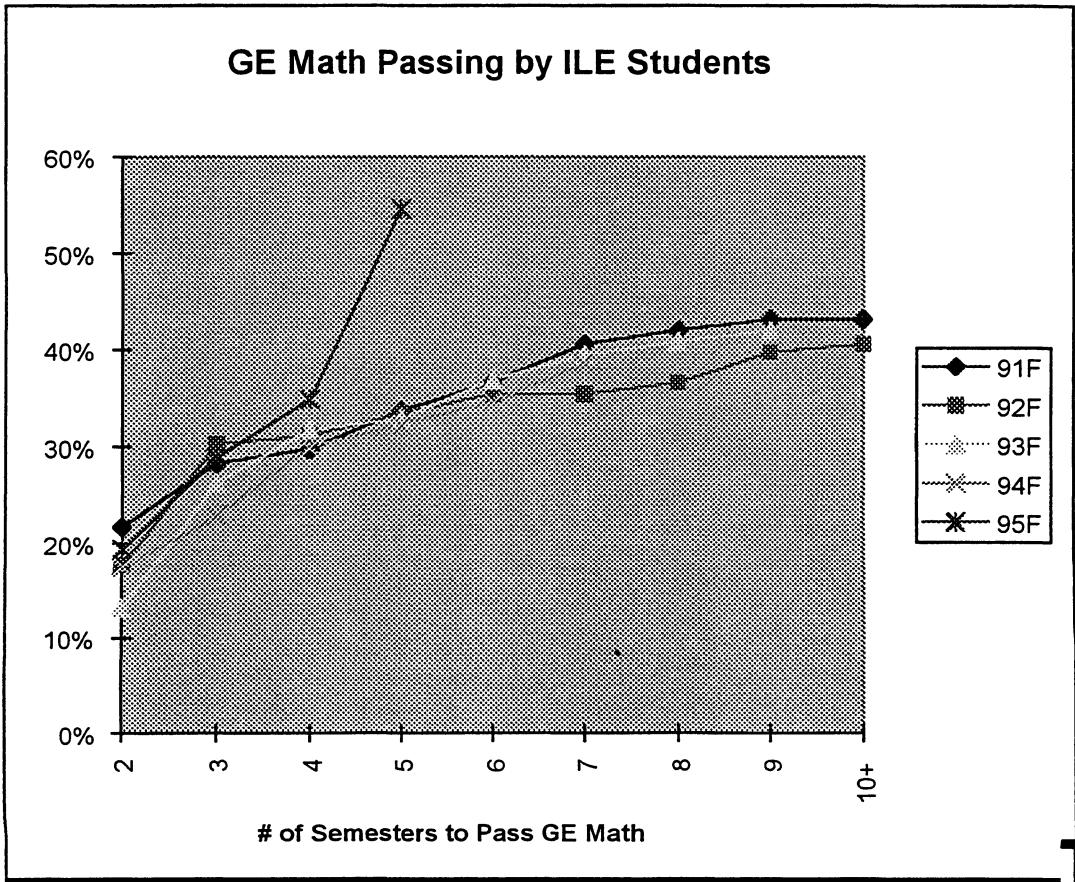
1. What do you do if you encounter a problem teaching this class? Who do you seek out for assistance (e.g., the professor or other students teaching Math 1)?
2. What has been your greatest challenge in teaching this course?
3. Ideally, what support is needed for undergraduate students teaching the Math 1 course?
4. Do you think the remedial students taking the course are receiving quality instruction? Do these students express any concerns about the quality of instruction?
5. Do you have any other comments or concerns about teaching this course?

Appendix II

Percent of Enrolled ILE Students who passed their GE math requirement

Year Enrolled	# Enrolled	+2 Sem	3 Sem	4 Sem	5 Sem	6 Sem	7 Sem	8 Sem	9 Sem	10+ Sem
91F	74	22	28%	30%	34%	36%	41%	42%	43%	43%
92F	96	18	30%	31%	33%	35%	35%	36%	40%	41%
93F	76	13	26%	32%	33%	37%	39%	41%	42%	
94F	127	17	23%	30%	32%	35%	39%			
95F	118	19	29%	35%	55%					

Note: 91F to 93F comprise the "PRE" group that were taught by regular faculty



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THE USE OF RESEARCH TO INFORM THE EVALUATION OF THE MARYLAND COLLABORATIVE FOR TEACHER PREPARATION

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Introduction

This paper presents a reflection on how the research conducted by a Research Group in Maryland Collaborative for Teacher Preparation (MCTP) informs the evaluation of the project. The MCTP is the only funded project within NSF Collaboratives for Excellence in Teacher Preparation Program (CETP) program that includes in its organizational structure both an Evaluation Group and a Research Group. This reflection by the Co-Directors of MCTP Research is conducted as a way to generate grounded theory [1] that will contribute new insight into the role of research and evaluation in CETP projects, in particular, and in all funded education projects, in general.

Structurally, the paper is presented in three sections. An overview of the MCTP and the MCTP research program are presented in the first section. Next, a review of the literature on evaluation and research is conducted in section two. Two sources for this review are NSF documents and publications of evaluation theorists. Lastly, in section three, reflections-on-practice of the use of MCTP research to inform evaluation are presented by the MCTP Co-Directors of Research.

Section One: An Overview of the MCTP and the MCTP Research Group

The MCTP

The MCTP is a National Science Foundation (NSF) funded statewide undergraduate program for students who plan to become specialist mathematics and science upper elementary or middle level teachers. The MCTP was funded originally in 1993 for up to a five year period, and in 1998 was funded for an additional three years. It is a project in the NSF Collaboratives for Excellence in Teacher Preparation Program (CETP) program. The CETP program "supports large scale systemic projects designed to significantly change

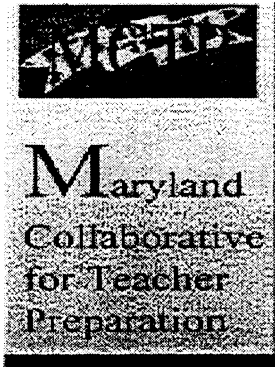
teacher preparation programs on a state or regional basis and to serve as comprehensive national models" [2]. Teacher candidates selected to participate in the MCTP program are, in general, representative of all teacher candidates in elementary teacher preparation programs in academic ability. MCTP teacher candidates are distinctive, however, by expressing an interest in teaching mathematics and science. Recruitment efforts have attracted many students traditionally underserved in the teaching force, most notably African Americans to the MCTP.

The goal of the MCTP is to promote the development of professional teachers who are competent to teach mathematics *and* science using technology, who can make connections between and among the disciplines, and who can provide an exciting and challenging learning environment for students of diverse backgrounds. This goal is in accord with the educational practice reforms advocated by the major professional mathematics and science education communities ([3] [4] [5]).

The MCTP was funded to create teacher education programs that contain (Figure 1, facing page):

- Specially designed courses in science and mathematics, taught by instructors committed to a hands-on, minds-on interdisciplinary approach.
- Internship experiences with research opportunities in business, industrial and scientific settings, and with teaching activities in science centers, zoos, and other institutions.
- Field experiences and student teaching situations with mentors devoted to the interdisciplinary approach to mathematics and science.
- Modern technologies as standard tools for planning and assessment, classroom and laboratory work, problem-solving and research.
- Placement assistance and sustained support during the induction year in the teaching profession.
- Financial support for qualified students.

Higher education institutions involved in this project include the majority of higher education institutions within the Maryland System responsible for teacher preparation. These include Bowie State University, Coppin State College, Frostburg State University, Morgan State University, Salisbury State University, Towson State University, University of Maryland Baltimore County, University of Maryland, College Park, and the University of



Program Overview

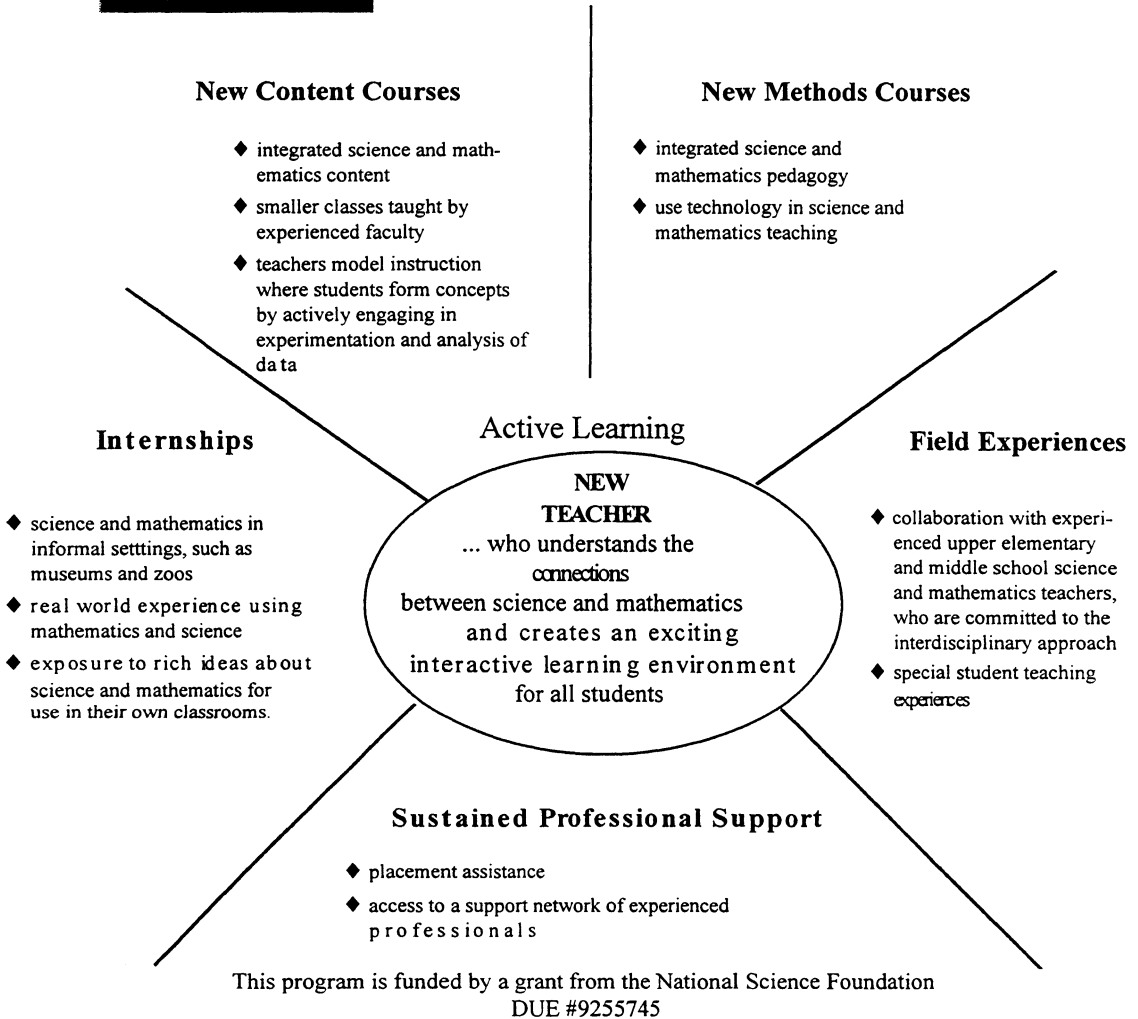


Figure 1. Program overview of the Maryland Collaborative for Teacher Preparation

Maryland Eastern Shore. Several community colleges also participate, including Baltimore Community College, Catonsville Community College, Prince George's Community College, and Anne Arundel Community College. In addition, large public school districts are active partners. These include these county public school districts: Prince George's, Montgomery, Baltimore, Baltimore City, and Allegany.

In practice, the MCTP undergraduate classes are typically taught by senior faculty in mathematics, science, and education who base primarily their course curriculum and instruction on two outcomes: 1) developing understanding of a few central concepts, and 2) making connections between the sciences and between mathematics and science. Faculty lecture is diminished and student-based problem-solving is emphasized which requires cross-disciplinary mathematical and scientific applications. These instructional strategies are thought within the context of the MCTP to be compatible with the constructivist perspective as recommended by the literature (e.g., student-centered, address conceptual change, promote reflection on changes in thinking, and stress logic and fundamental principles as opposed to memorization of unrelated facts) [6] [7]. In addition, faculty strive to infuse technology into their teaching practice.

The MCTP teacher candidates, selected by using criteria developed at each institution who provide evidence of an expressed commitment to specializing in the teaching of mathematics and science along with academic success in the learning of mathematics and science in precollege and college level courses, take the MCTP reformed undergraduate mathematics, science, and education courses offered at their campus. Furthermore, MCTP teacher candidates have the opportunity to apply for summer apprenticeships in Maryland mathematics and science rich environments under the guidance of a mentor at the site. A sampling of participating summer intern sites in 1998 included: Applied Physics Laboratory; Assateague Island National Seashore; Chesapeake Biological Laboratory; Horn Point Environmental Laboratory; Maryland Department of Natural Resources; NASA Goddard Space Flight; and the National Oceanic and Atmospheric Administration.

The MCTP Research Group

The proposal submitted to the NSF for the MCTP project included statements for both an Evaluation Group and a Research Group [8]. As typical, the proposal included a "Support

Group for Project Evaluation” section that stated that the project would conduct formative and summative evaluation. Innovatively, the proposal also included a “Support Group for Research on Teacher Education” section that stated the “project’s innovative approaches to teacher preparation will be studied by a research group....” (p. 19). These two support groups were displayed in a diagram that delineated their roles in the project structure (see Figure 2).

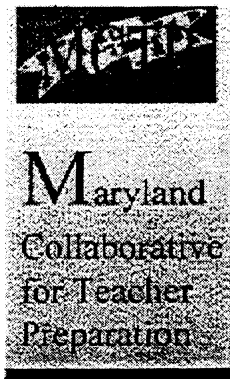
In essence, the primary purpose of research in the MCTP was articulated as the documentation and interpretation of the MCTP undergraduate mathematics and science teacher education program. The unique elements of the MCTP (particularly the instruction of mathematical and scientific concepts and reasoning methods in undergraduate content *and* methods courses that model the practice of active, interdisciplinary teaching) were targeted for longitudinal study from two perspectives: the faculty and the teacher candidate.

The research questions which were included in the grant proposal were:

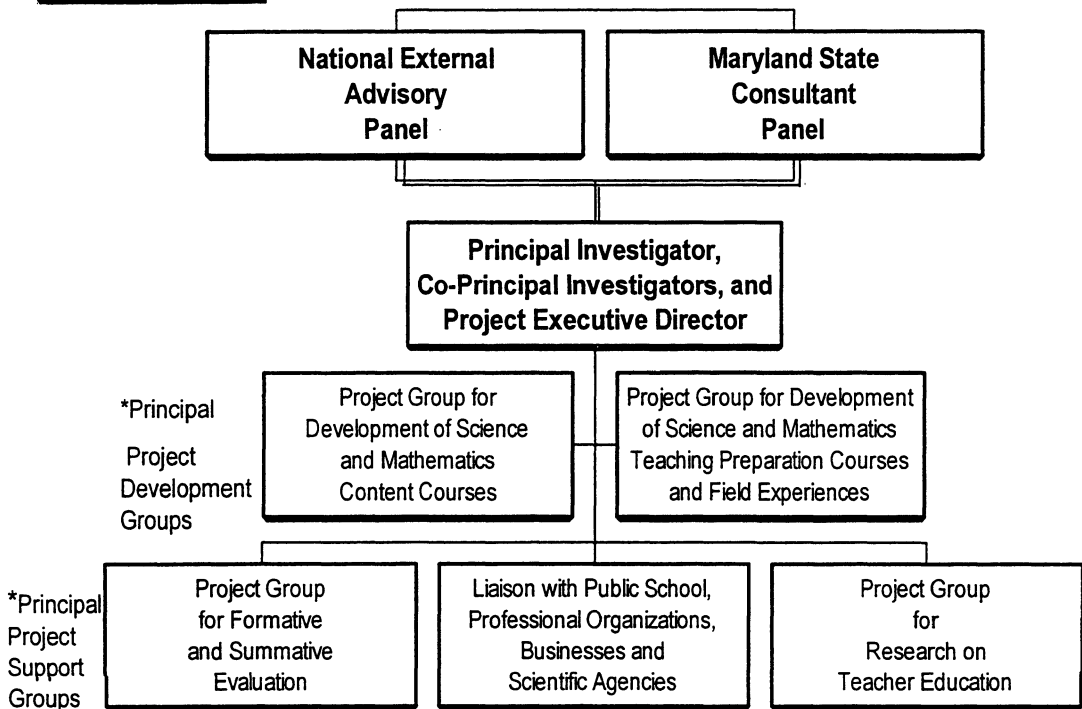
1. What is the nature of faculty and teacher candidates' beliefs and attitudes concerning: the nature of mathematics and science; the interdisciplinary teaching and learning of mathematics and science to diverse groups (both on the higher education and upper elementary and middle level); and the use of technology in teaching and learning mathematics and science?
2. How do the faculty and teacher candidates perceive the instruction in the MCTP as responsive to prior knowledge, addressing conceptual change, establishing connections among disciplines, incorporating technology, promoting reflection on changes in thinking, stressing logic and fundamental principles as opposed to memorization of unconnected facts, and modeling the kind of teaching/learning they would like to see on the upper elementary, middle level?

Answers to those questions were thought to inform the following research questions driving teacher education research in all subject domains:

1. How do teacher candidates construct the various facets of their knowledge bases?
2. What nature of teacher knowledge is requisite for effective teaching in a variety of contexts?
3. What specific analogies, metaphors, pitfalls, examples, demonstrations, and anecdotes should be taught content/method professors so that teacher candidates have



Program Structure



This program is funded by a grant from the National Science Foundation

DUE # 9255745

Figure 2. Program structure of the Maryland Collaborative for Teacher Preparation

some knowledge to associate with specific content topics?

While the original research questions served to orient the Research Group to the larger questions that need answers, over time additional research questions have emerged in response to the interest of members of the Research Group and in response to specific inquiries made by the NSF about the project:

1. Is there a difference between the MCTP teacher candidates' and the non-MCTP teacher candidates' attitudes and beliefs about mathematics and science?
2. Do MCTP teacher candidates' attitudes toward and beliefs about mathematics and science change over time as they participate in the MCTP classes?
3. How do the MCTP faculty perceive their own discipline as well as the other discipline (mathematics/science) with which they seek to make connections?
4. How do college faculty "model" good instruction in mathematics and science methods courses for teacher candidates and how is that perceived by the teacher candidates?
5. How do new specialist teachers of mathematics and science who graduate from an inquiry-based, standards-guided innovative undergraduate teacher preparation:
 - (a) view their subject disciplines;
 - (b) enact their roles as teachers; and,
 - (c) think about what they do when teaching science and mathematics with upper elementary/middle level students?

During the last five years, the MCTP Research Group has actively enacted a research program characterized by a multitude of diverse studies to answer these questions. Both hypothesis-testing and hypothesis-generation [9] research strategies have been used. Specific studies completed and ongoing as of this date include:

1. A Statistical Examination Of College Students' (Both MCTP Teacher Candidates And Other) Responses To A MCTP Attitude And Belief Survey On Mathematics And Science And The Teaching Of Those Subjects
2. A Discourse Analysis Of University Science And Mathematics Content Specialist And Pedagogy Professors' Perceptions About The Others' Discipline And Their Own
3. A Case Study Of Reform-Based Undergraduate Mathematics Teaching And Learning From The Professor And Teacher Candidate Perspectives
4. A Qualitative Analysis Of Faculty Perceptions On Modeling Making Connections

Between Mathematics And Science In An Innovative Undergraduate Teacher Education Program

5. A Qualitative Analysis Of Teacher Candidate Perceptions On Faculty Modeling Making Connections Between Mathematics And Science In An Innovative Undergraduate Teacher Education Program
6. An Action Research Analysis Of A Science Methods Professor Modeling Making Connections Between Mathematics And Science In An Innovative Undergraduate Teacher Education Program
7. A Case Study Of Six MCTP Teacher Candidates In Student Teaching
8. A Case Study of Five MCTP New Teachers in the Workplace (ongoing)

The MCTP supports an internet site (<http://www.wam.umd.edu/~toh/MCTP.html>) which provides information on the MCTP Research Group including full copies of the research reports.

Section Two: What Does the Literature State About the Role of Evaluation And Research?

To understand the intellectual contexts within the NSF and evaluation theorist communities that make it unusual for the MCTP to maintain both an Evaluation and a Research Group, it is helpful to conduct a selective literature review. This review first explicates how in its documents the NSF has defined evaluation and research. Second, this review summarizes how evaluation theorists have defined evaluation research, particularly the more contemporary view that argues for linkages between the two. Following this review, in Section Three, the researchers' reflections on how the research in the MCTP has informed the evaluation can then be assessed as to its contribution to the contemporary discussion on the relationship between evaluation and research.

National Science Foundation Documents

In 1981, The Joint Committee on Standards for Educational Evaluation defined evaluation as the "systematic investigation of the worth or merit of an object" [10]. The evaluation required by the MCTP to perform as a funded NSF project is described in the following manner:

Project evaluation...focuses on an individual project funded under the umbrella of the

program. The evaluation provides information to improve the project as it develops and progresses. Information is collected to help determine whether it is proceeding as planned; whether it is meeting its stated program goals and project objectives according to the proposed timeline (p. 11).

Research in the same document is defined broadly as “the general field of disciplined investigation” (p. 95). The general tone of this NSF document is that evaluation is conducted in a three step process (planning, formative, and summative) with a focus on quantitative data.

In a more recent NSF document on evaluation, there is a broadening of acceptance for evaluation data to include qualitative information in a mixed-methodological design [11]. Interestingly, words by Cronbach are included in that document which acknowledge that,

There is no single best plan for evaluation, not even for an inquiry into a particular program at a particular time, with a particular budget [12].

Publications of evaluation theorists

According to Worthen and Sanders, research and evaluation are nothing more than hypothetical constructs that provide us the conceptual space “to speak with consistency about certain approaches to the production of information or knowledge” (p.22) [13]. The difference between research and evaluation is apparent, “Research has many of the trappings of evaluation and shares with it many common activities, but it lacks evaluation’s explicit judgments of quality” (p. 23).

Similarly, for Smith and Glass the difference between research and evaluation is unambiguous. They state that research is “the disciplined search for knowledge” (p. 6) while “evaluation is the process of establishing value judgments based on evidence about a program or a product” (p. 30) [14].

Guba and Lincoln [15] propose a dramatic “mature” reconceptualization of evaluation which they term “fourth generation evaluation” (p. 8). This evaluation is based on two elements: responsive focusing and constructivist methodology. Responsive focusing requires determining “what questions are to be asked and what information is to be collected on the basis of stakeholder inputs” (p. 11). Constructivist methodology means “carrying out the inquiry process within the ontological and epistemological presuppositions of the constructivist paradigm” (p. 11). The product of the evaluation is not a set of value

judgments, but “rather an agenda for negotiation” of those claims, concerns, and issues not previously resolved. (p. 13). Guba and Lincoln, while never mentioning research directly, do discuss various “inquiries” (p. 163) which have differing purposes. One inquiry is to add knowledge or understanding in some way. An other inquiry is intended to assess some state of affairs. Their version of evaluation seeks to “eliminate the distinction between basic and applied inquiry” (p. 264). Interestingly, they claim that new roles emerge for evaluators in this fourth generation evaluation. While the traditional roles of evaluators were technician, describer, and judge, the fourth generation evaluator would take on the roles of “human instrument and human data analyst,” (p. 259) illuminator and historian, mediator of the judgment process, collaborator, learner and teacher, reality shaper, and change agent.

A recently well-received publication edited by Chelmsky and Shadish [16] provides thoughts on evaluation and research which promise to resolve the confusion of the roles of evaluation and research. Chelmsky [17], while continuing to acknowledge the traditional role of evaluation as determining the “efficiency of programs, projects, and their component processes,” also appears to support Guba and Lincoln’s reconceptualization of evaluation by recognizing evaluation as a process to “gain explanatory insights into social and other public problems and into past and present efforts to address them” (p. 9). The claim now is that “all of these purposes are legitimate” (p. 9). The different purposes are thought to fall into three general perspectives: evaluation for accountability (measurement of results or efficiency); evaluation for development (information collected to strengthen institutions); and evaluation for knowledge (acquisition of a more profound understanding in some specific area or field (p. 10). The role of the evaluator (distant to close) is dependent on which evaluation perspective is taken. Finally, key attributes of evaluation are for it to

Keep its skepticism about the conventional wisdom, its meticulousness about measuring achievements, its willingness to be persistent about getting the information out, and its dedication to democratic reform on the basis of knowledge (p. 25).

Section Three: Reflections-On-Practice In The MCTP

In the context of the continuing debate over the appropriate role of evaluation and research in large scale teacher enhancement projects such as the MCTP, we offer insights constructed from our five years of lived-in-practice as Co-Directors of the MCTP Research Group. Our insights regarding the evaluation and research efforts within the MCTP are presented as three researcher assertions. We believe these thoughts, in particular, underscore

the extent in which the three purposes of evaluation as explicated by Chelimsky and Shadish help to give direction to project investigators as they seek to fulfill NSF requests for accountability while simultaneously generating new knowledge on mathematics and science teacher preparation programs.

Assertion One: By necessity, a Research Group's work is a public activity within a project; Conversely, an Evaluation Group's work tends to be a private activity.

Because the Research Group focused on understanding the innovative teacher education program developed by the MCTP project from the participants' perspectives, our main research activity was to listen to the various stakeholders of the project: MCTP university/college faculty, MCTP teacher candidates, and MCTP mentor teachers. Moreover, because our aim was to share our findings with a wider audience, we needed to make sure that our analyses of data collected from MCTP participants were accurate and trustworthy. To do this, we often shared our tentative findings with the participants. This sharing sometimes happened in a group setting, such as a separate research reporting session during the summer MCTP conferences. Other times, we simply talked with individuals after they had a chance to read the MCTP research reports we mailed to them. Also, since so many participants in the project contributed data to our various studies, we found it beneficial to share our research reports expeditiously over the project's internet site. This public sharing also enabled interested parties outside of our project to share in our research findings.

On the other hand, the activities of the Evaluation Group remained essentially private. Members of the MCTP Evaluation Group did observe a number of MCTP designed/influenced mathematics and science courses, with the instructors permission, but oftentimes the instructors were the only ones who knew that the evaluators were visiting these courses. The MCTP evaluators' reports were provided to the MCTP Project Director who used them to guide the project and to write yearly reports for the NSF.

Assertion Two: The efforts of a Research Group can inform the evaluation within a project although tensions remain if the sole purpose of evaluation is perceived as for accountability.

Although most (if not all) of the MCTP participants came to accept the major premises of the MCTP philosophy underlying the teaching and learning of mathematics and science, many of them still wanted to have a third party "objectively" assess their activities. Many of

these participants turned to the Research Group for such an assessment, in part because the MCTP Research Group was highly visible within the project, in contrast to the Evaluation Group members. In addition, the MCTP PIs began publicly to portray the Research Group activities as a *part* of the evaluation of the project. At the beginning of the project, the MCTP Research Group conceived the roles of such an assessment to be in the domain of the Evaluation group. However, as we became more familiar with the perspective put forward by Guba and Lincoln and by Chelimsky, we, as a group, became more willing to accept that perspective of the role of evaluators. More specifically, we felt that we have something to offer in terms of evaluation for development as well as knowledge. Unfortunately, the MCTP participants, as well as the project leadership, often came with the view of a more traditional view of evaluation, evaluation for accountability. Sometimes, they wanted evaluation to inform their instructional activities (evaluation for development); however, they often expected quantitative/statistical data, comparing what they do against control groups. On the other hand, although the Research Group members became more willing to accept their activities as a type of evaluation, the main focus of the group remained on evaluation for knowledge. This mismatch of foci created some tensions between the interests of the Research Group and the MCTP participants, including the project leadership. This tension most often emerged as minor differences of opinion concerning which type of studies were of most important to conduct: studies that measured project impact as compared to exploratory studies.

Assertion Three: While the information that most shapes the PIs daily decisions about the project comes from the internal Evaluation Group, many of the PIs state that a lasting legacy of project is the Research Group products.

Due to the demands placed on the MCTP project by the NSF to collect and report data for accountability purposes, from our perspective the Evaluation Group shaped more of the project leadership's daily decisions than did the Research Group. However, the project leadership expressed appreciation for the Research Group's products as leaving a lasting legacy of the project. In a project characterized by lasting and widespread impacts difficult to measure and touch (such as faculty transformation) as opposed to more tangible products (such as new curricula), the reports by the Research Group offer hope that over time a record will be available documenting the energies devoted to the MCTP. This type of appreciation of the Research Group's efforts was supportive since the time required to collect data, analyze them, and report back to the project limited the immediate impact of the Research Group's

finding on the project.

Conclusion

We began our experiences viewing evaluation and research as two distinct, often incompatible, activities. However, our view of evaluation has broadened. We are now in agreement with the view that there are multiple purposes and perspectives of evaluation. Evaluation for accountability, which is often thought to be the primary purpose of evaluation, is important and necessary. However, evaluation for development can be of extreme value to the participants in a CETP project, or any large scale teacher preparation project. Moreover, evaluation for knowledge will inform a much wider audience, resulting in long lasting benefits to the educators beyond the specific project. Thus, it appears reasonable that future programs address these multiple perspectives in their evaluation activities. Therefore, we believe that the traditional conception of a dichotomy of evaluation and research should be recast. We concur with Chelimsky (with acknowledgment to Guba and Lincoln for initially challenging our thinking) that a more fruitful conceptualization for future evaluation activities is one based on multiple purposes: accountability, development, and knowledge generation.

Finally, in consideration of the best of all worlds, our experience leads us to strongly advocate for two separate groups working on different purposes of evaluation, such as we have enjoyed in the MCTP. The reason we hold this belief for two separate inquiry groups termed "Evaluation" and "Research" is the concern we hold for the quality of data. We believe that if one team handled all three purposes of evaluation as presented by Chelimsky [17] it would be difficult to obtain the rich valid data we have obtained from our project participants. It was our experience as members of a separate Research Group that the participants were open and honest with us. This form of openness and honesty was a refreshing difference from the guarded responses participants oftentimes offer those whom they see as evaluating them solely for the purpose of accountability. ■

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An earlier version of this paper was presented at the annual meeting of the American Educational Research Association, San Diego, California.

EDUCATIONAL RESEARCH ABSTRACTS

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Editor's Note: As noted in the first issue of The Journal of Mathematics and Science: Collaborative Explorations, the purpose of this Educational Research Abstract section is to present current published research on issues relevant to math and science teaching at both the K-12 and college levels. Because educational research articles are published in so many different academic journals, it is a rare public school teacher or college professor who reads all the recent published reports on a particular instructional technique or curricular advancement. Indeed, the uniqueness of various pedagogical strategies has been tacitly acknowledged by the creation of individual journals dedicated to teaching in a specific discipline. Yet many of the insights gained in teaching certain physics concepts, biological principles, or computer science algorithms can have generalizability and value for those teaching in other fields or with different types of students.

In this review the focus is on "assessment." Abstracts are presented according to a question examined in the published articles. Hopefully, such a format will trigger your reflections about exemplary math/science assessment as well as generate ideas about your own teaching situation. The abstracts presented here are not intended to be exhaustive, but rather a representative sampling of recent journal articles. Please feel free to identify other useful research articles on a particular theme or to suggest future teaching themes to be examined. Please send your comments and ideas via email to gmbass@facstaff.wm.edu or by regular mail to The College of William and Mary, P. O.Box 8795, Williamsburg, VA 23187-8795.

Assessing Student Performance in Mathematics and Science

"If tests determine what teachers actually teach and what students will study for - and they do - then test those capabilities and habits we think are essential, and test them in context."

Grant Wiggins (1989), President and Director
Center on Learning, Assessment, and School Structure

What is the purpose of testing students? Should tests serve an auditing function that simply provides a specific score for each student's performance? Should tests be the chief incentive that motivates student effort? Should tests be the key mechanism through which teachers determine merit ratings and placement decisions for individual students? Should tests be one component of a system that improves learning and instruction? Wiggins clearly believes testing is only one part of the larger issue of assessment and that the primary purpose of student assessment is for students to learn better and for teachers to teach better.

The National Council of Teachers of Mathematics published in 1989 their influential Curriculum and Evaluation Standards for School Mathematics. They categorized their fourteen evaluation standards according to a focus on general assessment, student assessment, and program evaluation. Four key themes underlie the 1989 NCTM evaluation standards:

- student assessment be integral to instruction;
- multiple means of assessment methods be used;
- all aspects of mathematical knowledge and its connections be assessed; and
- instruction and curriculum be considered equally in judging the quality of a program

Very practical classroom applications to assess what student know and how they think about mathematics were identified in that document. The Standards advance more attention to such assessment strategies as taking a holistic view of mathematics, developing problem situations that require the application of a number of mathematical ideas, and using standardized achievement tests as only one of many assessment indicators. (The 1989 NCTM Standards can be accessed on the Web at http://standards-e.nctm.org/1.0/89ces/Table_of_Contents.html)

Recently, the National Council of Teachers of Mathematics released a draft copy of their updated "Principles and Standards for School Mathematics." (The Standards 2000 project report can be found at <http://www.nctm.org/standards2000/>). These standards for the 21st century continue the emphasis on good assessment practices. The Assessment Principle guiding the new NCTM recommendations states "Mathematics instructional programs should include assessment to monitor, enhance, and evaluate the mathematics learning of all students and to inform teaching." In their continued emphasis on assessment as a process, the Standards 2000 draft asserts that teachers need to utilize a classroom assessment cycle that involves four key activities: Setting clear goals (planning assessment); Gathering evidence using various methods; Interpreting evidence (making inferences); and Making decisions

(taking action.) In the web-version of the Standards, electronic examples of how teachers can practice “best assessment” in each part of the cycle are illustrated.

In 1991 the National Research Council initiated an ambitious effort to develop national standards for science education in content, teaching, and assessment. They proposed five assessment standards:

- A: Assessments must be consistent with the decisions they are designed to inform;
- B: Achievement and opportunity to learn science must be assessed;
- C: The technical quality of the data collected is well matched to the decisions and actions taken on the basis of their interpretation;
- D: Assessment practices must be fair;
- E: The inferences made from assessments about student achievement and opportunity to learn must be sound.

However, it is in Teaching Standard C that the National Science Standards advocate “best practice” for teachers’ classroom assessment:

TEACHING STANDARD C:

Teachers of science engage in ongoing assessment of their teaching and of student learning. In doing this, teachers

- Use multiple methods and systematically gather data about student understanding and ability.
- Analyze assessment data to guide teaching.
- Guide students in self-assessment.
- Use student data, observations of teaching, and interactions with colleagues to reflect on and improve teaching practice.
- Use student data, observations of teaching, and interactions with colleagues to report student achievement and opportunities to learn to students, teachers, parents, policymakers, and the general public.

Clearly, student assessment is a very important part of educational reform in both mathematics and science. Amid the national claims and counterclaims as to the best way to conduct student assessment, it is often difficult for a K-12 teacher or college professor to know what exactly what kind of testing to do. In that context it is valuable to remember what

Elizabeth Badger, the Director of Assessment for the Massachusetts Department of Education, said in 1992,

“A perfect test or perfect task does not exist.... Almost any task can be used, provided that we recognize what information we want to obtain from it.”

How do teachers from elementary school through university level assess student achievement in mathematics and science? Are current practices the best ways to assess student understanding in mathematics and science? What alternative assessments techniques are being promoted and pilot-tested in mathematics and science classrooms? What valuable lessons have been learned from classroom research? What recommendations do K-12 and college-level instructors publicly offer about student assessment? The following set of articles provides a sample of recent academic writings on the subject of student assessment.

• **How can science professors make course examinations more creative, more meaningful, and more useful?**

“Every faculty member knows that exams drive student behavior.” So begins the preface to the 1997 book *The Hidden Curriculum - Faculty-made Tests in Science* by Sheila Tobias and Jacqueline Raphael. A year earlier they used the same quote to begin this article exploring how new theories about testing might lead college professors to new assessment practices. Findings from cognitive science research investigating expert-novice differences and the subject-specific heuristics in various disciplines have led college faculty to reconsider their teaching goals, classroom practices, and student testing procedures. For example, the Force Concept Inventory developed by physics educators David Hestenes and Ibrahim Halloun has verified that passing a college physics course does not eliminate many students’ misconceptions about force, mass, acceleration, and mechanics. Increasingly, other science professors have recognized that tests emphasizing algorithmic problem-solving strategies (“plug-and-chug”) will not necessarily encourage nor assess the students’ conceptual understanding of scientific principles.

Tobias and Raphael lament that most individual professors’ in-class testing innovations never become widely known among their colleagues. Their study of college science professors was intended to remedy this unfortunate circumstance. They collected 160 narratives of college science faculty’s efforts to integrate course curricular goals with new examination

strategies. In this article they highlight a sample of innovative science testing while a fuller description is available in their book. Among the new assessment practices they identify:

- Portfolio assessment by an astronomy professor
- Multi-step, “real-world” chemistry problems by an introductory chemistry professor
- Group format midterm exams by an earth science professor
- Optional grade-performance contracts by an organic chemistry professor
- Grading students’ work for both content and coherence, i.e. algorithmic solutions and conceptual understanding, by a physics professor

In separate focus group interviews with undergraduate and graduate students, Tobias and Raphael examined what both science majors and non-science majors thought of their science exams. Short answer and essay questions were preferred to multiple choice items. Grading students’ performance “on the curve” was felt to introduce competition and relative comparisons that students felt often masked knowledge gained through hard work. Timed tests were also seen as adding unnecessary stress to an already tense test-taking situation. In general, students wanted a diversity of assessment strategies used in their science courses, because of the diversity of learning styles among the students. In this article Tobias and Raphael introduce a variety of testing strategies used in actual college science classrooms and point the interested reader to a fuller description in *The Hidden Curriculum*.

S. Tobias and J. B. Raphael, “In-class examinations in college-level science: New theory, new practice”, *Journal of Science Education and Technology*, 5 (4), 311-319 (1996).

• **How can mathematics teachers improve their classroom test items?**

In the 1995 Assessment Standards for School Mathematics, the National Council of Teachers of Mathematics recommends teachers use multiple and complex assessment tools to judge “each student’s attainment of mathematical power.” The NCTM report advocates the increased use of performance tasks, projects, writing tasks, oral presentations, and portfolios and the decreased use of chapter quizzes and tests. Denise Thompson, Charlene Beckmann and Sharon Senk do not challenge the value of that recommendation, but they do contend there are strong practical reasons why classroom math teachers will continue to use in-class tests. They do propose ways to analyze and modify typical classroom tests that are

reasonably objective, easy to implement, and consistent with NCTM recommendations.

Thompson and her colleagues have created a test item classification scheme with which teachers can examine their classroom tests. Eight categories (*item format; level; skill; real context; open-ended; graphical representation; reasoning; technology*) can be used to analyze and then modify test questions to reflect the most important aspects of the mathematical curriculum. For example, *level* helps the teacher differentiate prerequisite skill items that require one or two steps to complete from other items requiring multiple steps. The *graphical representation* category reminds the teacher to identify test items that (1) entail graphical interpretation to find the answer, or (2) require a graphical construction as the answer, or (3) provide a graph that is superfluous for finding the answer, or (4) provide no graph or diagram. The *technology* category helps identify items that require a tool, permit a tool, or exclude the use of a tool. They use test items in algebra, geometry, and precalculus to illustrate how their approach can indeed produce exams that align with the NCTM mathematical content and processes. As Thompson, Beckmann, and Senk point out, "Students tend to value what is graded." Therefore, graded class tests should reflect what important concepts and skills teachers indeed value.

D. R. Thompson, C. Beckmann, and S. L. Senk, "Improving classroom tests as a means of improving assessment", *The Mathematics Teacher*, 90 (1), 58-63, (1997).

- **How can a professor use a student's misunderstanding on a class exam to increase physics learning?**

Any teacher who has ever given an exam knows there is often a wide gap in what students think they have learned and what teachers think they have taught. In fact, a course exam lets both student and teacher get a more public confirmation of what was learned (and not learned!). Unfortunately, some students only realize their misunderstanding after they have been confronted with a test problem they fail to complete successfully. Is it too late to use such "painful enlightenment" as an integral part of the teaching/learning process? While an exam should be a reliable and valid measure of student understanding, it can also be an assessment that guides future learning.

Thomas Ammirati, a physics professor, asks the intriguing question "Why not treat a student's test performance as a work in progress?" In recent years his students had expressed their frustration with physics exams that resulted in a low class average, e.g. below 70. Ammirati recognizes that his discouraged students might explain the overall poor class performance to unrealistically difficult test questions, to students' lack of ability and/or effort or, worse yet in his mind, to overall poor teaching. To remedy both his students' and his own frustration, he began offering students the option of reworking exam problems they originally had not completed successfully. He allows students to redo selected problems under "open book" circumstances, to meet with him individually for a review of this revised work, and to submit that work for him to regrade. Students can earn up to 50% of the lost points for each problem they successfully revise. Ammirati sees this targeted test revision opportunity allowing students to clarify and relearn misunderstood physics principles as well as add points to their test grades. He acknowledges that his conferencing with students is time intensive, but he has not had to add additional office hours. Now he really has students use his normal office hours to meet with him. His apprehensions that students might take the original exam less seriously has not happened since students are never sure which test items they will have the opportunity to revise. Finally, he believes students work toward a better understanding of physics through these problem revisions because they also know there is no revision option on the final exam. His students are better prepared for the final because they have a better understanding of the physics material covered in the course.

T. Ammirati, "Targeted test revision- another approach to science testing", *Journal of College Science Teaching*, 28 (2), 117-120 (1998).

- **How can testing in large lecture course actually lead to more interactive student learning?**

Since so many introductory college science courses are taught in large lecture settings, beginning college science students must not only master the challenging course content, but do it in a format that makes two-way communication with the instructor difficult. Course exams do provide students feedback about tested concepts, but seldom are given frequently enough to compensate for the large class size. In his chemistry course (83 students enrolled),

Thomas Holme regularly uses a technique he calls Interactive Anonymous Quizzes. He typically gives students a few multiple-choice questions that focus on key chemistry concepts at the beginning of the class. Students are given a few minutes to select the correct answer and to indicate their level of confidence ("Very confident," "Somewhat confident," "Just guessing"). Students are next given three minutes to convince those seated near them that they are correct. After these peer discussions, the students are again asked to select the alternative they believe is correct and indicate their confidence level. The students' quizzes are collected anonymously at the end of the class at which time the professor provides the correct answer.

Holme believes this simple technique helps both the professor and students. The teacher is able to scan the student answers very quickly to see if the most of the class understands each item. For questions with poor student performance, the professor can plan how to clarify or reteach key principles. The students are able to get almost immediate feedback on their chemistry understanding, first from other students and eventually from the professor.

Holme has used Interactive Anonymous Quizzes in classes as large as 250 students. He observes that only rarely do students change from the correct answer to an incorrect answer. Students regularly express more confidence in their answers after talking with peers even if they originally selected the correct answer. In most cases a sizable percentage of students (20% to 34%) switch from the wrong answer to the correct one on each item. Holme concludes these quizzes provide improved communication and student interaction which results in greater learning. Holme further reasons that the short amount of class time spent on these quizzes and relatively nonintrusive way it can be incorporated in a large lecture course makes Interactive Anonymous Quizzes an effective testing-teaching technique.

T. Holme, "Using interactive anonymous quizzes in large general chemistry lecture courses", *Journal of Chemical Education*, 75 (5), 574-576 (1998).

Additional Resources on Assessment Research and Practice

Some helpful electronic resources to explore:

Balanced Assessment in Mathematics is a National Science Foundation project charged with

developing new approaches to the assessment of mathematical competence in the elementary and secondary grades.

<http://edetc1.harvard.edu/ba/>

The ERIC® Clearinghouse on Assessment and Evaluation seeks to provide 1) balanced information concerning educational assessment and 2) resources to encourage responsible test use.

<http://ericae.net/MAIN.HTM>

Assessment & Evaluation on the Internet is a very complete list of links to other websites and documents on 40 topics from Action Research to Tests Online including mathematics and science assessment.

<http://ericae.net/intbod.stm>

Pathways to School Improvement

This website is a product of the North Central Regional Educational Laboratory in cooperation with the Regional Educational Laboratory Network and provides research-based resources and assistance to educators on a wide variety of topics including evaluation and assessment.

<http://www.ncrel.org/ncrel/ncrel/ncrel/sdrs/areas/as0cont.htm>

The Eisenhower National Clearinghouse for Mathematics and Science Education provides educational journal articles, teaching programs, and educational standards on the latest teaching trends and developments including assessment. For example, "Assessment in Action," a collaborative action research report focused on mathematics and science assessments, reports of twenty-three teacher research projects is found on this site.

<http://www.enc.org/>

Developing Educational Standards is an annotated list of Internet sites with K-12 educational standards and curriculum frameworks documents, maintained by Charles Hill and the Putnam Valley Schools in New York.

<http://putwest.boces.org/StSu/Science.html>

Some useful books on assessment to examine:

Mathematical Sciences Education Board, *Measuring what counts*, National Academy Press, Washington, DC, 1993.

G. Phye, *Handbook of classroom assessment*, Academic Press, San Diego, CA, 1997.

W. Popham, *Classroom assessment, what teachers need to know*, Allyn & Bacon, Needham Heights, MA, 1995.

T. Romberg, *Reform in school mathematics and authentic assessment*, State University of New York Press, Albany, NY, 1995.

S. Tobias and J. Raphael, *The hidden curriculum part I*, Plenum Press, New York, 1997.

S. Tobias and J. Raphael *The hidden curriculum part II*, Plenum Press, New York, 1997.

G. Wiggins, *Educative assessment, designing assessments to inform and improve student performance*, Jossey-Bass Publishers, San Francisco, 1998.

A I M S & S C O P E

Articles are solicited that address aspects of the preparation of prospective teachers of mathematics and science in grades K-8. The Journal is a forum which focuses on the exchange of ideas, primarily among college and university faculty from mathematics, science, and education, while incorporating perspectives of elementary and secondary school teachers. The Journal is anonymously refereed, and appears twice a year.

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- reports on projects that include evaluation
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