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ABSTRACT

Reforms advocated for elementary school mathematics call for knowledge few teachers possess--knowledge about content, inquiry, and the pedagogical use of mathematical knowledge. As part of a larger study, researchers at the National Center for Research on Teacher Education interviewed methods instructors at a sample of college based preservice programs. An initial examination indicates that methods instructors could take responsibility for this content, but might prefer to concentrate on attitudes toward mathematics and on specific teaching methods. The question arises, then, of who should take responsibility for future teachers' knowledge of mathematical content. One suggestion is to organize the methods course around mathematical experience, but to use the experience to help teachers live through a different type of learning. In such a course, the methods students observe an elementary school class in which the students conjecture about mathematical ideas, challenge each other's hypotheses, and seek proof for ideas presented. It is acknowledged, however, that the reforms called for by the National Council of Teachers of Mathematics (1989) go beyond mathematics methods courses and therefore may not be easy to attain. (Author/JD)

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National
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on Teacher Education

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Abstract

Reforms advocated for elementary school mathematics call for knowledge few teachers possess--knowledge about content, inquiry, and the pedagogical use of mathematical knowledge. An initial examination indicates that methods instructors could take responsibility for this content, but might prefer to concentrate on attitudes toward mathematics and on specific teaching methods.

LEARNING ABOUT MATHEMATICS IN ELEMENTARY METHODS COURSES

Robert E. Floden, G. Williamson McDiarmid, and Nancy Wiemers[1]

Methods instructors have inherited major--perhaps primary--responsibility for ensuring that elementary-school teachers have the knowledge they need about mathematics. Elementary teacher candidates seldom take more than one or two college courses in mathematics, after high school studies that may have included *no* mathematics courses in the final year or two. Mathematics is unlikely to be a major focus of other professional courses, most of which deal with other subjects or with general processes of teaching and learning. Whether by choice or by default, the burden for developing elementary teachers' mathematical understanding falls on methods instructors.

Proposals to require subject matter majors for elementary teachers are unlikely to shift this responsibility. Because elementary teachers seldom see mathematics as their favorite subject and often lack confidence in their mathematical abilities, they are unlikely to major in mathematics. Whether they major in English or elementary education, however, elementary teachers will continue to teach mathematics. Methods instructors will continue to be charged with providing the subject-specific knowledge they need.

The importance of this charge is increasingly salient. Several recent analyses (e.g., Buchmann, 1985; Grossman, 1989; Holmes Group, 1986; McDiarmid, Ball, and Anderson, 1989; Shulman, 1986, 1987; Wilson and Wineberg, 1988) have stressed the centrality of subject matter knowledge in teaching. Trends to increase emphasis on teaching for understanding (e.g., Porter, 1989; Prawat, 1989) make teachers' subject matter knowledge even more essential.

Thus, as practitioners, scholars, and policymakers consider changes in teacher education programs and requirements, the role of methods courses deserves careful, informed discussion. Decisions about change should be based both on a vision of what preparation might be like and on an understanding of the accomplishments and limitations of what preparation now is. To push that discussion along, we compare two prominent goal statements with examples of current practice. The National Council of Teachers of Mathematics (NCTM) has drafted standards for mathematics teaching (National Council of Teachers of Mathematics, 1989) that address what elementary teachers should know. In foundational work for the National Board of Professional Teaching Standards, Shulman

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(1986) has provided a more encompassing description of what teachers need to know about the subjects they will teach. We use these statements as lenses for considering current elementary mathematics methods instruction at three universities.

What Should Elementary Teachers Know About Mathematics?

In their recently released "Professional Standards for Teaching Mathematics" (NCTM, 1989), the National Council of Teachers of Mathematics offers a varied and broad definition of the kinds of mathematical knowledge and understanding teachers need, as well as recommendations for how professional development programs can assist teachers in acquiring such knowledge. The standards set forth by NCTM hold teachers accountable for a range of knowledge including knowledge of mathematical concepts and procedures; knowledge of mathematics as "a network of interconnected processes, concepts, and procedures with applications in other disciplines and in society" (NCTM, 1989, p. 133); the capacity to demonstrate mathematical reasoning; and knowledge of "various aspects of problem solving, including formulating and posing problems, applying a variety of strategies to solve problems, solving problems by various means, verifying and interpreting results, and generalizing solutions" (NCTM, 1989, p. 134).

These expectations for teachers' mathematical knowledge go well beyond conventional notions about what teachers need to know in order to teach. According to these standards, teachers need not only a thorough grounding in mathematical propositions and procedures--what most people have in mind when they think about mathematical knowledge--but a perspective on mathematics as a field, including an appreciation of the processes and standards of reasoning used in mathematical inquiry. These processes and standards guide interpretation and evaluation of the propositions, ideas, theories, and procedures that constitute the substance of the discipline. They enable one to judge, for instance, how much evidence exists for an idea and whether that evidence is sound. Mathematics is not a "cut and dried" subject consisting of procedures, formulas, and rules that must be memorized, but is rather a product of reasoning, amenable to collective sense making. Teachers with this perspective would likely try to foster classroom discourse: "Emphasizing reasoning and justification implies that students should be encouraged and expected to question one another's ideas and to explain and support their own ideas in the face of others' challenges" (NCTM, 1989, p. 14).

Shulman and his colleagues (Grossman, 1989; Shulman, 1986, 1987; Wilson, Shulman, and Richert, 1987) have also pointed out that subject matter knowledge--even broadly defined--is an insufficient basis for teaching. Teachers must understand, not only the content they would teach, but also ways of presenting and representing the content that will promote pupil learning. Shulman coined the phrase, "pedagogical content knowledge," to

refer to such knowledge, of which the most prominent part is the ability to create and evaluate analogies, metaphors, and examples of subject matter concepts.

Program designers must consider where teachers will acquire this additional substantive knowledge, understanding of mathematics as a field of inquiry, and pedagogical content knowledge. Which aspects of mathematical understanding should be the province of methods courses? Where and how might other aspects be learned? Discussion of these questions can be informed by considering what methods instructors currently attempt to accomplish and what they assume about the processes by which teachers learn about subject matter and how it can be effectively taught.

A Small Sample of Methods Courses

As part of its Teacher Education and Learning to Teach study, researchers at the National Center for Research on Teacher Education interviewed methods instructors at a sample of college-based preservice programs. Programs were selected to provide a diverse array of institutional purposes and contexts. The methods instructors considered in this paper work at three universities. *Stockton*[2] taught all the sections of elementary math methods at a large public research university. *Leona* was an adjunct faculty member serving as one of the math methods instructors at a public university with an open-enrollment policy; although she was teaching this course for the first time, she thought her course section similar to that taught by others at her institution. Because the teacher preparation program at *Myra*'s selective private university was too small to support methods courses for every subject, she taught a general methods course for elementary school.

Each instructor was interviewed using a semistructure protocol organized around the syllabus for the methods course (Floden, McDiarmid, and Wiemers, 1989). In the main body of the interview, the interviewer asked the teacher educator to imagine that they were providing information for a colleague enlisted to take over the course for a year. The interviewer showed the teacher educator an outline of the topics to be covered in discussing the syllabus, then proceeded through each part, with probes intended to press for comments about what the students would learn; what reasons the teacher educator had for choosing the particular content, readings, or assignments; and, what criteria the teacher educator uses to judge success in the course. Transcripts from these interviews were read to determine what the methods instructors believed about their responsibility for helping teachers develop their knowledge of mathematics and their ability to draw on that knowledge in teaching. Instructors' ideas about teacher learning provided insight into other opportunities teachers might have to learn the needed subject matter knowledge.

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[2]Instructors' names are pseudonyms.

Knowledge About Mathematics

Using the NCTM standards as a guide, we analyzed the interview data along two dimensions: knowledge of the substance of mathematics and perceptions of mathematics as a field.

Knowledge of the substance of mathematics. The NCTM argues that teachers must learn mathematics beyond what they bring from high school: "Teachers need experiences that enable them to revisit the content that they will teach in order to revise and develop deeper understandings of the underlying principles and connection among ideas inherent in school mathematics" (NCTM, 1989, p. 74). Data on students in preservice programs (including Stockton's and Myra's) collected as part of the Teacher Education and Learning to Teach study appear to bear this out: Fewer than 2 out of 10 prospective teachers could correctly represent a simple proportions problem *at the end of their program* (McDiarmid, 1989). To illustrate 1 1/4 divided by 1/2, only 3 out 10 preservice teachers chose an appropriate representation, indicating a lack of understanding of division (Ball, 1988).

What role do the methods instructors think they should play in teaching students the substance of mathematics? Two of the instructors, Stockton and Myra, take their students' knowledge of the substance of mathematics as a given. Commenting on his students' knowledge of mathematical content, Stockton said, "I think they know it pretty well." He attributes his students' knowledge of mathematics to the state-mandated system of achievement testing they undergo in school. Because Stockton believes that the content of the school mathematics curriculum is unstable, subject to fads and fashion, he thinks that course time should be spent on learning general principles for mathematics teaching, rather than mastering specific content.

Myra's view of the adequacy of her students' knowledge of mathematical content is similar to Stockton's:

> They need to learn processes, not so much content stuff. . . . I've got students who are bright enough and have varied experiences. . . . Most of them have come from very good schools so they've had a lot of experiences. They've been the best students in their class. I don't have to fill in that stuff.

For Myra, students' past school success--and, implicitly, their acceptance into the selective college at which Myra teaches--is a sufficient warrant for her belief that they know the substance of mathematics.

Leona, on the other hand, makes different assumptions about her students' substantive mathematical knowledge, based in part on her recognition that many of her

students have extensive teaching experience. She reviews propositions and procedures "to make sure that they understand different concepts":

> I might say, "Give me an example of the associative property of addition," you know. And that could be someone telling me, or someone coming up to the board, or my asking, you know, does everyone understand?

Determining how much of Leona's course is devoted to teaching students mathematical content is not possible without observing every class. Based on this interview, she appears to use a "fill-in-the-holes" approach, teaching content only when it is necessary to learning the method.

These instructors' treatments of mathematical content differ, in part, because of differences among the institutions in which they teach. Whereas Myra and Stockton are faculty at selective colleges, the college at which Leona teaches has open enrollment. Presumably, the knowledge her students bring to her methods class is less predictable than what Myra and Stockton can expect. In one sense, all three of these instructors assume that responsibility for teaching mathematical content lies outside their purview. Leona only teaches mathematical ideas and procedures when deficiencies in students' knowledge interfere with getting her students to feel "comfortable" with teaching mathematics. She no more considers helping prospective teachers develop their knowledge of mathematical content part of her job than do Myra and Stockton. These three mathematics methods instructors provide prospective teachers little opportunity to "revisit the content that they will teach."

Perceptions of mathematics. In addition to knowing the substance of school mathematics, the NCTM stresses teachers' sense of mathematics as a field. Teachers should know how mathematical ideas are discovered, developed, tested, judged, and revised. How does someone go about proving a conjecture? Teachers should see mathematics as an activity that involves understanding and discussion of ideas, rather than mere memorization of facts and algorithms. "Learning experiences should emphasize the conceptual foundations of mathematics and actively engage learners in making sense of mathematical situations. . . . Instruction should be organized around searching for solutions to problems and should include continuing opportunities to talk about mathematics" (NCTM, 1989, pp. 66-67). The NCTM standards call for teachers to portray mathematics as a subject in which pupils are capable of figuring things out for themselves, in which, individually and in groups, pupils can make sense of problems, can communicate their understandings, and can disagree with one another and with "outside authorities."

The methods instructors do see student perceptions of mathematics as important, but they stress *attitudes* toward mathematics rather than *understanding* what it means to do

mathematics. Among our methods instructors, Leona seems most intent on changing her students' perception of mathematics. She worries that prospective teachers are uncomfortable with mathematics, that they think it is harder than it really is, and that the resulting negative attitude about mathematics will be communicated to their pupils:

> I think that people, when dealing with mathematics, have a tendency to panic, and have decided the concepts are just too difficult for them to understand and far too difficult for them to explain to someone else. . . . I want them to feel comfortable with that, so when they walk into their classroom, there's no fear when they open and see fractions.

When Leona evaluates class projects, she makes no reference to whether the projects give an accurate picture of mathematics as a field of inquiry. Her emphasis is on factors that will keep students engaged, not on whether the engagement is mathematical. Describing a good learning center (developed as a class assignment), she says, "It met all the requirements: It was manipulative; it was bright; it made you want to go over and see what was inside; it had a lot of different activities that could be changed to different grade levels."

Like Leona, Stockton includes addressing students' attitudes in his responsibilities:

> On the first day of class. . . . I say, "How many of you, when you were in elementary school or high school . . . would have put math in the top three of all the subjects you studied?" . . . I get about three or four hands up you know. "How many of you would have put math in the bottom three . . . ?" I get more than half the class that will put math in the bottom three. . . . I'll constantly work on attitude, self-concept and development of self-concept. . . . If I can change their attitude towards mathematics and they like doing mathematics, then they are going to like doing it with kids.

When asked about her standards for judging the five lessons that she requires students in her course to prepare, Myra similarly does not mention subject matter. She seems intent on helping her students reformulate their general understandings of what it means to teach and to learn. We could find no evidence in her interview, syllabus, or assignments that she addresses the nature of mathematical knowledge.

Myra's circumstances are different from those of Stockton and Leona. She teaches a *generic* methods course rather than a *mathematics* methods course. (Students in her program attend workshops put on by local teachers. Some of these workshops cover specific methods for teaching mathematics topics.) This may in part explain her neglect of students' grasp of the nature of mathematics.

Stockton is the only one of the three instructors who alludes to the conceptual underpinnings of mathematics and their importance. He recognizes that his students have been taught merely to remember, not to understand, mathematics:

> [Mathematics] wasn't taught to them by understanding. It was taught to them by rote. And they learned it by rote. So, I try to break that cycle by saying, "Don't go back out there and teach the kids by rote. When they say "Why?" you say, "Because I told you so" or "Because this is the way you get the right answer." You want to give them the whys. You want to know the whys.

In describing the course topics, assignments, grading criteria, and his own teaching, Stockton does not reveal, however, how his course will enable or dispose teachers to engage their pupils in activities and discussions that will help them understand the conceptual frames much less the structures of mathematics. For instance, in describing the class designated as "Problem Solving" on his syllabus, Stockton said:

> Here is kind of an outline of my lecture that I give and I will expand and talk about problem solving--the process. I defined it and then I give them the skills and I expound upon each one of these kinds of things.

Collective problem solving--advocated by NCTM as a way to teaching mathematical inquiry--is evident neither in the interview nor on the syllabus or assignments.

None of these instructors, then, define their responsibility to include helping teacher education students develop an understanding of mathematical inquiry. While Stockton knows that mathematics is not just a given set of rules, his course does not include discussions of topics or problems that would involve students in thinking about how to produce or judge mathematical conjectures. These instructors assume limited responsibility for helping prospective teachers learn the subject matter knowledge sketched in the NCTM standards. Instead, they assume that students already have sufficient knowledge of the subject matter. Their responsibility is to teach ways of presenting mathematics and to help students develop positive and confident attitudes--either towards mathematics and mathematics teaching or toward teaching and learning in general. They believe, however, that they can accomplish this without addressing students' conception of mathematics as a field of inquiry.

Drawing on Mathematical Knowledge in Teaching

The NCTM standards stress teachers' knowledge of mathematics per se. To promote learning, however, teachers must have more than mere content knowledge. They

must also be able to draw on this knowledge in providing explanations, making curriculum decisions, and responding to students. As Shulman (1986) points out, good teachers must go beyond being good students of a subject; they must also have the pedagogical content knowledge that will aid in helping others learn particular content.

Teachers must draw on their subject matter knowledge to devise pedagogically effective teaching strategies, such as the use of analogies, examples, or teaching tasks that represent the content accurately *and* help pupils come to understand the content. Students only get practice in this use of subject matter knowledge if they have had experience teaching (e.g., as a peer tutor).

If teachers are to learn how to use their subject matter knowledge to select or design teaching tasks, methods courses seem a likely place for such learning to take place. Subject-specific methods courses, in particular, seem created to help teachers come up with ways of teaching specific content. What responsibility do these methods instructors take for helping their students learn to make good pedagogical use of their subject matter knowledge?

The methods instructors in this study are all concerned with helping their students learn ways of teaching mathematics topics. Leona said, for example, that her course was "intended to give teachers . . . methods and techniques for presenting mathematics concepts to young children." They want students to learn how to devise and evaluate methods for teaching the mathematics topics; they vary in the priority they give to helping teachers to master existing methods for teaching central topics. None of them, however, report giving attention to helping teachers learn to draw on their knowledge of mathematics in designing or evaluating teaching activities.

Given the range of topics in the elementary school curriculum, methods instructors cannot teach teachers individual methods for every possible topic. Instructors might deal with this situation by teaching methods for each of the "major" topics or they might put more emphasis on helping teachers learn general principles for devising or selecting methods. Stockton argues that it would be unwise to concentrate on learning methods specific to current curriculum topics. Not only is there insufficient time for all the topics, the topics covered in schools are likely to change:

> I let my students know that in a three-hour course in 16 weeks there are going to be many concepts that we will not cover. . . . [They] are going to be teaching things out there 10 years from now that we aren't even thinking about teaching now.

For Stockton, then, methods for teaching specific topics are illustrations of methods appropriate for teaching mathematics. Teachers may use them in their teaching, but they must realize that they will have to find or construct methods for teaching other topics.

Leona puts more emphasis on learning methods for individual topics. The methods textbook she uses (and likes) is organized around major topics, giving several methods for teaching each topic. One of her main course activities is having the teachers each build a "math file" containing ideas for teaching each topic. The methods course is organized around these topics, with each session devoted to methods for different elementary school math content. Leona's "main concern was to create activities on different concepts," referring to currently used textbooks as a source of concepts. Although Leona also emphasizes some general teaching methods (e.g., lesson planning), her hope is clearly to give teachers some options to choose from for each of the topics they must teach.

Whether or not the methods instructors hope to provide methods for the full range of major topics, they all stress teachers' ability to add to their repertoires for each topic they teach. Leona emphasizes collecting methods; Myra and Stockton stress creating them. None of these instructors ever discuss how they would help students judge whether a given teaching method is true to the subject matter. The emphasis in evaluation is on student engagement, not content accuracy. This absence of subject matter criteria for judging methods might flow from an assumption that subject matter evaluation will come naturally to the students, or it might follow from a judgement that subject matter accuracy poses few problems in teaching elementary school mathematics.

How Do Teachers Learn the Subject Matter They Need?

These methods instructors only take responsibility for a fraction of the subject matter knowledge that prominent authorities consider important. In reflecting on this situation, it may be helpful to consider how these instructors think about learning to teach. Examining methods courses in a broader context may suggest where else teachers might be expected to gain the needed mathematical knowledge.

The methods instructors assume that teachers already possess the needed substantive knowledge. Because mathematics is learned primarily in school, these instructors must rely on formal study--in elementary school, secondary school, and a few college courses--to supply the knowledge needed. With this assumption, responsibility for strengthening this knowledge would fall outside the professional program, probably with college mathematics instructors. If teacher educators wish to follow these recommendations, cooperation with other college departments is indicated.

Shulman (1987) writes about acquiring pedagogical content knowledge through the "wisdom of practice," which comes through teaching itself or learning about teaching

through secondary accounts (e.g., case studies). These methods instructors also see experience as the primary way students gain pedagogical content knowledge. Myra is perhaps the more strident advocate of learning by experience: "They will have some idea of some materials, especially again from the person who does the workshops on mathematics, but they're not going to learn it until they start doing it." Leona echoes Myra's idea when she explains why she has students present their learning centers and math files to each other in class: "I think that learning to teach . . . is learning by doing and hopefully that's what we're doing in class. We're learning by doing." Stockton requires students in his course to plan and teach at least one lesson out in the field, as a way of getting students to try out some of the ideas they are discussing in class. In all of these cases, actually teaching, either peers or younger students, is viewed as a way for students to hone or refine their pedagogical content skills.

These instructors also use modeling to help students' general approaches to teaching. Stockton believes that he should "teach things to the teachers, very much like what you want them to do." Myra writes that much of what she does in her class is modeling the kind of actions and behaviors she sees as necessary for teachers: "What I'm really trying to do is to model for them a way of dealing with people as we talk about dealing with people." These modeling experiences are intended to pass on "wisdom of practice." They are consistent with the instructors' goals in their emphasis on general learning processes, rather than on subject matter appropriateness.

Because the methods instructors give little attention to judging activities in terms of the subject matter, their interviews give no indication of how or where teachers might learn to make such judgments. Teachers learn a variety of methods, mostly through experience. Are all the activities in the bag of tricks supposed to be equal or are some more useful than others? Many researchers have discussed the pitfalls of experiential learning (Feiman-Nemser and Buchmann, 1985; Grossman, 1989), most generally that students see only the visible product and not the decision making or reasoning that goes into developing the product. It is difficult to tell from these interviews if and how these methods instructors deal with these problems.

Could Methods Courses Be Otherwise?

These methods instructors take similar positions on the aspects of subject matter knowledge for which the math methods course should be responsible. Responsibility for substantive mathematical knowledge is limited to the minor remediation needed to allow teachers to feel comfortable with the methods taught in the course. The methods course has responsibility for developing a positive view of mathematics, but not for appreciating mathematics as a field of inquiry. The primary responsibility of the methods course is to

help teachers acquire methods for teaching some of the topics in the current school curriculum and to learn how to develop similar methods for other topics. The criteria promoted for choosing these topics is based in student engagement, not in the mathematical content itself. Although these are subject matter methods instructors, they emphasize learning and affect, not content.

What does this small sample suggest about methods instruction in teacher education more generally? Is there reason to think that other math methods instructors would take on different responsibilities for subject matter? These instructors probably represent their own institutions, since two of the three instructors provide all the elementary math methods instruction in their programs. The sample of institutions was chosen to represent diversity of programs, so the uniformity is suggestive: If a sample chosen to build in variation has none, then wide variation in the population as a whole seems unlikely. Nevertheless, the sample is small. Perhaps a different picture would emerge from careful study of other colleges. This initial study suggests, at least, that some existing patterns of practice share the goal of helping teachers learn to teach a specific subject, but construe what is needed to do so quite differently than the NCTM or the advocates of pedagogical content knowledge.

The uniformity may represent adaptation to prevalent features of teaching and teacher education. Teacher educators have relatively little time to prepare their students. Elementary candidates do not see themselves as strong in mathematics. Teaching contexts press for approaches to mathematics teaching that emphasize rote memorization, rather than mathematical discourse.

For all this, these data do not demonstrate that math methods courses can take *only* these responsibilities. In a recent paper, Ball (1989) describes a math methods course that takes responsibility for helping prospective elementary teachers understand the substance of some the mathematics they will teach. Ball's approach is based on a view of teacher learning that uses the power of experience, but goes beyond using experience as way to "try things out" as teachers, using it to help teachers live through a different type of learning. Experiences as both teachers and learners combine to challenge their assumptions about the subject matter and about pedagogy.

For Ball, what counts as "knowing" mathematics is having pupils construct mathematical knowledge in the classroom. They conjecture about mathematical ideas, challenge each others' hypotheses and seek proof from each other for ideas presented. Teachers are collaborators in learning, posing tasks for their students and encouraging them to work together to find solutions and supporting justifications. By observing and working in such a class, Ball's methods students are exposed to different images of what elementary

school mathematics looks like and what the role teachers and students play. Their assumptions about what they might "do" as teachers are challenged.

Ball's students also gain different experiences as learners of mathematics. Ball gives her methods class challenging problems that use school content that typical students can work with, but do not understand. By experiencing as learners a "different" type of mathematical knowledge, Ball's students gain a deeper understanding of how their own students might learn this knowledge and how they, as teachers, might foster that learning.

The reforms advocated for teaching elementary school mathematics call for knowledge few teacher education graduates currently possess--knowledge of mathematical content, of mathematical inquiry, and of how to use mathematical knowledge in developing or selecting teaching methods. In discussing possible responses to these reforms, teacher educators should pay careful attention to current practice, especially to responsibilities assumed by different program components. Math methods could, for example, take on these additional instructional responsibilities. This initial sample of methods courses, however, indicates that methods courses may be more concerned with attitudes toward mathematics and with providing a variety of potentially valuable instructional methods. It will be challenging to help elementary teachers understand mathematical content, to help them see mathematics as topic for discussion and debate, and to help them learn to evaluate how well teaching methods represent the subject matter. Teachers are unlikely to get this help from simple teaching experience.

Where should responsibility for providing this assistance lie? Assistance might be provided in a methods course, but methods instructors may have other priorities. Mathematics professors could make a contribution, but may have little interest in preparing elementary school teachers. Is anyone ready to take on these changes? Or are the reform proposals themselves unrealistic or misguided? Stronger subject matter preparation has obvious advantages, but they may not be easy to obtain.

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