Mathematical Knowledge for Teaching: Explicating and Examining a Program of Research

Projects (1985 – 2008):

National Center for Research on Teacher Education (NCRTE) and dissertation
Mathematics And Teaching through Hypermedia (MATH)
Mathematics Teaching and Learning to Teach (MTLT)
Study of Instructional Improvement (SII)
Learning Mathematics for Teaching (LMT)
Center for Proficiency in Teaching Mathematics (CPTM)
Mathematics Methods Planning Group (MMPG)
mod4

American Education Research Association Annual Meeting • New York, NY
March 24, 2008

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Reframing the teacher knowledge question: How does mathematical knowledge play a role in teaching?

mathematical knowledge ← teacher education ← instruction ← student learning

4. In improving teacher education, one place to start could at least be to help teachers learn the content well enough to teach it but this turns out to be less simple than it seems

3. Improving instruction depends on teacher education and why

2. Improving student learning depends on improving instruction, and why

What do teachers need to know of mathematics in order to teach it effectively (i.e., produce student learning)?

Retracing our – and the field's – steps

Purposes of this session

- To re-trace our program of work on mathematical knowledge for teaching
  - Describe how we have been working
  - Explain what we have found
  - Take stock of unsolved problems and specify next steps in this program of work

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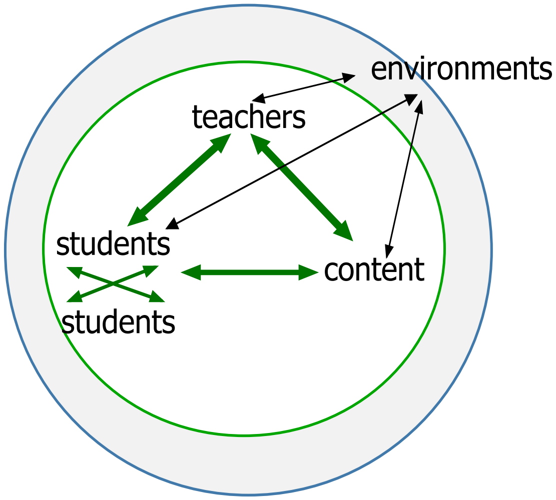
The problems of mathematics education

- Too many students not learning mathematics well enough for—
  - Everyday life
  - Continued mathematics study
  - Global economic competitiveness
  - Personal and intellectual development
- Pervasive inequality
  - Unequal distribution of mathematical success by race, social class
- Lack of capacity for improvement
  - Public understanding, support, investment
  - Persistent discord and debate distracting from coordinated improvement
  - Teacher shortages, weak interventions, thin professional knowledge base
  - Teacher educator development and resources

Instruction matters, and thus, teachers

- Common approaches—improve curriculum, standards, assessments, incentives—yet little improvement—why?
- Teachers and teaching are key; teacher effects are large (e.g., Konstantopoulos, 2007; Nye, Konstantopoulos, Hedges, 1999, 2004; Goldhaber, 2002)
- Instructional resources depend on teachers' capacity, yet teachers often left unconsidered in improvement strategy



Improving instruction through teacher education

- Focus professional training in and on practice
- Help teachers know more subject matter
  - Require more university coursework
  - Use school curricula to drive teacher education
  - Design tests to hold teachers accountable for increased knowledge

But *<u>what</u>* do teachers need to know?

- One obvious, but contested, element: knowledge of mathematics

Question:
Does teachers' mathematical knowledge make a difference?

Does …

- **“what teachers know…”**
  - Proxies
  - More direct measurement

- **“…make a difference?”**
  - Linking teacher characteristics and student achievement
  - Existing evidence vis-à-vis student achievement

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What do we learn from "educational production function" studies?

- Predicting student outcomes from "inputs"
  - Student characteristics
  - Teacher characteristics
  - School characteristics
- Student outcomes typically standardized test scores
- Often account for student prior achievement levels in models

Common ways of measuring "what teachers know"

- Possession of teaching license
  - Generally not related to student outcomes
- Possession of subject-specific teaching license
  - Weakly positively related to student outcomes but only in high school samples
- Number of math courses, possession of mathematics degrees
  - Only positive relationship at the secondary level, and not consistent
  - Selection effect

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Teacher knowledge and student achievement – the Coleman Report

- Linked to student achievement in reading and mathematics
- But what is verbal facility?
  - Vocabulary?
  - “General intelligence”?

Test of verbal facility

Q: Dick apparently had little ______ in his own ideas, for he desperately feared being laughed at.

a) interest
b) depth
c) confidence
d) difficulty
e) continuity

Direct measures of teacher knowledge

- Coleman report, 1966, the most common model: Teacher verbal ability predicts student achievement
- More recently, teachers' mathematics knowledge predicts student mathematics: Small positive effect

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Problem: Measures not calibrated to the work done by teachers in classrooms

- In mathematics, teacher knowledge measured by: end of 8th grade assessment, SAT scores, math test given to kids

- Solution: Measures of teacher content knowledge more closely calibrated to classroom work

From *teacher* knowledge to knowledge for *teaching*

- Study instruction to see what teachers <u>do</u>
- Develop language and constructs about teaching that would better surface the intricacies of the work *(e.g., language, reasoning, representation) (Lewis, 2007)
- Analyze the knowledge demands of the work: knowing in and for teaching practice

The logic of our inquiry

mathematical knowledge ← teacher education ← instruction ← student learning

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Across the program of research

- Different kinds of work, expertise, projects –– coordinated
  - Studies of classroom instruction
  - Development of assessments of teacher knowledge
  - Research and development: Teachers' opportunities to learn
- Where are we now? New problems, next steps
- Commentaries on the program of research

Research questions for a practice-based theory of knowledge

- **What** mathematical knowledge is entailed by the work of teaching?
- **Where** and **how** is mathematical knowledge useful and used within the work of teaching mathematics?

Our initial approach to the problem

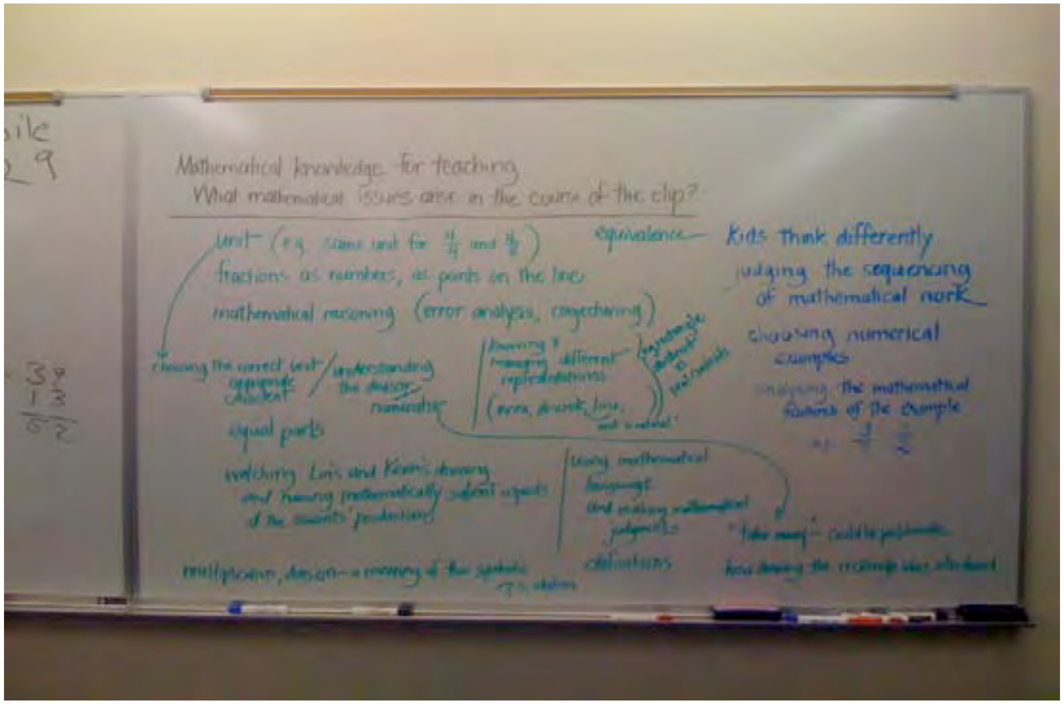
- A "job analysis" of classroom teaching (similar to e.g., Noss & Hoyles)
- Records of practice
  - One year of third-grade mathematics teaching
  - Video, transcripts, teacher journal, and students' notebooks, homework, quizzes and tests
- Mathematical commentaries ⇒

  Multi-disciplinary analysis

An example of studying instruction: A clip from a third grade lesson

Which is more –

$\frac{4}{4}$ **or** $\frac{4}{8}$ **?**



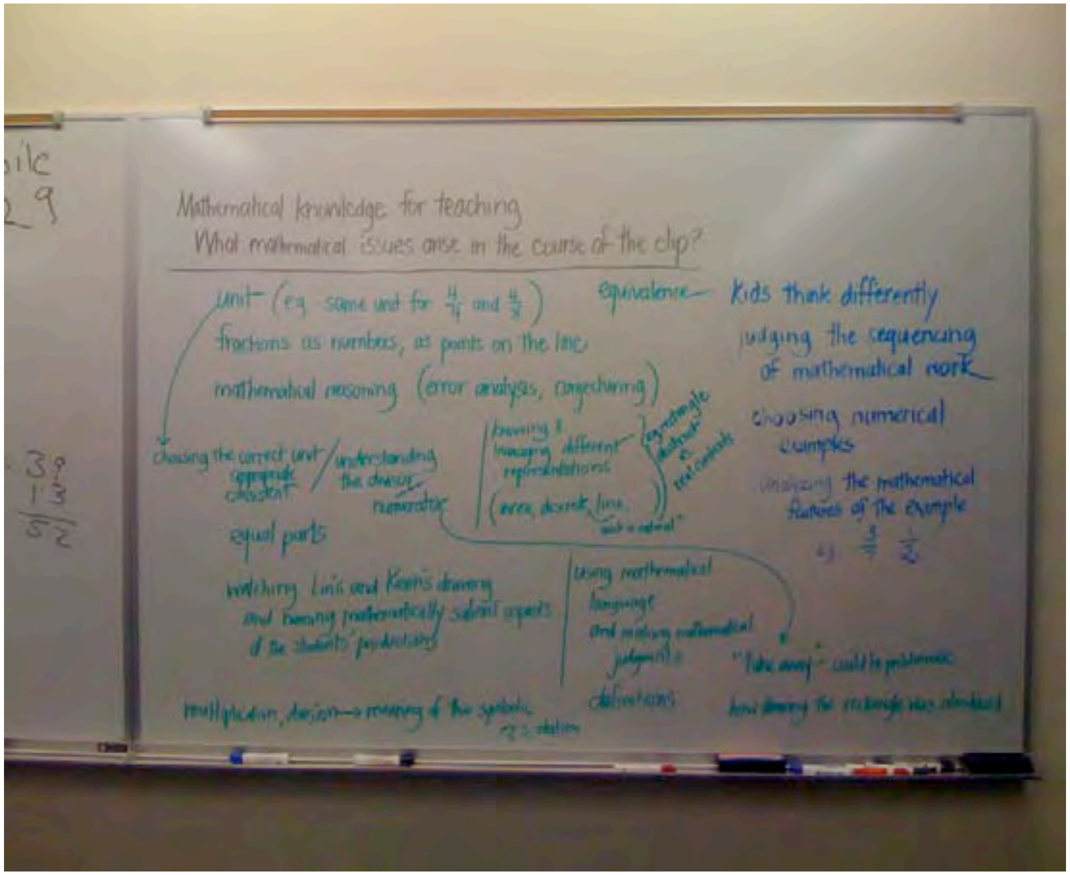
Focus:

What mathematical issues arise?


PM 1:00:16

What mathematical issues arise?

What is the teacher doing?
What mathematical challenges arise?
What is there to see and hear mathematically?



- Choosing task, specific numbers
- Eliciting, hearing, and using student responses (e.g., Lin, David, Bernadette, Kevin)
- Attending to mathematical language ("take away")
- Managing representational contexts
- Scaffolding mathematical practices (reasoning, error analysis)
- Formulating mathematically productive questions, e.g. "If a fourth grader said to you that 4/4 is the same as 4/8, because they are both 4 pieces, what would you say to convince them?"

What is a “mathematical eye”?
What is involved in a structured use of the discipline as a lens for studying practice?

Mathematical foci for studying instruction

- Problems used
- Answers (mathematical structure, completeness)
- Promising ideas and approaches
- Staging of mathematical work (formulate, solve, justify)
- How ideas are expressed
- The nature of explanations
- Types of consistency and convention
- Roles, dispositions, responsibility of students and teacher: who does what

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A practice-based theory of Mathematical Knowledge for Teaching (MKT)

- Frame: knowledge used in practice
  - "knowledge *entailed by* the work of teaching"
- What do we mean by "knowledge"?
  - Mathematical knowledge, skill, habits of mind
- What do we mean by the "work of teaching"?
  - The activities in which teachers engage, and the responsibilities they have, to teach mathematics, both inside and outside of the classroom

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What is involved in analyzing practice? (to identify MKT)

Mathematical eye ➡ Structured use of the discipline

Pedagogical eye ➡ Structured use of the instructional framework

Structuring the coordination of perspectives

- Engaging the perspectives with each other
- Mathematical and instructional practices
- Mathematical tasks of teaching
  (give explanations, hear students, choose examples, …)

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What mathematics do teachers need to know?

They need to know the content they assign to students . . .

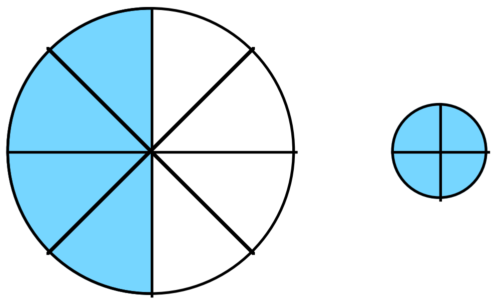
Which is more?

$$\frac{4}{8} \text{ or } \frac{4}{4}$$

. . . but they also need to know much more!
What is the nature of that "more"?

Analyzing and evaluating representations for comparing fractions

a)



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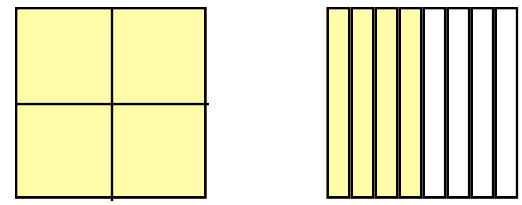

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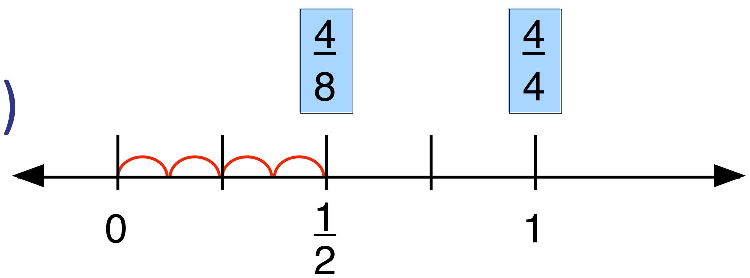
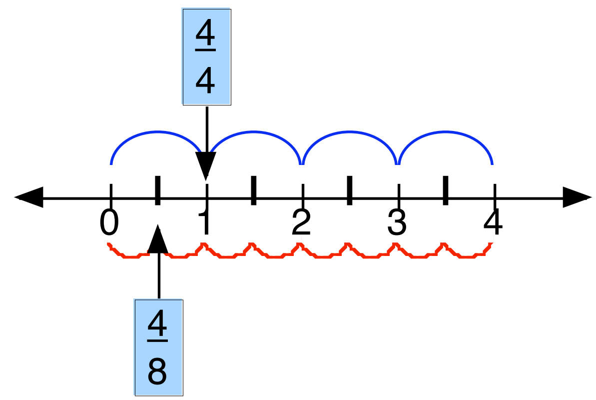


e)



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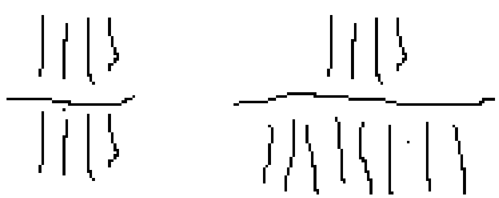
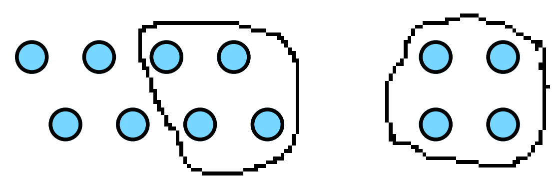


f)



“Measuring” mathematical knowledge for teaching

Questions:

- Can we measure the mathematics that teachers know and use in teaching (MKT)? If so, how?
- Is MKT related to student achievement?
- Is MKT related to mathematical quality of instruction?

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Overview of measurement work

- Surveys
  - Multiple choice
  - Variety of content domains
  - Items meant to assess different kinds of MKT

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Example of survey item

Which of the following story problems could be used to illustrate $1\frac{1}{4}$ divided by $\frac{1}{2}$? (Mark YES, NO, or I'M NOT SURE for each possibility.)

	Yes	No	I'm not sure
a) You want to split $1\frac{1}{4}$ pies evenly between two families. How much should each family get?	1	2	3
b) You have $1.25 and may soon double your money. How much money would you end up with?	1	2	3
c) You are making some homemade taffy and the recipe calls for $1\frac{1}{4}$ cups of butter. How many sticks of butter (each stick = $\frac{1}{2}$ cup) will you need?	1	2	3

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Validating our measures: Do our instruments measure what we want?

- Good reliability and strong technical properties
- *But*: Are the measures valid?

  Do they measure what we think they measure?
  - i.e., are they good representations of what teachers can do, mathematically, in teaching?
  - Are differences in teacher scores related to differences in student achievement?
- Test and improve the validity of our emerging theory of MKT

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Using multiple sources of evidence to evaluate our claims

1) Scores capture teachers' mathematical knowledge

Cognitive interviews

2) Higher scores are related to improved student learning

Study of Instructional Improvement student gains analysis

3) Scores reflect different dimensions of MKT

Mathematician and non-teacher interviews

Item response theory and factor analysis

4) Higher scores are related to higher-quality mathematics instruction

Videotape validation study

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Videotape validation study

- Question:

  Do higher teacher scores correspond with higher-quality mathematics in instruction?

Mathematical quality: Sample constructs and codes

- Mathematical errors
  e.g., Computational, misstatement of mathematical ideas
- Language
  e.g., Careful use of mathematical language – including translating everyday into mathematical language
- Richness of the mathematics
  e.g., Presence of multiple (linked) representations, explanation, justification
- Equity
  e.g., Explicit student tasks and work

See LMT website for complete set of video codes:
http://sitemaker.umich.edu/lmt/home

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Example: Mathematical quality of instruction

Example: Using student errors in class

Uses students' errors: Use this code to record when teachers respond to, use, or otherwise address student errors (errors from the teacher's perspective) in some way other than simply telling the student it is wrong or ignoring the error. One compelling instance in the segment is enough to code for appropriate use of errors. Mark (P-A) if teacher used a student error appropriately; (PI) if teacher used student error in a way that significantly distorted the mathematics or missed the point of the student error; (NP-A) for no significant student errors, no need for teacher interpretation (this is the default code); (NP-I) for cases when teachers should have used student errors in order for instruction to reasonably proceed.

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The challenge: The need for a knowledge base for helping teachers develop MKT

- How can MKT be developed?
- How can teacher educators and professional developers be supported as they create opportunities for teachers to learn MKT?

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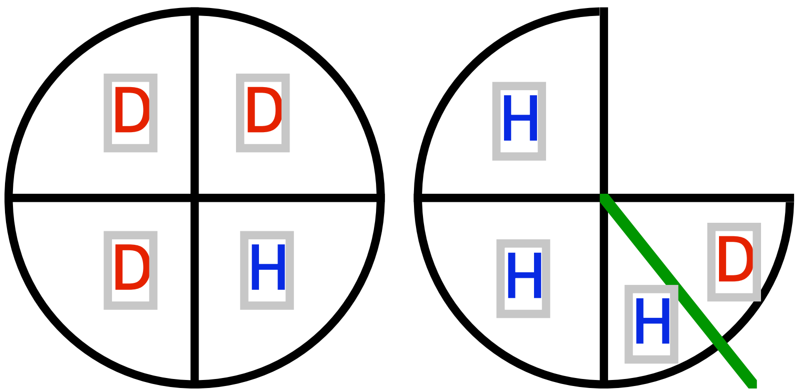
Example: Task for developing MKT

$$1\frac{3}{4} \div \frac{1}{2}$$

1. Calculate the answer.
2. Write a story problem, or describe a situation, that corresponds to this division expression.

I have two pizzas. My friend eats one quarter of one of the pizzas. I have one and three quarters pizzas left. Then I split it evenly between two of my other friends. Each person gets three and a half pieces of pizza.



1. What is wrong with this?
2. Write a story problem that correctly represents the division.

Our approach to developing MKT

- Design tasks that create opportunities for learning mathematical knowledge for teaching
  - Situate teachers' opportunities to learn MKT in the contexts of use
  - Provide opportunities to practice the kinds of mathematical thinking, reasoning, and communicating used in teaching
- Enact tasks in ways that maintain the focus on developing MKT and the ability to use it in teaching
- Assess MKT in ways that reflect how it is used in practice

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Challenges of this approach

- Staying focused on the mathematics, and not on how to *teach* the math
- Keeping the problems focused on MKT and not just "M"
- Unpacking the mathematics sufficiently and convincingly helping them see what there is to learn and do
- Making visible the connections to the kinds of mathematical thinking, judgment, reasoning one has to do in teaching

Helping teacher educators and professional developers create opportunities for teachers to learn MKT

- Materials
- Structures for collective work

Materials

- Extensive collection of MKT tasks, problems, assessments, projects, etc. to use with teachers
- Highly elaborated and detailed instructor/facilitator support materials
- Records/recordings of teacher education and professional development sessions

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Sesson plan excerpt: Division of fractions

DESCRIPTION OF ACTIVITY	NOTES AND CAUTIOUS POINTS
Launch whole-group discussion: Does anyone have any thoughts about why the problem on slide is wrong?	*Important points to extract in analysis of incorrect problem:* *–unit is shifting* *–dividing by 2, not by ½* *–language issues – difference between dividing <u>in</u> half, dividing <u>by</u> a half.*
After incorrect problem is analyzed, ask if anyone thought of a correct problem. Discuss this example. Have them write problems with a partner – if needed, provide a context to get them started: 1 ¾ yd. ribbon; 1 ¾ L of favorite drink	*A correct problem will probably utilize a measurement model. Important to emphasize shift in thinking, away from thinking about of a ½ a group to thinking about how many ½s in 1 ¾. Nice connection to why it is important to understand both interpretations of division.*
Share out and record. Discuss whether each problem correctly models problem.	*Students might suggest a problem that uses a partitive model. Important to highlight that this is a correct model for dividing by ½, but don't want to dwell here unless people are comfortable with measurement model.*
(if there's time) Try another example: 2 ÷ 2/3 or 2 1/2 ÷ 3/4 Task: Write a story problem that goes with this problem. Then make a picture for that interpretation of division. Write both a division and multiplication sentence for your picture. If people start to finish, ask them to try the other interpretation. Share on board and discuss whether it corresponds to problem. Reflect briefly in notebook – What was new? Is anything still shaky?	*SAMPLE PROBLEMS:* *Measurement: I have 1 ¾ yards of ribbon. How many ½ yard pieces are in 1 ¾ yards of ribbon?* *Partitive: If ½ of a jump rope is 1 ¾ feet long, how long is the whole rope?*

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Structures for collective work

- Instructor planning groups
- Cross-institutional study groups
- Institutes, workshops, courses
- Laboratory classes

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When do teachers learn MKT from professional development?

Hill & Ball, JRME (2004)

- Measurement items used in California's Mathematics Professional Development Institutes (MPDI)
  - Instructors: Mathematicians and mathematics educators
  - 40-120 hours of professional development
  - Focus is squarely on mathematics content
  - Summer 2001
  - Pre/post assessment format (parallel forms)

MPDI evaluation: Other findings

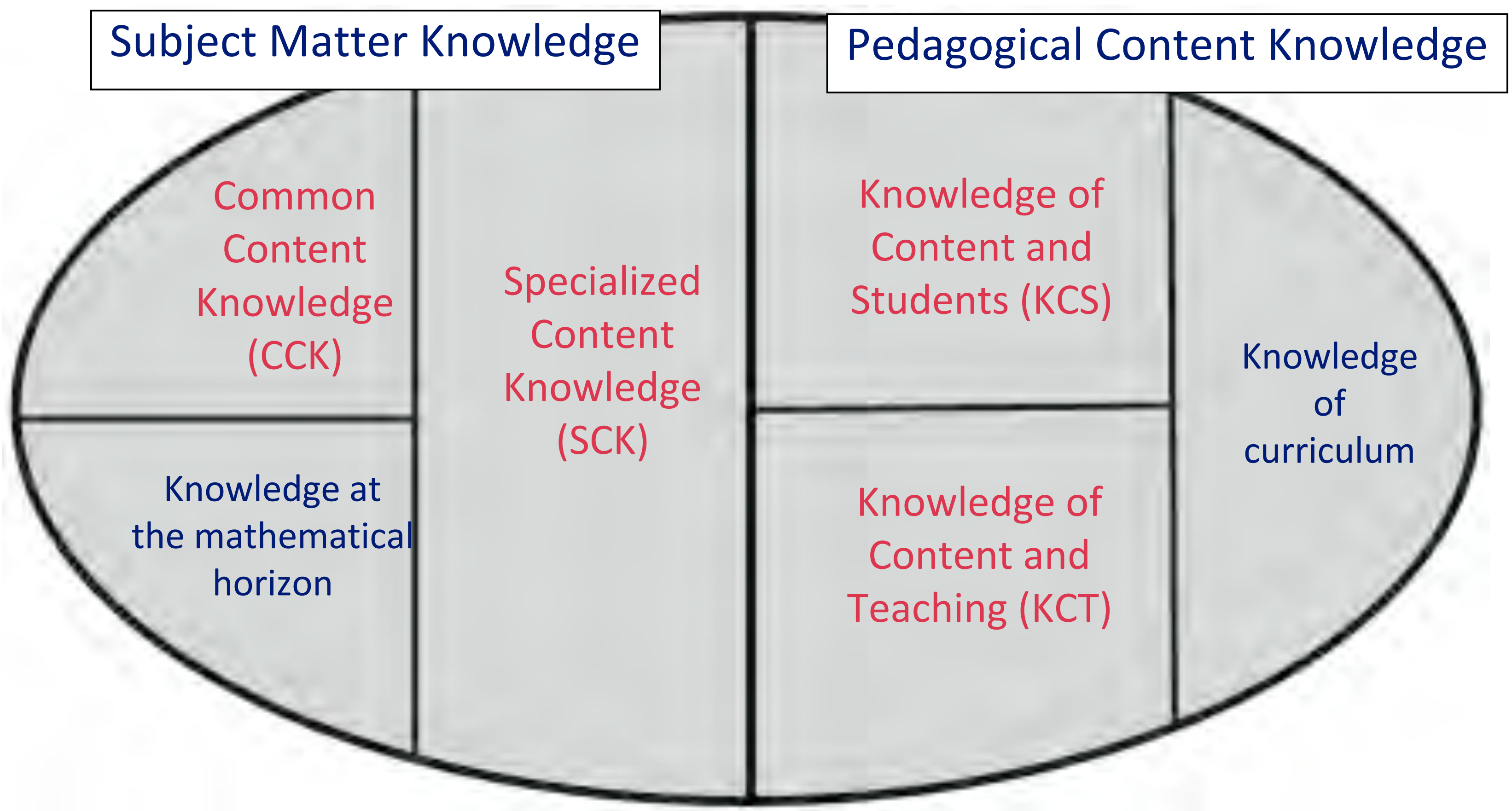
- For all institutes for which we have data, teachers gained roughly ½ standard deviation
- However, variation among institutes
- Length of institute predicts teacher gains
  - 120-hour institutes most effective, on average
  - But some 40-hour institutes very effective
- Focus on mathematical analysis, proof, and communication leads to higher gains
- Many questions remain

Studying MKT

What problems remain unsolved?

What new questions have emerged?

What is the structure of mathematical knowledge for teaching?



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Unsolved problems

- Mapping and articulating the work of teaching
- Understanding and articulating *mathematical reasoning* characteristic of and entailed by teaching
- Understanding specific aspects of other topics within mathematics and practices
- Unpacking the "mathematical perspective" in teaching ("knowledge at the horizon")

New problems and questions

- Articulating the interface of attention to equity and MKT
- The mathematical knowledge needed by teacher educators (seems to be again more than what their students need to learn [MKT])
- How MKT can be made visible and learned by mathematics teacher educators
- What is involved in a curriculum for teaching MKT?
- Identifying MKT to teach secondary school

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Discussants

- Pam Grossman, Stanford University
- Stephen Lerman, King's College, London

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