



# Measuring the Quantity and Quality of the K-12 STEM Teacher Pipeline

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## Executive Summary

*In this paper, Suzanne Wilson, a nationally renowned expert on teacher preparation and professional development, reviews recent efforts to measure aspects of teaching and teachers' work that are difficult to quantify but that are more closely related to student learning outcomes than the most commonly used proxies for teacher quality. Wilson then describes the range of learning opportunities available to STEM teachers and the data available on the frequency and distribution of those teacher learning opportunities.*

STEM teachers are essential to any effort to improve U.S. STEM education, both for students who eventually will work in STEM-related fields and for the general public. Efforts to enhance the quality of STEM teachers have focused on attracting more academically capable people to the field, improving the quality of teacher education programs, supporting teachers' continued learning once they have joined the profession, or rewarding and retaining the most effective teachers. In its report *Monitoring Progress Toward Successful K-12 STEM Education*, the National Research Council (2013) proposed the development and use of two indicators of STEM teacher quality:

- Teachers' science and mathematics content knowledge for teaching
- Teachers' participation in STEM-specific professional development activities.

Currently available data on science and mathematics teacher quality have improved considerably over the last 25 years, and researchers are no longer dependent on proxies like teachers' college grade point average or number of math or science courses taken. This is heartening because measures like these have shown weak—if any—relationship to student learning and engagement.

### Content Knowledge for Teaching

Research has shown that the knowledge needed for teaching goes well beyond that of disciplinary subject matter per se, and few if any districts or states would claim to have valid, consistent data on teacher content knowledge for teaching. The NRC Monitoring Progress report recommended an indicator of content knowledge for teaching, which includes not only the understanding of a discipline that one might develop as an undergraduate

major or minor, but also specialized disciplinary understanding specific to teaching (such as the specific mathematics taught at the grade level one teaches) and pedagogical content knowledge, which includes the subject-specific understanding of how to teach the relevant subject matter content and how students learn that content. Several research projects are under way to improve our ability to assess teachers' content knowledge for teaching by developing measures that could be used on a large scale for tracking teacher content knowledge for teaching.

### STEM-Specific Teacher Learning Opportunities

The NRC Monitoring Progress report also argued for an indicator that tracks teachers' participation in STEM-related professional learning opportunities. Professional development itself is being reconceptualized to include formal and informal opportunities to learn, in and out of school. Teachers have regularly noted that serving as mentors for new teachers, as peer observers, or on textbook selection committees has been an important source of professional growth. Many widely administered teacher surveys track the amount of time that teachers spend in professional development, but survey questions typically refer to all kinds of professional development rather than calling out STEM subjects in particular. Moreover, survey items on professional development often are understood to address formal professional development sessions and fail to ask about less structured learning opportunities, such as mentoring and collaboration with colleagues. A comprehensive measure of the quantity of STEM professional learning opportunities teachers have would include the latter kinds of activities.

## Current Efforts to Track and Promote Teacher Quality

Current efforts to track STEM teacher quality collect information on teachers' years of experience, credentials and licenses, out-of-field teaching, and test scores. The table below shows the differences across states in the areas in which they mandate tests of teacher quality. As the table indicates, teachers' instructional practice (pedagogy) is the component of their competence that is least likely to be tested.

Recently, several states have invested in more comprehensive data systems that can assess teacher quality, including professional learning and teacher evaluations. The North Carolina Education Research Data Center was established in 2000 to store and manage data on the state's public schools, students, and teachers. The ability to work across these data sets has enabled researchers to investigate many questions concerning teacher quality. For example, using data from a biannual working conditions survey, researchers found that the level of support in a school environment matters for teaching and learning: North Carolina schools with the most supportive professional environments also had more qualified teachers.

Table ES-1. U.S. Teacher Testing Requirements

	Basic Skills	Content Knowledge	Pedagogy
Required	AL, AK, AR, CA, CY, DC, DE, FL, GA, HI, ID, IL, IN, IA, LA, KY, MA, MD, ME, MI, MN, MS, MO, NE, NH, NV, NM, NY, ND, OH, OK, OR, PA, SC, TN, VT, VA, WA, WV, WI	AL, AK, AR, AZ, CA, CO, CT, DC, FL, GA, HI, ID, IL, IA (elementary teachers only), KS, KY, LA, ME, MA, MI, MN, MS, MO, NH, NC, NJ, NV, NM, NY, NC, ND, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WV, WI, WY	AZ, AR, DC, FL, ID, IL, IA (elementary teachers only), LA, KS, KY, ME, MN, MS, MO, NH, NC, NV, NM, NY, OH, OK, PA, RI, SC, SD, TN, TX, UT, WV
Maybe/it depends/sometimes	NC, TX	DE, MD	VA
Not required	AZ, CO, KS, NJ, RI, SD, UT, WY	MT, IN, NE	AL, AK, CA, CT, CO, DC, DE, GA, HI, IN, MA, MD, MI, MT, NE, NJ, ND, OR, VT, WA, WI, WY

## Implications for Policy and Practice

**Schools and districts should provide STEM teachers with opportunities to engage in professional learning throughout their careers.** STEM fields are constantly evolving, and teachers need ongoing opportunities to learn about relevant developments. Additionally, teachers need opportunities to learn about new teaching and curriculum standards, instructional methods, and research that enhance their capacity to meet the needs of all children.

**States need databases that permit them to link teachers' characteristics and learning opportunities with student and school outcomes to investigate questions concerning teacher quality.** Currently, states typically maintain separate databases for teacher and student information and have limited ability to relate teacher qualifications and teacher support programs to student outcomes.

**Districts and states should consider using surveys that measure teacher content knowledge for teaching and teachers' opportunities to learn** and that gather important contextual information about teachers' backgrounds and experiences, teaching assignments, working conditions, and beliefs about students and subject matter. While these survey measures are not appropriate for making judgments about individual teachers, they are useful for estimating patterns for larger groups of teachers and thus for identifying areas where teacher preparation and ongoing support should be strengthened. At present, available assessments of content knowledge for teaching do not cover all relevant content areas for K-12 mathematics and science teachers. A national indicator system would need to even out those differences in coverage and conceptualization.



## Introduction

STEM teachers matter. In fact, they are essential to any effort to improve STEM education in this country, both for students who go on to work in STEM-related fields and for the general public, which needs sound understanding of mathematics, technology, engineering, and the sciences to be critical consumers and empowered citizens. Recently, efforts have been made to increase the number of high-quality STEM teachers by enhancing their recruitment, preparation, retention, and ongoing support. This is reflected in the 100Kin10 movement, which involves more than 200 institutions collaborating to produce 100,000 new STEM teachers by 2021, and in the Association of Public and Land Grant Universities (APLU) Science and Mathematics Teaching Imperative, in which university presidents pledged to increase both the quantity of secondary science and mathematics teachers (a goal of 10,000 each year) and the quality of their preparation at their universities. Yet another effort is the STEM Master Teacher Corps, which was created in 2010 with 50 master teachers in each of 50 locations across the United States, and has the goal to expand to 10,000 within 4 years.

Not only do we need more STEM teachers, but we need good STEM teachers and we need to provide them with ongoing support. In its 2013 report *Monitoring Progress Toward Successful K-12 STEM Education*, the National Research Council provided a framework for the development of a set of metrics for measuring the quality of K-12 STEM education in this country and proposed that the metrics focus on two indicators of STEM teacher quality:

- Teachers' science and mathematics content knowledge for teaching (Indicator 6)

- Teachers' participation in STEM-specific professional development activities (Indicator 7).

*Content knowledge for teaching* is an expansive view of teachers' knowledge that includes but is not limited to the understanding of a discipline that one might develop as an undergraduate major or minor (e.g., Ball, Thames, & Phelps, 2008; Hill & Ball, 2009; Hill et al., 2008) and the specialized disciplinary understanding that is specific to teaching. The logic is that teachers need an in-depth understanding of the subject matter specific to the K-12 school curriculum, which is often not included in disciplinary majors and minors.

Further, content knowledge for teaching includes pedagogical content knowledge, a concept introduced by Shulman (1986, 1987) and his colleagues, who argued that teachers also need subject-specific understanding of how to teach the content and of how students learn the content. While content knowledge involves mastery of the school subject one teaches, pedagogical content knowledge (PCK) is a form of practical knowledge that is used by teachers to guide their actions in highly contextualized classroom settings (e.g., Baumert et al., 2010; Hill et al., 2008; Hill, Rowan, & Ball, 2005; Kersting, 2008; Kersting, Givvin, Thompson, Sangata, & Stigler, 2012). It includes knowledge of how to represent academic content; knowledge of the common conceptions, misconceptions, and difficulties that students encounter when learning particular content; and knowledge of the specific teaching strategies that can be used to address students' learning needs.

The NRC report also recommended an indicator that tracks teachers' participation in STEM-related professional learning opportunities. STEM

fields are constantly evolving, and teachers need ongoing opportunities to learn about new relevant developments in science, technology, mathematics, and engineering. Additionally, as professionals, teachers need opportunities to learn about new teaching and curriculum standards, instructional methods, and research that enhances their ability to meet the needs of all children. Sizable investments are made in teacher professional development each year, and the proposed indicator would provide insight into how much of it was specific to the needs of the STEM teacher workforce.

With these two indicators in mind, this paper has two goals:

- summarize how the quality of the STEM teacher workforce is currently tracked by states and
- describe measures and data sources that serve as potential resources for improving our capacity to assess the quality of the STEM teacher workforce.

## Current State Systems for Monitoring STEM Teacher Requirements and Quality

Each state has its own system for collecting data on its teacher workforce and public schools; few generalizations can be made about what data are collected or how. Furthermore, each state has different definitions of specific terms (e.g., “highly qualified teacher”) and different metrics, making cross-state comparisons complicated and national analyses extremely labor intensive. Nor is there a centralized system for collecting state teacher quality data that can then be pooled for use in national comparisons.

That said, many states can estimate the number of STEM teachers currently employed in their public middle and high schools in a given year. They can also report on the number of elementary teachers currently employed (many of whom teach mathematics and science to their students), but states in general do not have accurate estimates of how many schools/districts use specialists to teach mathematics and science in elementary schools or whether engineering or technology is taught.

In terms of content knowledge for teaching, many states also can estimate how many prospective teachers have graduated from STEM teacher preparation programs in the state. Some but not all states can determine how many students are being taught by teachers not certified in the STEM courses they are teaching. It is generally more difficult to document the STEM backgrounds of newly certified elementary teachers because states mandate different approaches for the content preparation of elementary teachers. For example, in some states elementary teachers can opt for an elementary concentration in a specific subject area; prospective teachers then take a smattering of courses across the other academic content domains.

Another model stipulates broad study across all content areas, with no specialization in one. Elementary teacher preparation programs design their requirements on the basis of their state requirements, and in some states institutions are free to select from different options for how to prepare elementary teachers. This leads to considerable variability in how many STEM-specific courses prospective elementary teachers will take. In one state, a new teacher may have taken one course in elementary mathematics content; in another, a new teacher might have taken five or more courses. Thus, even if we know teachers’ certification status and educational backgrounds, we do not know their levels of disciplinary knowledge, specialized content knowledge, or pedagogical content knowledge.

Most but not all states use mandated tests to assess aspects of the professional knowledge of entering teachers. These tests can focus on basic skills, content knowledge, and/or pedagogical knowledge (National Research Council, 2001). While some states have a long history of mandating tests for new teachers, others have only recently begun to institute such requirements. Because states vary in certification/licensure requirements and because no centralized system exists for keeping track of state policies, it is difficult to accurately describe exactly how many states require what kinds of assessments. Based on reports by the Education Commission of the States (Baber, 2008) and National Association of State Directors of Teacher Education (NASDTEC, 2015), the national picture shown in Table 1 emerges.

Most states require some sort of content knowledge test, but the content knowledge in these tests does not reflect the ambitious conception of content knowledge



Table 1. U.S. Teacher Testing Requirements

	Basic Skills	Content Knowledge	Pedagogy
Required	AL, AK, AR, CA, CY, DC, DE, FL, GA, HI, ID, IL, IN, IA, LA, KY, MA, MD, ME, MI, MN, MS, MO, NE, NH, NV, NM, NY, ND, OH, OK, OR, PA, SC, TN, VT, VA, WA, WV, WI	AL, AK, AR, AZ, CA, CO, CT, DC, FL, GA, HI, ID, IL, IA (elementary teachers only), KS, KY, LA, ME, MA, MI, MN, MS, MO, NH, NC, NJ, NV, NM, NY, NC, ND, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WV, WI, WY	AZ, AR, DC, FL, ID, IL, IA (elementary teachers only), LA, KS, KY, ME, MN, MS, MO, NH, NC, NV, NM, NY, OH, OK, PA, RI, SC, SD, TN, TX, UT, WV
Maybe/it depends/sometimes	NC, TX	DE, MD	VA
Not required	AZ, CO, KS, NJ, RI, SD, UT, WY	MT, IN, NE	AL, AK, CA, CT, CO, DC, DE, GA, HI, IN, MA, MD, MI, MT, NE, NJ, ND, OR, VT, WA, WI, WY

for teaching expressed in the *Monitoring Progress* indicator. In fact, there is very little information on the content of traditional teacher content knowledge tests, and that which does exist suggests that those tests assess high school levels of content knowledge (Wilson & Youngs, 2005). Many states also test for basic skills, although in some cases that test is required for participation in a teacher preparation program rather than as a certification requirement per se. Basic skills are defined differently across states; reading, writing, mathematics, and technology assessments play different roles. The GRE, SAT, and ACT are used by some states for basic skills assessment. Less frequently, states require some standardized assessment of teaching knowledge and/or skill. Many states also have assessments of teaching knowledge and skill that are not standardized tests, such as teaching portfolios.

The tests used across states come from different developers. Dominating the market are the Educational Testing Service, both through its Praxis I, II, and III tests and through tests it has developed for specific states, and the National Evaluation Series. States determine their own cut scores on these tests. A recent

addition to this testing landscape is Pearson's edTPA, a performance-based assessment system designed for use in teacher preparation programs. Despite widespread teacher testing in the United States, there is very little empirical work on the relationships between performance on teacher tests and student achievement (Wilson & Youngs, 2005).

Another challenge to measuring teacher quality is that states generally do not have consistent data on the characteristics of currently employed teachers who are not recent graduates of teacher preparation programs. That is, whereas a state might have data on the certification of new teachers, it may have little to no up-to-date information on the credentials of its entire teacher workforce or on its teacher workforce's preparation to teach STEM subjects. Obtaining information about more experienced teachers would require assessing the development of teachers' knowledge over time.

In terms of teachers' STEM-specific opportunities to learn, very few states have traditionally gathered statewide information on teachers' professional development opportunities or participation. Even though professional development has been seen as crucial to

ongoing support for teachers, neither school districts nor states have had data systems that track the subject-specific opportunities that teachers have been offered and/or have participated in to update their knowledge.

As interest in teacher quality has grown, several states have begun addressing this problem. North Carolina offers an example. The North Carolina Education Research Data Center (NCERDC) was established in 2000 through a partnership with the N.C. Department of Public Instruction and Duke University to store and manage data on the state's public schools, students, and teachers. The data, which include information dating back to the mid-1990s, are available to researchers for ongoing analyses.

The NCERDC data system contains extensive information at the district, school, classroom, teacher, and student levels. In addition to current and prior test performance, student-level variables include gender, age, ethnicity, absenteeism, free or reduced-price lunch status, gifted or disabled status, limited English proficiency status, and parents' education level.

Teacher data include their education backgrounds (degrees earned and institutions), credentials (licensure areas and degree level), experience, absenteeism, teaching out of field, salary history, Praxis scores, evaluation ratings, and teachers' perceptions of their work environment from a statewide survey administered every other year (e.g., Clotfelter, Ladd, & Vigdor, 2007) (see Table 2).

Researchers also have access to data on such school characteristics as school size, orderliness, per-pupil expenditures, average teacher salary supplements, percentage of students who qualify for subsidized school lunch, and percentages of ethnicities (Bastian & Henry, 2014). See the appendix for a listing of all data sources in the NCERDC.<sup>1</sup>

Enriching these data even more, the University of North Carolina (UNC) system began the Teacher Quality Research Initiative in 2008 to gather and use data on the effectiveness of teacher preparation programs by developing value-added estimates of its teacher

**Table 2. Sources of Teacher-Related Data Maintained by North Carolina Education Research Data Center**

Source	Data
National Board Certification, 1995–2007, 2014	Year of certification and certificate area for NBPTS-certified teachers per year
Personnel Absence, 1995–2008	Absenteeism records for all education personnel
Personnel Education File, 1995–present	Educational attainment for each instructor, including graduation date, degree, and institution of higher education
Personnel License File, 1995–present	License information for every instructor
Personnel Pay History File, 1995–present	Detailed information for every teacher's position and salary
Personnel Testing File, 1995–present	Testing information on Praxis for each instructor
Working Conditions Survey, 2002–2014 (biennial)	Teachers' perceptions of the work environment, including time management, resources, school leadership, personnel empowerment, and professional development

*NBPTS = National Board for Professional Teaching Standards*

<sup>1</sup> Also see <https://childandfamilypolicy.duke.edu/research/nc-education-data-center/> for details about the NCERDC.

education graduates (Henry & Bastian, 2015). That work has involved merging several data sets so that longitudinal student achievement scores could be linked to class rosters, teacher education and preparation records, and school characteristics. The UNC General Administration provided data on teacher preparation graduates and their preparation portals. The North Carolina Department of Public Instruction provided student roster files so that teacher IDs could be linked to student IDs and to student test scores (teachers' and students' names are not available).

The ability to work across these data sets has enabled researchers to investigate many questions concerning teacher quality. For example, Clotfelter, Ladd, and Vigdor (2007) were able to establish that teachers of grades 3, 4, and 5 with more experience were more effective at raising student mathematics achievement than their peers with less experience (p. 675). Having a graduate degree, on the other hand, had no significant effect on student achievement in mathematics or reading. The researchers also found that students of teachers who had acquired a regular teaching license (as opposed to those who have not completed the professional coursework necessary for regular licensure) had significantly higher mathematics achievement and that those with National Board-certified teachers had significantly higher achievement scores as well.

In another study, Patterson and Bastian (2014) reported on analyses of the effectiveness of graduates of different programs into teaching in North Carolina from 2008-09 through 2011-12. The researchers analyzed the retention and performance of early-career teachers in North Carolina public schools who entered the teaching profession through different routes of preparation or "portals." These included teachers prepared at the undergraduate level by UNC system institutions, teachers prepared at the undergraduate level by North Carolina private independent colleges or

universities; teachers prepared at the undergraduate level at a college or university outside of North Carolina; teachers entering through Teach For America (TFA); and teachers entering prior to completing all requirements for initial licensure (alternative entry).

Overall, they used 2.9 million student test score records from 1.4 million students taught by 28,223 North Carolina public school teachers with less than 5 years of experience (p. 8). Given the extensiveness of the North Carolina data bases, the researchers were able to control for numerous variables in their value-added models, including students' prior test scores, absenteeism, gender, poverty level, age, mobility, and the like. They were also able to control for teachers' years of experience, out-of-field teaching, and dispersion of achievement within the classroom, as well as school size, rates of school suspension and violent acts, total per-pupil expenditures, and concentration of poverty.

The analyses demonstrated clearly that teachers' preparation has significant effects on student achievement, as well as on teachers' evaluations and persistence in teaching. Drawing on numerous value-added comparisons of teachers' effects on student learning across the programs, the researchers concluded that Teach for America (TFA) teachers were the most effective early-career teachers, significantly outperforming teachers prepared at the UNC in nine value-added comparisons and performing no differently in two. They also had significantly higher odds of being rated "above proficient" on all five North Carolina Professional Teaching Standards. Graduates of the UNC traditional undergraduate programs were significantly more effective in 12 value-added comparisons than peers who came through other pathways, less effective in 15, and performed no differently in 67. Graduates had similar odds of being rated above proficient in all five North Carolina Professional Teaching Standards.

The researchers also found some evidence for the importance of content knowledge for improving student achievement in high school STEM courses. Early-career teachers with graduate degrees from North Carolina private universities, those with licensure-only preparation, and TFA corps members were more effective in high school science than teachers who were prepared in any other pathway; TFA corps members and teachers with graduate degrees from UNC institutions were more effective in mathematics. The researchers hypothesized that teachers who came through these routes had more extensive STEM-related coursework and all had greater odds of achieving “above proficiency” on North Carolina Professional Standard 3: Teachers Know the Content They Teach.

In another analysis, Kraft and Papay (2014) used the NCERDC data to study the effects of professional environments on teacher development in Charlotte-Mecklenburg Schools. In their sample were observations of 3,145 teachers and more than 280,000 students. Because the data included results from a working conditions survey administered every other year, the researchers were able to look at the relationships between student achievement in mathematics and such aspects of teachers’ professional environments as peer collaboration, school culture, and professional development. Kraft and Papay found that schools with the most supportive professional environments employed more qualified teachers (those with more experience, National Board certifications, and master’s degrees and graduates of more competitive colleges). On average, after 3 years, teachers working in schools at the 75th percentile in terms of professional environment ratings improved their effectiveness 12% more than teachers working in schools at the 25th percentile. After 5 years, the gap was 20% between

the two groups, and after 10 years, it was 38%. In sum, after 10 years, teachers at a school with a more supportive professional environment moved upward in the distribution of overall teacher effectiveness by approximately one fifth of a standard deviation more than teachers who worked in less supportive professional environments.

These are but three examples of a growing literature that is enabled by state investments in the development of robust databases that allow linking university, district, school, classroom, teacher, and student data. Other states have also been developing similar capacity, most notably the states collaborating through the National Center for Analysis of Longitudinal Data in Educational Research (CALDER), including Florida, North Carolina, Washington, Mississippi, Texas, New York, and the District of Columbia. Louisiana has also taken important steps in this direction (Gansle, Noell, & Burns, 2012). These efforts to improve the consistency, quality, and accuracy of data on the entire teacher workforce in each state are promising.

Noteworthy as well has been the rise of educator evaluation systems. Although teacher evaluation is not new, the use of state-mandated standardized instruments for observations, evaluations, and weighting various components of the systems (student learning outcomes/standardized tests, student or parent surveys, principal evaluations, observations, etc.) is new. These educator evaluation systems generate considerable information, but states vary in where those data are stored and how they are used. However, as instruments like teacher observation protocols are refined, the data collected in these systems have the potential for contributing to national estimates of teacher quality as well.

In sum, current efforts to track STEM teacher quality collect information on teachers’ years of experience, credentials and licenses, out-of-field teaching, and, in the case of recent graduates of teacher preparation programs, teacher test scores (see Table 3). Recently, several states have invested in the development of more comprehensive data systems with additional variables that can be used to assess teacher quality, including teacher self-reports on professional learning opportunities and teacher evaluations.

Developing national estimates for these indicators would present several challenges. Certification and licensure requirements differ across states, so developing a national data set for teachers with similar certification status would be problematic. In addition, states vary in terms of what tests are required, as well as the content of those tests and the cut scores established for competence. States have varying policies about their teacher evaluation systems in terms of the instruments used in observations and evaluations and the categories and weighting used to judge teacher competence. These differences would make cross-state comparisons difficult.

Table 3. Summary of Current Systems to Measure STEM Teacher Quality

Quality Measure	Traditional Data	Promising Developments in State Systems
In general	Years of experience Licensure/certification Out-of-field assignments	edTPA
Content knowledge for teaching	Basic skills, content knowledge, and/or pedagogy teacher tests	Teacher evaluations, including teacher observations
STEM-specific professional learning opportunities		Work conditions surveys



## Additional Available Data Sources and Measures of Teacher Quality

Although states generally do not have consistent data on teacher content knowledge for teaching or professional learning opportunities, several major projects have invested in the development of measures that could be used on a large scale in the United States for tracking these indicators. These are international surveys like the Teacher Education and Development Study in Mathematics (TEDS-M), as well as large-scale studies of teaching practice in the United States like the Measures of Effective Teaching (MET) Project. In addition to these research projects with limited time frames, the National Center for Education Statistics (NCES) conducted the Schools and Staffing Survey (SASS) from 1987 to 2011, gathering information on teachers' assignments, preparation, professional learning opportunities, and working conditions. These surveys and measures have considerable potential for use in a national indicator system. Consider example measures relevant to the two indicators—content knowledge for teaching and STEM-specific professional learning opportunities.

### Teachers' Science and Mathematics Content Knowledge for Teaching

Traditionally, it has been presumed that if teachers majored in a discipline closely related to the school subjects they teach, their content knowledge would be sufficient. This assumption was problematic for several reasons, two being that prospective elementary school teachers are responsible for teaching all academic areas (as well as music, art, and health) and that undergraduate coursework in a discipline does not correspond directly to K-12 school subjects. These limitations might account for the uneven and weak relationships that have

been documented in the research literature when researchers have used teachers' degrees (B.A./B.S., M.A./M.S., etc.) or teacher majors and minors in undergraduate and graduate study as proxies for teacher quality (e.g., Goldhaber & Brewer, 2000; Monk, 1994; Rice, 2003; Wayne & Youngs, 2003; Wilson, Floden, & Ferrini-Mundy, 2002).

Given the weak correlations between these proxy measures and teacher practice or student learning, researchers have been investing in the development of sound measures of content knowledge for teaching (CKT). The majority of this research has been on mathematics teaching.

### CONTENT KNOWLEDGE FOR TEACHING MATHEMATICS

Considerable work has been done on developing measures for large-scale assessments of mathematics teacher content knowledge for teaching. The three most noteworthy efforts are the (1) Learning Mathematics for Teaching (LMT) Project, which was then built upon by (2) the Measures of Effective Teaching (MET) Project and (3) the Teacher Education and Development Study in Mathematics (TEDS-M).<sup>2</sup>

The Learning Mathematics for Teaching (LMT) project aimed to investigate the design, implementation, and effects on student achievement of three of the most widely adopted whole-school reform programs in the United States: Accelerated Schools, America's

<sup>2</sup> Both these lines of work have built on relevant previous work, including two large-scale international studies, the Third International Mathematics and Science Study (TIMSS; Schmidt et al., 1996; Schmidt, McKnight, Valverde, Houang, & Wiley, 1997) and the Mathematics Teaching in the 21st Century Study (MT 21; Schmidt et al., 2007; Schmidt, Blömeke, & Tatto, 2011), as well as the Study of Instructional Improvement, which included the Learning Mathematics for Teaching Project (LMT; Hill & Ball, 2004; Hill, et al., 2005; Hill, Ball, & Schilling, 2004).

Choice, and Success for All.<sup>3</sup> As part of that work, researchers at the University of Michigan developed survey items to assess the CKT for elementary mathematics. For example, LMT items assessed how teachers solve the special mathematical tasks that arise in teaching, including evaluating unusual solution methods, using mathematical definitions, representing mathematical content to students, and identifying adequate mathematical explanations. The items cover the following content domains:

- Elementary number and operations (K-6, 6-8)
- Elementary patterns, functions, and algebra (K-6, 6-8)
- Geometry (3-8)
- Rational number (4-8)
- Proportional Reasoning (4-8)
- Data, probability, and statistics (4-8).

Several research projects have reported on results using the LMT measures. For example, Hill and Ball (2004) used the measures to assess teacher learning in California's Mathematics Professional Development Institutes. On the basis of data from 398 teachers in 15 institutes, they found that institute participants' CKT scores reflected a significant gain of between a third and a half of a standard deviation. Administering the items to a nationally representative sample of teachers, Hill (2007a) found that teachers with more mathematical coursework, subject-specific certification, and high school teaching experience had higher levels of CKT as measured on the assessments. Hill, Rowan, and Ball (2005) reported on results from an analysis of teacher knowledge and student achievement in 115 elementary schools that were all engaged in some form of instructional improvement. Teacher CKT was a significant predictor of student gains in first and third grades, translating into approximately one half to two thirds

of a month of additional growth. In fact, teacher CKT was the strongest teacher-level predictor of student achievement in mathematics, having a greater impact than teacher background characteristics or average time spent daily on mathematics instruction (p. 396).

The LMT measures were archived, training materials and protocols were developed, and researchers, evaluators, and teacher developers regularly use them to create assessments to track the effects of teacher education and professional development programs (e.g., Bell, Wilson, Higgins, & McCoach, 2010; Delaney, Ball, Hill, Schilling, & Zopf, 2008; Hill & Ball, 2004; Welder & Simonsen, 2011). The researchers explicated several caveats concerning item use, however. First, because the assessments focus on particular content domains, each domain needs multiple items, and between 12 and 25 items are needed to achieve adequate reliability for the six domains of elementary mathematics teacher content knowledge. This means that comprehensive assessments of content knowledge for teaching mathematics can be very long. Second, the LMT items were not developed with the goal of making statements about individual teacher knowledge and thus can be used responsibly only for measures of groups of teachers. Third, the measures do not work well with teachers who are highly knowledgeable (Hill, 2007b).

The Measures for Effective Teachers (MET) project tested multiple measures of effective teaching to determine how evaluation methods could best be used to provide an accurate, reliable picture of teaching effectiveness, including a survey that built on the LMT measures. MET researchers have produced three content knowledge assessments for mathematics teachers: Grades 4-5, Grades 6-8, and Algebra I.<sup>4</sup> An important note is that these assessments were not

<sup>3</sup> Instruments used in the Study of Instructional Improvement are available at <http://www.sii.soe.umich.edu/instruments/>.

<sup>4</sup> See <http://www.icpsr.umich.edu/icpsrweb/METLDB/holdings/documentation> for the relevant surveys and codebooks.

used in isolation but as part of a portfolio of measures that included classroom observations, student surveys of teacher practice, and student achievement gains, a point expanded on in the conclusion to this paper.

The MET researchers found that effective teaching can be measured using a combination of classroom observations, student surveys, and student achievement gains (Bill & Melinda Gates Foundation, 2013; Kane, McCaffrey, Miller, & Staigher, 2013). As a group, the teachers who were identified as more effective produced greater student achievement growth than other teachers at the same school, grade, and subject. However, the researchers also found that MET teachers who performed better on the CKT measures were not more effective in improving student mathematics achievement. This puzzling result may be due to the fact that the LMT research used teacher groups in its analysis, while the MET project examined the CKT measures predictive validity at the individual level. And the researchers caution that this result might be due to the relatively early-stage development of the MET CKT assessments (Bill & Melinda Gates Foundation, 2013, p. 15).

In the third study, the Teacher Education and Development Study in Mathematics (TEDS-M), researchers investigated the preparation of elementary and lower secondary mathematics teachers in 17 countries under the aegis of the International Association for the Evaluation of Educational Achievement (IEA).<sup>5</sup> The goal was to understand

both how teachers are prepared and the impact of various programs. As part of that work, the TEDS-M researchers created a teacher survey to assess teachers' mathematics content knowledge (MCK) and mathematics pedagogical content knowledge (MPCK). MCK items were classified along three dimensions: content (number and operations, geometry and measurement, algebra and functions, data and chance), cognitive (knowing, applying, or reasoning), and student curricular level (novice, intermediate, or advanced). The MPCK items were also classified along three dimensions: content, MPCK specific (curricular knowledge, planning, and enacting teaching and learning), and curricular level.

TEDS-M questions are both multiple choice and constructed response. As in the LMT project, a testing design was developed that did not overburden individual test takers because comprehensive assessments of each participating teachers' CKT would require unacceptably long tests. Test booklets covered algebra, geometry, number, data, mathematics curriculum and planning, and mathematics instruction, but no one teacher was tested in them all.

These booklets were then included in teacher surveys that also contained items about teachers' opportunities to learn specific domains of (1) general mathematics (19 topics in continuity and functions, discrete structures and logic, geometry), (2) school-level mathematics (numbers; measurement; geometry; functions, relations, and equations; data representation, probability, and statistics; calculus; and validation, structuring, and abstracting), and (3) mathematics education and pedagogy (including, affective issues, foundations, instruction, standards and curriculum). These self-report measures of

<sup>5</sup> Instruments used in this study had some questions that had been developed in previous projects, including LMT and Mathematics Teaching in the 21st Century (MT21), a small-scale international study conceived as a follow-up to the 1995 Third International Mathematics and Science Study and funded by the National Science Foundation to examine the preparation of middle school mathematics teachers. Items were then pilot-tested in four countries and field-tested in 11. The earlier MT21 project had found that relative to some other countries, the United States in general recruits prospective teachers with average mathematics knowledge (by international standards), and—in many cases—from the lower half of the U.S. achievement distribution. The researchers also found that U.S. teacher preparation programs focus primarily on general

pedagogy and spend little time on formal mathematics, with the exception of secondary teachers. Consistently, this produced U.S. teachers with low mathematical knowledge and strong pedagogical knowledge (Schmidt et al., 2011).

opportunities to learn provide a general sense of ideas that teachers have been exposed to, but they do not assess, as do the multiple-choice and constructed-response items, what prospective teachers might have learned from those opportunities.

The TEDS-M researchers collected data from representative national samples of about 500 higher education institutions in 17 countries that prepare primary and secondary school teachers. Some 22,000 future teachers were surveyed and tested, and 5,000 instructors were also surveyed. The researchers found that countries such as Taiwan and Singapore had better prepared future math teachers because students in those countries receive rigorous math instruction in high school, university teacher preparation programs are highly selective and demanding, and the teaching profession is attractive, with excellent pay, benefits, and job security. U.S. primary teachers were ranked fifth in their content knowledge in international comparisons, trailing behind Taiwan, Singapore, Switzerland, and the Russian Federation. Lower secondary teachers in the United States were also ranked fifth, trailing behind Taiwan, the Russian Federation, Singapore, and Germany (Tatto et al., 2013). Top-performing countries also have rigorous quality assurance measures for recruiting and training new teachers. The findings of the TEDS-M survey also suggest that the diversity in teacher recruitment and training procedures represents a continuum that can provide countries with examples of systems designed to improve the mathematics knowledge and skills of their teaching force. The United States ranked very poorly on the International Association for the Evaluation of Educational Achievement's quality assurance system metric that included information on teacher preparation program selection and recruitment strategies, program certification and accreditation, and the criteria for successful program completion and graduation (Tatto et al., 2013).

## CONTENT KNOWLEDGE FOR TEACHING SCIENCE

While researchers have a substantial interest in elementary and secondary science teachers' content and pedagogical content knowledge (e.g., Berry, Friedrichsen, & Loughran, 2015; Lederman, & Gess-Newsome, 1992; Loughran, Berry, & Mulhall, 2012; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; VanDriel, Verloop, & de Vos, 1998), no item banks or assessments comparable to those for TEDS-M or LMT have been pilot- or field-tested at scale. Noteworthy are the assessments developed by the Misconceptions-Oriented Standards-Based Assessment Resources for Teachers (MOSART) Project at Harvard University, those developed by Horizon Research, Inc.'s Assessing Teacher Learning about Science Teaching (ATLAST) Project, and the Diagnostic Teacher Assessments in Math and Science (DTAMS) designed by the University of Louisville's Center for Research in Mathematics and Science Teacher Development.

The Misconceptions-Oriented Standards-Based Assessment Resources for Teachers (MOSART) assessments focus on K-12 physical science and earth science content and K-8 life science content. They are frequently used to assess student learning in classes of teachers who have participated in National Science Foundation (NSF) Math-Science Partnerships, and the authors promote their use with teachers as well. Sadler et al. (2013) reported on a study of 9,556 students of 181 middle school physical science teachers. The researchers found that teachers who could identify students' misconceptions had larger classroom gains, much larger than if the teachers knew only the correct answer to a particular assessment item. On items on which students did not exhibit misconceptions, teacher subject matter knowledge alone accounted for higher student gains. The authors concluded that teacher content knowledge and pedagogical content knowledge are

associated with higher student science achievement.

Researchers working on Horizon Research, Inc.'s Assessing Teacher Learning about Science Teaching (ATLAST) Project developed teacher assessments in the content domains of middle school force and motion (29 items), processes that shape Earth (e.g., plate tectonics, 30 items), and flow of matter and energy in living systems (29 items).<sup>6</sup> Three types of multiple-choice items are in the ATLAST assessments:

- Level 1: knowledge of science content
- Level 2: using content knowledge to analyze/ diagnose student thinking
- Level 3: using content knowledge to make instructional decisions.

Note that although the researchers did not use the language of CKT, these three levels of knowledge fall within that concept. The assessments are available for use by researchers and educators but, like the previously described assessments, are not appropriate for making decisions about individual teachers and are best for evaluating groups of teachers with sufficient numbers ( $N > 20$ ). No research linking these items to student achievement has been published (e.g., Smith, 2009).

The University of Louisville's Center for Research in Mathematics and Science Teacher Development designed the DTAMS for elementary and middle school mathematics teachers and for middle school science teachers.<sup>7</sup> The science assessments address physical science, life science, and Earth/space science. Six versions of each assessment are available, each composed of 25 items—20 multiple choice and 5 open response. The tests are designed to assess four “knowledge types”:

declarative knowledge (e.g., facts and definitions), scientific inquiry and procedures (e.g., knowing how to “do science”), schematic knowledge (understanding of concepts, laws, theories, and the like), and pedagogical content knowledge. The assessments are available free of charge but are scored by center staff for a fee. No published research has examined the relationship of teachers' scores on these assessments to measures of student learning.

Although perhaps promising, neither the ATLAST nor the DTAMS assessments have been used at a large scale, so further development of their items would be needed before using them to generate national teacher quality estimates. The MOSART items also have promise, but, as is the case with all content knowledge for teaching items, they are subject specific and items do not yet exist for all content domains in the K-12 mathematics and science curricula.

## CONTENT KNOWLEDGE ASSESSMENTS IN MATHEMATICS AND SCIENCE

In addition to assessments intended to measure CKT, including disciplinary knowledge, specialized content knowledge, and pedagogical content knowledge, are content-specific teacher tests used across the states, such as the Praxis II subject assessments (Earth and Space Science, General Science, Chemistry, Middle School Science, Mathematics, Middle School Mathematics, and Physics) from the Educational Testing Service, which have both multiple-choice and constructed-response questions. A study by Goldhaber (2007) found no evidence that teachers' scores on the Praxis II Content test in mathematics predicts student achievement.

Other researchers have been working on the development of additional teacher content knowledge assessments. Some have adapted student assessments to be used with teachers (for example, the ACT mathematics exam or the mathematics and science portions of the Iowa Test of Basic Skills); other researchers have used content examinations that are used for other purposes (for

<sup>6</sup> See [http://www.horizon-research.com/atlast/?page\\_id=111](http://www.horizon-research.com/atlast/?page_id=111) for user manuals for the three ATLAST assessments.

<sup>7</sup> <https://louisville.edu/education/centers/crmstd/diag-sci-assess-middle> <https://louisville.edu/education/centers/crmstd/diag-sci-assess-middle> .



example, content examinations developed by the American Chemical Society Division of Chemical Education Examinations Institute).

Many of these materials were collected by the Community for Advancing Discovery Research in Education (CADRE) in its *Compendium of Research Instruments for STEM Education, Part I* (CADRE, 2013). This is a resource of tools that were used to measure teacher practices, pedagogical content knowledge, and content knowledge across 295 projects funded by NSF. Similarly, NSF’s Math and Science Partnership created the Math and Science Partnership Knowledge Management and Dissemination Project to house its research, development, findings, and contributions, including instruments and relevant papers available to all partnership participants by subject, type of knowledge measured, grade levels, and nature of instrument (i.e., interview protocol, observation protocol, multiple choice/constructed response, and concept maps).

SUMMARY OF CONTENT KNOWLEDGE FOR TEACHING MEASURES

The high interest in assessing teachers’ content knowledge for teaching mathematics and science far outstrips our current capacity to do so. However, several research projects have created instruments that might form the foundation for assessments of content knowledge for teaching that could be used to generate nationally representative data (see Table 4).

Considerable investments have been made in developing measures of content knowledge for teaching mathematics, and those measures have been used in several large-scale studies. However, evidence linking higher teacher scores on such measures to higher student achievement is uneven. Lesser investment has been made in developing similar measures for science teachers. Some researchers have resorted to using assessments that were developed for other purposes, including K-12 student tests. These existing measures do not assess the full range of knowledge and skill included in CKT (common content knowledge, specialized content knowledge, and pedagogical content knowledge), and thus would be less than ideal for generating estimates of U.S. science teachers’ content knowledge for teaching.

Teachers’ Participation in STEM-Specific Professional Development Activities

Teaching is an occupation that requires continual learning. As teachers accrue years of classroom experience, they have increased opportunities to expand their practice in terms of both how well they understand how to teach the content and how well they understand the students they work with. As standards and policies change and as new research informs teaching and learning, teachers need sustained opportunities to enhance their professional knowledge.

Two challenges are associated with conceptualizing teachers’ participation in STEM-specific professional

Table 4. Summary of Current and Promising Measures of STEM Teacher CKT

	Traditional Data	Promising Developments in State Systems	Promising Developments in Research Projects
Content knowledge for teaching	Basic skills, content knowledge, and/or pedagogy teacher tests	Teacher evaluations, including teacher observations	CKT in mathematics items developed by LMT, MET, and TEDS-M  CKT in science items developed by MOSART, ATLAST, and DTAMS

development activities. The first concerns where teachers are in their own development, and the second is the myriad contexts and venues that can be used to enhance teacher learning. For example, teacher learning opportunities vary according to whether teachers are in their initial preparation

programs (teacher education), receiving early-career support (teacher induction), or participating in in- and out-of-school professional learning (professional development) (see Table 5).

Table 5. Opportunities for Teacher Learning Across the Career

Teacher Education	Teacher Induction	Professional Development
<ul style="list-style-type: none"><li>• University or program-based courses</li><li>• Field/clinical experiences</li><li>• Supervised student teaching or internships</li></ul>	<ul style="list-style-type: none"><li>• District or school orientation</li><li>• Mentoring</li><li>• Co-teaching/planning</li></ul>	<ul style="list-style-type: none"><li>• University courses</li><li>• Summer/out-of-school institutes/workshops</li><li>• School or district workshops/professional development days</li><li>• Teacher study groups</li><li>• Professional learning communities</li><li>• Coaching</li><li>• Lesson study</li></ul>

Different kinds of learning opportunities are characteristic of these “stages” in a teacher’s career. Preservice professional learning often includes coursework and field experiences that are paired to prepare new teachers with content and pedagogical knowledge, as well as repeated opportunities to apply that knowledge in real-world school settings. Typically, there is a capstone student teaching experience for an extended period (ranging from 8 weeks to a yearlong internship). Early career support often consists of an initial orientation for new teachers to introduce them to the school district’s policies and procedures and a mentoring program through which new teachers can receive a range of types of support, as when a coach observes and debriefs a new teacher’s practice or new teachers are given opportunities to observe the teaching of more experienced colleagues. Ongoing professional development can range from university coursework to seminars offered by school districts to summer fellowships to work in science laboratories to

NSF-sponsored projects designed to enhance teachers’ CKT. While teacher preparation programs can be more coherent, teacher learning opportunities after certification tend to be more of a patchwork and catch-as-catch-can.

The fact that teachers’ opportunities to learn come in so many forms and are provided by so many different sources makes capturing them challenging for researchers. Various instruments have been developed to collect this information. In particular, because ongoing professional learning is not simply formal workshops or seminars outside the school or school day, some information is best gleaned from data on working conditions (e.g., do teachers have an opportunity to collaborate) while other information is best gleaned from questions about formal opportunities to learn (e.g., professional development workshops).

Several large-scale measures currently exist for documenting teachers’ self-reports of their opportunities to learn and their working conditions. These include

TEDS-M Future Educator Survey and the survey used in the Pathways Project for teacher preparation, as well as the Measures of Effective Teaching (MET) Teacher Survey, the Third International Mathematics and Science (TIMSS) teacher questionnaire, the Schools and Staffing Survey (SASS) for professional development, state/district surveys of teacher working conditions, and the National Survey of Science and Mathematics Education. Each is described in turn.

### TEDS-M FUTURE EDUCATOR SURVEY

In addition to the CKT questions described in the previous section, the new teachers in the TEDS-M study were asked a series of questions about their opportunities to learn the teaching methods their instructors used, their field experience, and their perceptions of their program's coherence and effectiveness. First, future teachers were asked about their opportunity to learn various mathematics topics. They were also asked about their opportunity to learn different topics concerning mathematics education, including the development of mathematics ability and thinking, mathematics instruction, developing teaching plans, mathematics teaching (including observation, analysis, and reflection), mathematics standards and curriculum, and affective issues in mathematics.

In addition to being asked what they learned about, respondents were asked what activities they engaged in while participating in their program (analyzing teaching examples, writing mathematical proofs, working in groups, analyzing student assessment data, developing instructional materials, etc.).<sup>8</sup>

The TEDS-M researchers found that future primary teachers were not expected to learn mathematics content beyond that included in the school curriculum.

Future secondary teachers had more coverage of mathematics content, but there was more variability in opportunity to learn among the future teachers being prepared for middle school. The countries with programs providing the most comprehensive opportunities to learn challenging mathematics had higher scores on the TEDS-M tests of knowledge. Primary and secondary teachers in Chinese Taipei, Singapore, and the Russian Federation had significantly more opportunities than their primary and secondary peers in other participating countries to learn university- and school-level mathematics.

### PATHWAYS PROJECT

As part of the *Examining Teacher Preparation: Does the Pathway Make a Difference?* project, teacher preparation program graduates were surveyed each year (Boyd et al., 2006; Boyd, Grossman, Lankford, Loeb, & Wyckoff, 2009). In addition to questions concerning the location and focus of their teacher preparation programs, respondents were asked to report on their opportunity to learn about a range of topics, including understanding student development, motivation, and needs. They were asked to report on their interactions with their cooperating teacher and any program personnel who worked with them on their field experiences in the program. Prospective mathematics teachers were asked whether they had taken high school courses, university courses, and summer workshops in a range of 22 mathematics topics. They were asked to report on how extensive their experiences had been with learning to help students solve problems, learning specific techniques to teach number theory, learning about students' typical difficulties with particular mathematical topics, and learning how to use manipulatives in the classroom.<sup>9</sup>

<sup>8</sup> See p. 52 of this report for the complete list: [http://www.iea.nl/fileadmin/user\\_upload/Publications/Electronic\\_versions/TEDS-M\\_technical\\_report.pdf](http://www.iea.nl/fileadmin/user_upload/Publications/Electronic_versions/TEDS-M_technical_report.pdf).

<sup>9</sup> See the math supplement survey at <https://cepa.stanford.edu/tpr/teacher-pathway-project-old> for the complete set of prompts.

The researchers found variation across the 31 early childhood programs studied in terms of the in the average effectiveness of the teachers they were supplying to New York City schools (Boyd et al., 2009). Some programs graduated teachers who have a significantly greater effect on student achievement. The results also suggest that features of teacher preparation can make a difference. In particular, the researchers found that teacher preparation that concentrates more on the work of the classroom and provides opportunities for teachers to study what they will be doing as first-year teachers appears to produce teachers who, on average, are more effective during their first year of teaching, as reflected in student achievement test scores in mathematics. “Learning that is grounded in the practice of teaching,” (p. 434) the authors argue, matters, as reflected in multiple opportunities to put ideas learned in teacher preparation into action in classrooms and opportunities to learn about the New York City curriculum. The congruence of a prospective teacher’s field experiences with the school and classroom that she or he worked in during the first year of teaching also matter. The magnitude of these effects was approximately the same as that of the gain a teacher makes after the first year of teaching (Boyd et al., 2009).

In sum, both the Pathways Project and TEDS-M developed survey items used with thousands of prospective teachers that were designed to collect information on

- The substantive focus of the opportunity to learn mathematics or mathematics education
- The pedagogy of the opportunity to learn (e.g., mentoring, small-group work, capstone projects)
- Respondents’ perceptions of the usefulness of these learning opportunities.

Surveys have also been developed to ask early-career and practicing teachers similar questions.

### MEASURES OF EFFECTIVE TEACHERS (MET) TEACHER SURVEY

The MET study also administered a survey to teachers that had several questions directly addressing their views on their own professional development. Teachers were asked for their perspectives on whether they received the appropriate amount of professional development (PD), whether it was data driven and differentiated by teachers’ needs, and whether—as a result—the professional development had deepened their content knowledge, enhanced their ability to improve student learning, encouraged reflection, or provided ongoing opportunities for learning. They were also asked to note whether they needed professional development in several domains: special education (students with disabilities; gifted and talented,), differentiating instruction, working with English language learners, closing the achievement gap, their content area, methods of teaching, student assessment, classroom management, reading strategies, or integrating technology into instruction.

Another MET question asked whether respondents worked in professional learning communities, were encouraged to improve their instruction, or were provided supports like learning communities or coaching to improve their instructional practice. Early-career teachers were asked a series of questions about whether they were formally assigned a mentor, participated in seminars for new teachers, had formal time to work with mentors, engaged with common planning time with colleagues, could attend an orientation for new teachers, and had access to a professional learning community. They were also asked to report on their perceptions of the effects of being mentored on

their instructional strategies, content knowledge, classroom management, differentiating instruction, creating a supportive classroom environment, working collaboratively with other teachers, and connecting with key resource professionals.

The relationship between teachers' responses to these questions and measures of teacher effectiveness has not yet been reported.

## STUDY OF INSTRUCTIONAL IMPROVEMENT (SII)

Each year of the Study of Instructional Improvement (SII), participating teachers responded to a questionnaire about their teaching practice, school context, and working conditions. On that survey were questions about teachers' professional development. Teachers were asked to report on how many PD sessions they participated in that academic year in the following areas: student assessment, curriculum materials, teaching methods, multicultural/diversity issues, classroom management, school governance, school improvement, social services for students, school climate issues, or parent/community involvement. They were also asked to report on how much time they spent analyzing or studying mathematics curriculum materials, improving their skills at developing mathematics tasks for students, improving their knowledge of number concepts and how computational procedures work, and extending their knowledge of different representations of number concepts and operations. The teachers were asked how often they watched another teacher model instruction, provided feedback to another teacher on his/her instruction, received feedback from a teacher colleague who had observed them, watched an instructional leader model instruction, or received feedback from an instructional leader who had observed their instruction. The survey also included questions about the qualities of their formal and

informal opportunities to learn along the dimensions of coherence, focus, usefulness, and relevance.

In an analysis of SII teachers in 80 schools, Camburn (2010) found that teachers who had greater embedded learning opportunities, namely, collaborating with other teachers on curriculum and working with school-based instructional experts (e.g., coaches), engage in reflective practice more often than colleagues with fewer such opportunities. Teachers who participated in more traditional professional development that focused on instruction also had higher rates of engaging in reflective practice, but not as often as teachers who regularly collaborate with colleagues and work with instructional experts.

## NATIONAL TEACHER AND PRINCIPAL SURVEY (NTPS)

The new NTPS is a system of linked questionnaires that elicit descriptive data on the condition of U.S. elementary and secondary education. The set of questionnaires builds on the Schools and Staffing Survey (SASS), which NCES conducted from 1987 to 2011, integrating that survey's content with other U. S. Department of Education tools. The goal is to create a system that collects information on teacher and principal preparation, classes taught, school characteristics, and labor force demographics every other year. An innovation of NTPS is that it will include rotating modules on topics of interest: working conditions, educator evaluation, and educator professional development among them.

Because the NTPS is still under development, the specific content of its survey modules was not available for this analysis. We do know the SASS collected information from teachers on when they began teaching, how many years they have taught, the grade levels and subject matter they have taught, and the range of students they have worked



with. The survey also gathered information on teachers' undergraduate, masters, and professional degrees, including their majors, minors, degrees, and the names of their institutions. The SASS asked respondents questions about how well prepared they were in their first year of teaching to handle classroom management, use a variety of instructional methods, teach their subject matter, use computers in instruction, assess students, differentiate instruction, use data to inform instruction, and meet state content standards and whether they participated in an induction program, which might have featured common planning time, seminars or classes for beginning teachers, extra classroom assistance, regular communication from a principal or other leaders, and work with a mentor or master teacher.

Regarding their professional learning opportunities, SASS respondents were asked to report on their opportunities in the past 12 months. Questions concerned both the locations for learning (university courses, observation visits to other schools, workshops or conferences) and the topic of the professional development—e.g., their content area, computers, reading instruction, student discipline and management, students with disabilities, English language learners. Respondents were also asked to report on whether they received compensation for the time spent in professional development. Concerning their working conditions, teachers were asked whether they had an opportunity to engage in individual or collaborative research and schedule collaborations with colleagues and whether and how often they were observed and received feedback on their instruction.

### THIRD INTERNATIONAL MATHEMATICS AND SCIENCE STUDY (TIMSS) SCIENCE TEACHER SURVEY

Whereas most large-scale survey work is either generic or concerns the professional learning of mathematics teachers, in 1999 the TIMSS project included a questionnaire for science teachers. Part of that survey addressed teachers' working conditions (e.g., How often do you have meetings with other teachers to discuss curriculum or teaching approaches?), their degrees (undergraduate and graduate), and their professional development activities in the last academic year. Teachers were asked how often they observed teacher colleagues or were observed by colleagues and how many hours they spent in a range of learning opportunities, including

- within-district workshops or institutes,
- courses for college credit,
- out-of-district workshops or institutes,
- teacher collaboratives or networks,
- out-of-district conferences,
- immersion or internship activities,
- receiving mentoring/coaching/lead teaching,
- conducting research,
- reading professional material,
- teacher resource center,
- committees or task forces,
- teacher study groups, and
- other forms of organized professional development.

Respondents were also asked about the focus of those varied opportunities, whether it was curriculum, subject-specific pedagogy, general teaching methods, assessment, technology, teaching diverse learners, understanding how students learn science, leadership development, or deepening their understanding of science.

## STATE/DISTRICT SURVEYS OF WORKING CONDITIONS

Another potential source of helpful instruments is state and district surveys on teachers' working conditions, as some researchers have found that teachers' perceptions of working conditions are correlated with both teacher retention and student achievement. As noted, using teachers' survey responses, Kraft and Papay (2014) found that teachers who work in more supportive environments are more effective at raising student achievement on standardized tests over time.

Several states and districts have developed such instruments. For instance, several researchers have used the North Carolina Teacher Working Conditions Survey (e.g., Kraft & Papay, 2014; Ladd, 2009), which has been used statewide every 2 years since 2002 (Hirsch & Emerick, 2006) and can be linked to other North Carolina data through the NCERDC. The North Carolina survey conceptualized working conditions in six categories: leadership, facilities and resources, teacher empowerment, professional development, mentoring, and time. Sixty-five of the survey questions relate to professional development; 40 concern mentoring (Ladd, 2009). Teachers are asked a range of questions about sufficiency of time to work on instructional improvement, sufficiency of resources and materials to promote student learning, and the nature of their own professional learning needs. They are asked to report on how often they plan with colleagues, participate in professional development, reflect on their own practice, and collaborate with colleagues on the improvement of instruction. They are also asked about the quality of the school's leadership, the school culture, and whether their school is a good place to “work and learn.”<sup>10</sup>

In addition to this range of measures, Horizon, Inc. has conducted a National Survey of K-12 Science and Mathematics Education (NSSME) five times since 1977. NSF commissioned the first NSSME in 1977. It involved a comprehensive literature review, a set of case studies of districts across the United States, and a national survey of teachers, principals, and district and state personnel. A second NSSME of teachers and principals was conducted in 1985–86, a third in 1993, and a fourth and fifth in 2000 and 2012, respectively.<sup>11</sup>

The 2012 NSSME was designed to answer the following questions:

- What instructional/assessment practices do science and mathematics teachers use, and how well do they align with current understanding of learning?
- What factors influence teachers' decisions about content and pedagogy?
- What are the characteristics of the science/mathematics teaching force in terms of race, gender, age, content background, beliefs about teaching and learning, and perceptions of preparedness?
- What are the most commonly used textbooks/programs, and how are they used?
- What formal and informal opportunities do science/mathematics teachers have for ongoing development of their knowledge and skills?
- How are resources for science/mathematics education, including well-prepared teachers and course offerings, distributed among schools in different types of communities and different socioeconomic levels? (Horizon, 2013)

<sup>10</sup> See <http://www.ncteachingconditions.org> for the complete survey and explanation of the program.

<sup>11</sup> For complete information, see <http://www.horizon-research.com/2012nssme/about-the-study/>.

Separate NSSME surveys were developed for science and mathematics teachers. They gather information on teachers' educational background and experience, teaching assignment, course currently taught, STEM courses taken at the undergraduate and graduate levels, participation in professional development, self-perception of preparedness to teach certain topics, self-perception of preparedness to work with diverse students, beliefs about science teaching and learning, instructional strategies and pedagogical practices, and resources and technologies available. The surveys also ask for in-depth information about a recently completed instructional unit.

The researchers found that although more than 80% of middle and high school science teachers and over half of elementary teachers have participated in science-focused PD in the last 3 years, only one third of secondary teachers and 4% of elementary teachers had more than 15 hours of professional development. The findings were similar for mathematics teachers. Teacher study groups were offered in about half of secondary schools and less than half of elementary schools in the last 3 years. Working in teacher study groups was more common among mathematics teachers than science teachers.

SUMMARY OF MEASURES OF TEACHERS' STEM-SPECIFIC OPPORTUNITIES TO LEARN

Each of the instruments described above has been used on a large scale (see Table 6).

These instruments differ along several dimensions:

- how they conceptualize and define professional development for survey respondents,
- whether they include mathematics- and science-specific prompts about professional learning opportunities, and
- what they nominate as the focal topics for professional development (e.g., technology, student assessment, creating mathematical tasks) and as venues for professional learning (networks, college courses, and the like).

This diversity of approaches to surveying teachers about their learning opportunities in some ways mirrors the diversity of professional development available to teachers. Their differences also highlight the importance of asking career-stage-specific questions: Learning opportunities for new teachers are often structured much differently from those for more experienced teachers.

Table 6. Summary of Promising Measures of STEM Teacher Professional Development Opportunities

Traditional Data	Promising Developments in State Systems	Promising Developments in Research Projects
STEM-specific professional learning opportunities	Work conditions surveys	Surveys developed by: TIMSS, Pathways, MET, NSSME, TEDS-M, and SII

## Conclusion

The current state of available measures that might be used as indicators of science and mathematics teacher quality has benefited considerably from strong research and development work conducted in the last 25 years. We are no longer dependent on rough proxies like grade point average or number of courses taken in mathematics or science. This is heartening because measures like that have shown weak—if any—relationship to student learning and engagement. Furthermore, as Kraft and Papay (2014) commented about the working conditions survey used in North Carolina, there are efforts under way to measure aspects of teaching and teachers' work that are much more difficult to quantify than traditional indices like school infrastructure, teacher credential status, or numbers of teachers.

That said, several points bear consideration. First, the survey items that have been developed to measure teacher content knowledge for teaching and teachers' opportunity to learn are part of larger surveys that gather important contextual information about teachers' backgrounds and experiences, their teaching assignments, their beliefs about students and subject matter, and their working conditions. The data on content knowledge for teaching and teachers' opportunity to learn are best understood as embedded in those larger contexts. Related to this is the point made by every survey development team: The measures that currently exist are not appropriate for making individual judgments or high-stakes decisions but rather for estimating patterns for larger groups of teachers.

Second, there are some challenges to be overcome if these measures are to be used to develop national estimates of STEM teacher quality. The available

assessments of content knowledge for teaching do not cover all relevant content areas for K-12 mathematics and science teachers. Moreover, it is not clear to what extent existing survey items align with emergent student standards, for instance, the Common Core State Standards or the Next Generation Science Standards. Nor is it clear whether existing items assess teachers' understanding and mastery of mathematical or scientific practices or how those practices are applied along with particular math and science concepts. Some differences also exist in the theoretical underpinnings of different assessments. Recall that the TEDS-M content knowledge for teaching items were conceptualized in three domains—content, cognitive (knowing, applying, or reasoning), and curricular (novice, intermediate, or advanced)—while the DTMAS items were based on a conceptualization that involved four different “knowledge types”—declarative knowledge, scientific inquiry and procedures, schematic knowledge, and pedagogical content knowledge. Generating national teacher quality data on a consistent and recurring basis would require evening out those differences in coverage and conceptualization.

In terms of STEM-specific professional learning opportunities, the landscape is even more conceptually unclear. There are the differences already noted across teacher preparation, induction, and ongoing support. There is also the issue that professional development itself is being reconceptualized to include formal and informal opportunities to learn, in and out of school. Thus, in current instruments some relevant professional learning questions are embedded in questions about working conditions (How often do teachers in your

school meet to discuss instruction?), as well as in sections clearly marked as professional development. The new National Teacher and Principal Survey provides a promising context in which to create modules that might focus on working conditions, external and job-embedded opportunities to learn, and different subject areas over time.

Unfortunately, the rise of interest in educator evaluations further muddies the water: The best educator evaluation systems are designed to be educative, so future instruments might need to collect much more extensive information about how teachers are evaluated as another context directly relevant to professional development. The increasing interest in teacher leadership offers yet another example: Teachers have regularly noted that serving as mentors for new teachers, as peer observers for colleagues, or on districtwide textbook selection committees has been an important source of professional growth. Developing a comprehensive set of questions about teachers' opportunities to learn will require extensive reconsideration of such formal and informal, planned, and serendipitous teacher learning opportunities.

Finally, it is important to note the growing realization of the need for insight into teachers' instructional practices. Understanding what teachers know and whether they have had ongoing, high-quality, relevant opportunities to learn is essential to building a strong STEM teaching workforce. But that understanding will be enhanced by additional insight into practice. Considerable energy and effort are currently being poured into measuring practice—through observation protocols and through surveys like those used in the MET study. Additional investment in the development of those measures might allow the creation of an indicator that gets even closer to instruction in U.S. classrooms: surveys and observations of teaching practice itself. However, in the interim, we can draw on the substantial work that has been done in developing instruments that can be used at large scale to collect nationally representative data on basic information regarding STEM teacher knowledge and teachers' opportunities to learn. These data would substantially enhance the portrait of the STEM teaching workforce beyond the sheer number of teachers currently teaching STEM subjects.



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## Appendix: Data Housed in the NCERDC (North Carolina Education Research Data Center)

System Level	Data Sets	Available Data
District	Community Index Data, 2004	Per LEA, percentage of students scoring at certain levels on end-of-grade/-course tests; living in single-parent households, living below the poverty line, having one parent without a high school diploma. Index of relative disadvantage compared with state average
	District Finance, 1997–2011	LEA finance information: assets, debts, revenues, and expenditures
	District Report Cards, 2001–present	Snapshots of district characteristics, student academic performance, and district spending
	Dropout Rate, 1995–2003	Number of dropouts and dropout rates by LEA
	High School Graduates, 1983–2002, 2005–06	Counts of high school graduates per school district and charter school, including demographic breakouts of graduates
	Juvenile Justice, 2003–06	Intake statistics, detention, admissions, and youth development commitments per county
	Legally Reportable Incidents, 1996–2002	Legally reportable incidents (e.g., robbery, drug possession) per district
	Local Education Agency Universe, 1993–2013	District counts of staff (by type), diploma recipients and other high school completers by ethnicity and gender
	Per Pupil Expenditure, 1980–2004	Per-pupil and total expenditures per school district
	Personnel, 1998–2005	Number of principals, teachers, principals, staff, etc., by race and gender for LEA
School	Salary Supplement Years, 1987–2011	Number of teachers, principals, superintendents, and other school staff receiving local salary supplements and average amount of supplements
	Attendance, 2004–2011	Average daily membership and daily attendance per school
	Growth Scores, 1997–2009	Results of the state accountability testing system per school, including school's overall state rating
	Private School Survey, 1996–2004	Information on private school emphasis, length of school day, high school graduates, composition of student population, etc.
	Public School Universe, 1993–2013	Pupil-teacher ratio, counts of free and reduced-price lunch-eligible students, and counts of students by race, ethnicity, and grade per school
	School Report Cards, 2001–present	Snapshot of school characteristics, student academic performance, teacher quality, and school safety
Classroom	School Activity Reporting (SAR) Directory/Student Count, 1995–present	Course titles, credits, number of semesters, grade level per school, including information about student race-gender counts and exceptionality
	SAR Personnel File, 1995–present	Information on instructors assigned to activities, including teacher race, gender, and level of experience
	Meeting Codes, 1995	Number of times and number of minutes for all activities per district and school within district



System Level	Data Sets	Available Data
Teacher	National Board Certification, 1995–2007, 2014	Year of certification and certificate area for NBPTS-certified teachers per year
	Personnel Absence, 1995–2008	Absenteeism records for all education personnel
	Personnel Education File, 1995–present	Educational attainment for each instructor including graduation date, degree, and institution of higher education
	Personnel License File, 1995–present	License information for every instructor
	Personnel Pay History File, 1995–present	Detailed information for every teacher's position and salary
	Personnel Testing File, 1995–present	Testing information on Praxis for each instructor
	Working Conditions Survey, 2002–14 (biennial)	Teachers' perceptions of the work environment, including time management, resources, school leadership, personnel empowerment, and professional development
Student	Address data, 1995–2012	Bus route data on all students that can be linked to student test files
	Advanced Placement, 2010–present	Information on AP classes per course per student
	Alternate assessments, 2009–present	Mathematics and reading alternative assessment scores
	ASSET Test Scores, 2002–07	Numerical skills test, reading skills test, writing skills test, elementary algebra test
	Course Membership, 2006–present	Information on students in each course: number of students in the course, student race/ethnicity, school, section, and semester
	Demographics and Absences, 2006–present	Information on students, their race/ethnicity, gender, language, previous school, days absent, number of days in school membership, homeless, academically gifted, and immigration code
	Dropout Data, 1996–present	Information on age on dropout date, reason for dropout, grade on dropout, school code
	End of Grade Tests, 1995–present	Individual student test records and information about any modifications for grades 3–8. Includes information about student class work, age, race, gender, free/reduced-price lunch eligibility, and exceptionality status
	End of Course Tests, 1997–present	Student test records for subject-specific academic tests and a high school comprehensive exam in 10th grade. Data also include student test records, extracurricular activities, time spent on homework, age, race, gender, and exceptionality status.
	Exceptional Children, 2001–03, 2005–present	Records for students receiving special education and related services
	GPA, 2005–present	12th-grade student GPA, class ranking, and high school completion
	Graduates, 2009–present	Demographic information, course of study, and postgraduate intentions of high school graduates
	Growth, 2006–12	Student growth and proficiency in each subject
	Masterbuild, 1997–present	Date and score per student for every test and exemption status. Also includes student absences, student participation in a school, intended course of study, retention status, age, gender, race, and limited English proficiency.
	Offense- Consequence Data, 2001-present	Data on legally reported offenses, out of school suspensions, expulsion, and referrals to other schools per student per year
	PSAT, 2013-present	Scores for all students
	SAT, 2009-present	Scores for all students

System Level	Data Sets	Available Data
<b>Student (Continued)</b>	School Exit, 2006-present	Information on student transfer, dropout and graduation status
	Tests, 2006, 2008-present	Student test results for each year, test ID, test date, score, achievement level, and exemption code.
	Alternate Assessments, 2009-present	Assessments for students with disabilities
	ASSET Test Scores, 2002-2007	Data on reading, writing, and math test scores used by community colleges for admission and placement
	Course Membership, 2006-Present	Information on students' courses, title, enrollments in each course. This can be linked to teacher data.
	Demographics and Absences, 2006-present	Demographic information on every student, as well as absenteeism rates and student movements across schools and districts within a school year
	Dropout Data, 1996-present	Data on race, gender, age, school, and grade for each identified dropout
	Transcripts, 2005-present	Courses taken, credits, class ranking, and course grades for each student
	Youth Risk Behavior Survey, 1995-2011	Assesses health risk behaviors of middle and high school students

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