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A CENTURY OF LEADERSHIP IN
MATHEMATICS AND ITS TEACHING

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Christopher J. Huson

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The Role of the Mathematics Supervisor in K–12 Education

Carole Greenes
Arizona State University

The implementation of *the Common Core Standards for Mathematics* and the assessments of those concepts, skills, reasoning methods, and mathematical practices that are in development necessitate the updating of teachers' knowledge of content, pedagogical techniques to enhance engagement and persistence, and strategies for responding to the needs and talents of students. Following a brief history of the role of supervisors, the key responsibilities of current supervisors are described and include strategies for: establishing a framework for instruction, collaborating with other content curriculum supervisors to explore ways to enhance key concept acquisition in two or more fields, identifying students' academic needs and monitoring their progress, designing and conducting ongoing PD programs, closing learning gaps, and celebrating achievements of both students and teachers. The chapter concludes with an identification of the qualifications and characteristics of effective supervisors of mathematics.

Keywords: Supervisors of mathematics, PD programs for mathematics teachers, framework for implementation of the Common Core Standards in mathematics, closing the achievement gap

Introduction

In the 1950s, leadership in mathematics education at the school district level was most often the responsibility of the high school mathematics department chairman. Chairmen held teacher meetings, selected textbooks, and made course assignments. When their responsibilities extended to junior high schools, and then to elementary schools, these chairmen were given new titles, that of Supervisors of Mathematics. In the late 1950s and early 1960s, the introduction of “new math” programs (e.g., University of Illinois Committee on School Mathematics (UICSM), School Mathematics Study Group (SMSG)) and the use of mathematical manipulative materials (e.g., base ten blocks, Cuisenaire Rods[®]) to enhance concept and skill acquisition required major updating of teachers in both content and pedagogy. Not only did supervisors have to know the instructional materials well, but they also had to figure out best and most efficient ways to get teachers to utilize them effectively. Supervisors began to seek guidance from other supervisors. This led to the birth of the National Council of Supervisors of Mathematics in the late 1960s.

Over the next 50 years, numerous national standards documents (e.g., the National Council of Teachers of Mathematics [NCTM] *Agenda for Action*, 1980, *Curriculum and Evaluation for School Mathematics*, 1989, and *Principles and Standards for School Mathematics*, 2000), “education movements” (e.g., Back to Basics), and technology-delivered instruction intensified the need for school-wide mathematics leadership. The job of the leader was to establish curricular goals and select instructional materials to enhance learning of the concepts and techniques for assessing their acquisition (Klein, 2003).

Now, the *Common Core State Standards for Mathematics* (CCSSM) (National Governors Association Center for Best Practices & Council of Chief State School Officers [NGA & CCSSO], 2010), the *Partnership for Assessment of Readiness for College and Careers* (PARCC)(U.S. Department of Education [USDE], 2010), and new “smarter” technologies to enhance teaching and learning are contributing to major changes in curriculum, expectations for student achievement, and the role of mathematics teachers in the education enterprise.

Concurrent with the development of revised standards and assessments is the increasing number of new technologies that show great promise not only for changing how students explore and learn new concepts, skills, and reasoning methods, but also how their classrooms and time for learning, both in and out of school, can be structured (Johnson, Adams, & Cummins, 2012). With the relatively recent focus on Science, Technology, Engineering, and Mathematics (STEM) education and the creation of STEM schools nationwide (U.S. Congress Joint Economic Committee, 2012), there is even greater pressure on schools and teachers to figure out ways to provide programs that address the integration of curricular areas (e.g., mathematics instruction in the sciences, and vice versa), the implementation of engineering design principles, and the use of workplace technologies (Mayes & Koballa, 2012).

Depending on the school district or school, leadership may be assumed by a mathematics supervisor, curriculum coordinator, cluster leader, instructional specialist, or department chairman. Regardless of title, the major work of the leader is to increase student interest in and success with the study of mathematics (Conference Board of the

Mathematical Sciences, 2012). In this paper, from this point on, the term *supervisor* will be used to encompass all those named above.

In the discussion that follows, the responsibilities and tasks of supervisors of mathematics will be described, followed by qualifications required of those who would be expected to handle the tasks. These are informed by the projects conducted by me and my colleagues in the PRIME Center at Arizona State University, as well as by the many great thinkers who have considered and studied the work of supervisors of mathematics.

Key Responsibilities of Supervisors of Mathematics

I. Establishing a Mathematics Curriculum Framework for Instruction

First and foremost, the mathematics supervisor must ensure that the district has a comprehensive, well-articulated, and rigorous curriculum framework that embraces both the CCSSM Standards and Mathematical Practices (NGA & CCSSO, 2010), with high expectations for achievement by all. If this document does not exist, then it is the supervisor's responsibility to collaborate with administrators, other curriculum coordinators, and teachers to develop such a framework for instruction. Coordination with supervisors of other content areas is very important, since the same "big ideas" may be treated not only in several domains of mathematics (e.g., number, measurement, algebra), but also in other content areas (Mayes & Koballa, 2012). With planning, reference can be made to the various applications of the same big idea (e.g., function, proportional reasoning) and thereby strengthen student understanding.

When the curriculum framework is in place, it is the supervisor's responsibility to conduct information sessions to be sure that all teachers, administrators, and related staff (e.g., literacy coaches, science leaders, special education experts), understand the curricular goals and big ideas and the articulation of those across grade levels. The supervisor then oversees the work of a committee of teachers, staff, and administrators, to select instructional materials that advance the goals of the framework for instruction.

II. Collaborating on Curricular Integration

The idea of integrating instruction of two or more curricular areas is not new. Reading and writing across the curriculum has been widely accepted as a valuable approach for enhancing the learning and assessment of student understanding of mathematics and of other content areas (Kosanovich, Reed, & Miller, 2010). Likewise, making connections between mathematics and the sciences has been

explored in the past (e.g., NSF's USMES Project in the 1970s) and is currently highlighted in both the CCSSM (NGA & CCSSO, 2010) and *A Framework for K-12 Science Education* (National Research Council, 2012). The Mathematical Practices described in the Common Core Standards and the Scientific and Engineering Practices cited in the Science Framework are closely aligned (Mayes & Koballa, 2012). Commenting on the qualities of mathematically proficient students, the CCSSM describes them as being able "to apply the mathematics they know to solve problems arising in everyday life, society, and the workplace" (p. 7). The Science Framework cites using mathematics information, computer technology, and computational thinking as essential practices required of all students in the study of the sciences.

Support for the integration of curriculum, versus the siloization of content areas for instruction, also comes from research and studies focusing on the power of integrated projects to enhance student acquisition, recall, and application of key concepts, skills, and reasoning methods, and to motivate them to learn (Markham, Larmer, & Ravitz, 2003; Greenes et al., 2011). Vergnaud, in his *Theory of Conceptual Fields* (2009), posits that learning occurs when a "set of situations and a set of concepts are tied together (the conceptual field)" (p. 86). That is, students gain greater insight into and learn concepts if those concepts are applied to solutions of problems in multiple contexts. Likewise, contexts cannot be fully analyzed with only one concept, but rather, by the application of multiple concepts. Providing students with complex problems for which they must analyze contexts in order to determine concepts, skills, reasoning methods and types of technologies to bring to bear to address the challenges, and learn new ones at point of need, is a fruitful approach for enhancing learning. Challenges in a variety of contexts provide students with opportunities to not only strengthen their conceptual understanding, but also to gain greater insight into their own talents.

The need for more workers in STEM fields is placing pressure on schools, with leadership from the content-area supervisors, to implement integrated curricular programs that will strengthen the pipeline to careers in STEM fields. In its April 2012 report, the U.S. Congress's Joint Economic Committee stated that the "existing STEM pipeline leaves too many students without access to quality STEM education, and without the interest and ability to obtain a degree or work in STEM." (p. 3). They recommended providing more opportunities for students at all grade levels to engage in STEM-related activities both inside and outside of school.

III. Identifying Needs and Monitoring Progress

Student-focused: Assessment is critical for determining the impact of the instructional program on student learning, and for monitoring students' progress toward achieving the

curricular goals (Reeves, 2009). All learning goals must have dates for assessment that are well-known by all staff and adhered to by all educators. Because PARCC (USDE, 2010) and other national or state assessments do not provide information about students' accomplishments on a sufficiently frequent and ongoing basis that would be useful to modify instruction to address their talents and academic needs, the supervisor may have to identify existing tools or participate in the development of new ones. To assess learning progress and students' depths of understanding of fundamental concepts and reasoning methods, group observation protocols, structured or flexible one-to-one interviews, and tasks for think-aloud problem solving evaluation may be employed.

Teacher-focused: Teaching certifications or credentials vary by state and grade band (e.g., elementary, secondary), and to obtain them, teachers must demonstrate, usually through transcripts, the completion of some number of courses in mathematics and methods of teaching mathematics. Since elementary school teachers are trained as generalists, expected to be able to engage students in explorations in all subject areas, it is not surprising that only a few states require them to have mathematics training beyond high school mathematics, and the completion at college of perhaps one course in mathematics and one in mathematics methods of teaching elementary school. Some states are changing requirements for elementary school mathematics teaching certification in response to the increasing numbers of school districts who are hiring mathematics specialists to work with their young students (Fennell, 2011). At the middle or junior high school levels, teaching requirements vary by state. Some states require completion of the equivalent of a major in mathematics (like those required for high school mathematics teaching); others allow elementary-certified teachers with a special interest in the subject to provide instruction.

Thus, as well as assessing student needs, the supervisor may have to identify or create instruments to gauge teacher knowledge of mathematics and their knowledge of “the mathematics for teaching” (i.e., how key concepts grow and become more complex and how to facilitate students' understanding of those concepts). Knowing what teachers know about strategies for assessing student learning, interpreting the results, and modifying their approaches, provides supervisors with essential baseline data for a needs assessment, so they can design and conduct professional development programs that will increase teacher effectiveness.

IV. Designing and Conducting On-Going Professional Development (PD) Programs

Since the New Math era in the 1950s, teachers and other school staff have been bombarded with many new mathematical topics, instructional materials, pedagogical approaches, assessment strategies, and school reorganizations.

As a consequence, in many districts, teachers are “pushing back.” Some show lack of interest in and are unwilling to pursue new initiatives, and many are leaving the profession before completing 5 years (Bagnall, 2013). For this reason, it is important that professional development programs take into consideration the needs of both students and teachers obtained through the types of assessments described in section III, and focus on 1) a few major academic goals to be achieved, 2) instructional approaches that can enhance achievement of those goals by learners with varying interests and talents, and 3) assessments that can measure achievement of the goals at frequent intervals (e.g., twice a month). With regard to the latter, waiting until the end of a semester or marking period is too late to identify gaps and fill them (Reeves, 2009; Wei, Darling-Hammond, & Adamson, 2010).

Because of the causal relationship linking teaching and leadership practices with student achievement (Elmore, 2000), PD program participants must know the CCSSM Standards and Mathematical Practices, their content foci and coherence or articulation within and across grade/age levels, and assessment tools and the data they provide to determine causality. How these are accomplished in PD programs may take on a variety of forms, for example, webinars, institutes, academies, professional learning communities, hybrid virtual PD, and mathematics circles (Vescio, Ross, & Adams, 2006). What is key to the success of all PD programs is their intensity (2–4 hours in duration), their frequency (at least once every two weeks), and their length (sustained over several years). The PD schedules must be published and the time slot held sacrosanct, enabling explorations and discussions to take place with no distractions (e.g., general announcements, double-scheduling). Convening teachers by grade band (e.g., K–3, 4–8, 9–12), and involving all teachers in that grade band in PD have been linked to improved student learning (Reeves, 2009).

Several of those meetings must involve school principals, district administrators, and guidance counselors. Principals need training in order to know what to look for when observing and evaluating teachers. District administrators and guidance counselors need to understand the curriculum and assessment tools in order to speak knowledgeably about them to families of students, and to the community at large. Knowledge of students' academic performance is particularly important information for high school guidance counselors, who are often called upon to advise students about high school courses and post-high school options, and to prepare letters of recommendation for them for colleges or the workforce.

Recommended Topics for Exploration

The topics described below are those that we, and the supervisors in training that we have mentored, have found to be successful in terms of increasing teacher knowledge

of content, pedagogy, and assessment, and their interest in improving their pedagogical practices.

Identifying curricular goals to close learning gaps. Exploring the *Common Core State Standards in Mathematics* (NGA & CCSSO, 2010) and having teachers identify fundamental concepts and strategies for enhancing student understanding at both their grade level and the levels before and after theirs should be a major and long-term focus of professional development. Reeves (2009) wisely recommends that we ask teachers, “What advice will you give to the teacher in the next lower grade with respect to the knowledge and skills that students need in order to enter your class next year with confidence and success?” (p. 30).

Knowing what students know. A study of students’ and teachers’ current understanding of key concepts of linearity (Postelnicu, 2011; Postelnicu & Greenes, 2012) was conducted with 1561 grades 8–10 students and their 27 mathematics teachers. Students and teachers solved a set of seven problems (three multiple-choice, three short-answer, and one extended response), rank-ordered the problems by difficulty, and provided a description of the nature of the difficulty for the two most difficult problems. Teachers ranked the problems based on how they thought their students would perform. Subsequently, 20 teachers and 40 students (two per teacher) were interviewed. Analyses showed that teacher ranking was the inverse of student performance. What teachers rated as the least difficult item was the item the greatest number of students failed to solve. Teachers were stunned to find that their students, even the higher achieving students, had difficulty with certain items. As one teacher said, “We worked on that topic for 4 months. What went wrong?” Said another, “Oh my. I beat that concept to death.”

The same type of assessment format, with simpler linearity problems, was administered to students in grades 5–8 and their mathematics and science teachers as part of the STEM in the Middle Project funded by the Helios Education Foundation (2010–2013, Greenes, PI. For a description of the project see Auffret, 2013). On that assessment, once again, teacher ranking did not match student performance. Furthermore, teachers discovered that they themselves did not have deep knowledge of several of the concepts.

At both the high school and middle school levels, that type of solving and ranking assessment items followed by analyses prompted teachers to want to know more about what their students know and their depths of understanding, ways to find out, and what to do with the results. So, designing assessments with ranking components, followed by comparing teacher perceptions of difficulty to actual student performance, is a valuable activity to stimulate the need for professional development. Of course, the follow-up is to figure out ways to revise instruction to address the difficulties.

Developing modules for instruction. Based on the above, a good process for the development of instructional modules is as follows: In early needs assessments conducted with teachers, hard-to-learn or hard-to-teach (they may be one and the same) concepts, skills, and reasoning methods are identified. Having teachers at a PD meeting rank-order the difficulties for attention by the entire group should be a first step. Subsequent to that, teams of teachers can collaborate and discover existing programs of instruction and activities, or create others that target the “tough” ideas. Some existing programs may be computer-based, or use online learning or hybrid approaches. Software products may be useful in the exploration of key concepts (e.g., slopes of lines, computing with decimal numbers). Once modules are developed and implemented, student artifacts can be collected and analyzed by the group to determine if the modules and activities are enhancing achievement. Another useful approach is to film students, and bring both the films and student work to the PD for group analyses and discussion.

Developing proposals for funding needed resources. When teachers are implementing new or revised instructional programs, it is often the case that they do not have all of the necessary resources (e.g., materials, technology, experts) to conduct long-term investigations that use mathematics to model and solve problems in other content areas. To deal with this problem, one approach is to instruct teachers about how to prepare proposals to companies and other groups (e.g., DonorsChoose), that fund resources. During proposal preparation, teachers learn to clearly and precisely describe their academic goals, the procedures/activities to accomplish the goals, the resources needed, and the strategies that they will use to assess student mastery. These are the same procedures that are core to good teaching. Almost 40% of 170+ teachers in our leadership programs have garnered funding ranging from \$200 to \$40,000 (Greenes et al., 2011).

Making problems more complex and designing adventure tours. In discussions about curricula, teachers not only desire additional resources for students who are having difficulty, but they also are searching for activities for students who need greater challenge. However, as we have found, teachers don’t want those talented students “going off on different topics.” To address this issue, we had our supervisors in training experiment with strategies for making problems more demanding. First they identified strategies for altering the difficulty of a mathematical problem. These included: 1) changing the types of numbers used (e.g., rational numbers, integers), 2) omitting relevant data so that the solver has to experiment or search for the information elsewhere, 3) increasing the number of solution steps, 4) using different or more types of representations (e.g., graphs, table, symbols) and placing some of the required information in text and other information in a table, 5) changing the context to one that is not mathematics, and 6) introducing some new mathematics

that students may not have seen before and that they have to figure out or seek help to understand. Several teachers chose to involve their students in this activity and ended up with a file loaded with challenges!

Based on that experience and the eagerness of teachers to develop more explorations for their students, we taught them how to design *Mathematical Adventure Walking Tours*. We designed a mathematical problem-solving adventure in the Arizona Science Center (PRIME Center web site, 2012), took our grades 5–8 teachers on the tour, and had them verify the answers. While on the tour, they made measurements, searched for information, conducted experiments, and solved problems. Thereafter, their job was to select a location near their schools and design a 3-hour walking tour of the environment that required using mathematics to solve problems related to the location. Their chosen locations were quite varied and illustrated their out-of-school hobbies or interests, including the Riparium, Musical Instrument Museum, Home Depot, a supermarket, a baseball stadium, a waterpark, the post office, the light rail route, the fisheries, the Frank Lloyd Wright home/museum, the art museum, an arts/hobby supply store, the university, and a bagel shop. Problems in the Adventures showed applications of mathematics to physics, ecology, biology, anatomy, economics, geography, and music. Teachers are now taking their students on these Adventures as a way of demonstrating that “mathematics is everywhere and it is useful.”

V. Closing the Opportunities Learning Gap

Numerous national (e.g., NSF’s ITEST and DRK–12 programs) and state groups are conducting and evaluating before-school, after-school, Saturday morning, or summer programs designed to increase student interest and achievement in mathematics, as well as in the sciences, technology, and engineering (Peterson, 2013; Redd et al., 2012). Unlike school classes or courses, these out-of-school opportunities are frequently not grade level specific, but rather involve students from a range of grade levels (e.g., grades 1–4, 5–8, and 9–12). Meeting sessions are several hours in duration, providing sufficient time to wrestle with important ideas. The pedagogical approach reverses the learn-then-apply format to one in which problem solvers bring to bear what they already know to solve a problem or complete a project, and learn at the point of need—usually when they get stuck, know what they don’t know, and have to learn in order to proceed with their work.

One such out-of-school project, PRIME the Pipeline Project (P³): Putting Knowledge to Work (NSF #0833760, Greenes, PI), evaluated the Scientific Village Strategy to enhance student interest in STEM subjects and update science, mathematics, engineering, technology, and business education teachers in their own and sister fields. In Scientific Villages,

high school students and teachers (as learners) collaborated to work on long-term (20 or 40 hours) challenging problems/projects, designed and led by university or industry scientists, and mentored by undergraduate student STEM majors. In these villages, held at a university campus, mathematics was used to model and solve problems in other content areas, and workplace technologies were incorporated to facilitate solutions. A project-driven approach was employed in which the nature of the project determined the knowledge to be applied, or if not learned before, learned as need required. Research results showed significant differences favoring P³ students versus their matched controls on 1) number of advanced STEM courses completed in high school, 2) overall high school GPA, and 3) the number of high school graduates attending college (and in STEM majors) (Greenes, 2013). In their own classrooms, P³ teachers changed their instruction. They implemented integrated projects, provided greater time for explorations, talked less and required more participation and “struggling” from their students.

VI. Celebrating Achievements

Recognizing academic achievements is a major factor in enhancing students’ desires to continue to do well in school (Greenes et al., 2011). With the exception of report cards, there are few, if any, ways that schools showcase students’ accomplishments. One of the jobs of the mathematics supervisor is to establish regular and frequent opportunities for celebrating achievements. One such event, in both the P³ and STEM in the Middle projects, is the Showcase Open House, held near the end of each semester, that provides an opportunity for students to display their creations and projects, and “pick up the microphone” to describe their work to the community of families, friends, teachers, and other students. Not only does the Showcase provide families with greater knowledge of their children’s work, the job of preparing for the Showcase gives students opportunities to learn the time and effort it takes to improve on a project or product for presentation to the public. And it improves their presentation skills.

Also, there should be opportunities for teachers to share their accomplishments (e.g., presentations at conferences, awards, publications) with colleagues, administrators and the community. This may be accomplished through newsletters or social media. Supervisors need to set schedules for these recognition opportunities, and identify folks to lead them.

Qualifications and Characteristics of Supervisors of Mathematics

“Leadership requires knowledge about how teachers develop professionally, as well as the ability to build

momentum for school-wide changes” (Burch & Spillane, 2003). To tackle the responsibilities cited above, mathematics supervisors should be well trained in the following: 1) mathematics, and on understanding how fundamental “big” mathematical ideas in the various domains of mathematics grow and become more robust from pre-kindergarten through grade 12 and through the first year of college mathematics; 2) the application of mathematical concepts, skills, and reasoning methods to the solution of problems in a variety of contexts; 3) computer-based and online instructional resources, and ways to capitalize on technology to facilitate instruction and exploration both in and out of school; and 4) best practices in assessment, pedagogy, and professional development. Ideally, the mathematics supervisor should have some prior administrative experience. Personality-wise, a great supervisor must be enthusiastic and curious. Possessing public speaking skills to deal with administrators, teachers, parents, and the community is a must. Most importantly, the mathematics supervisor must demonstrate perseverance in dealing with the complex problem of guaranteeing that all children are learning mathematics and loving the challenge of solving hard problems.

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