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Professional Development Strategies to Support Student Success in Algebra I

Research Brief

This research brief is one of five that summarize the literature in different topic areas[1] related to helping struggling students in Grades 6–9 succeed in algebra. The research briefs are part of the *Promoting Student Success in Algebra I* (PSSA) project funded by the U.S. Department of Education's High School Graduation Initiative (HSGI). The PSSA project at American Institutes for Research is designed to provide actionable information for educational program developers/administrators in three ways. First, these research briefs together will summarize research on five strategies being implemented by HSGI grantees that help struggling students succeed in Algebra I, a critical gateway course for high school graduation and enrollment in college. Second, the project includes a forum for practitioners—district program developers/administrators and teachers—to make connections between the findings from the research briefs and their daily work, with the results of these discussions published in a series of perspective briefs. Third, the project includes profiles of practices that provide an in-depth look at the implementation of these five strategies.

This brief describes what is known about professional development as a strategy to improve the quality of algebra teaching and learning. Researchers and policymakers in the United States uniformly agree that pre-service education cannot fully prepare mathematics teachers for the complex job of teaching, and studies of teacher preparation programs have found that elementary and middle school teachers—particularly those trained as generalists—do not always enter the profession with

[1] The five topic areas are Curricular Alignment, Instructional Practices, Supplementary Learning Supports, Professional Development, and Instructional Coaching.

the mathematical content and pedagogical content knowledge needed to teach to rigorous mathematics standards (Fey et al., 2007; National Mathematics Advisory Panel [NMAP], 2008; Tatto et al., 2012).

Pre-service education cannot fully prepare mathematics teachers for the complex job of teaching, and studies of teacher preparation programs have found that elementary and middle school teachers—particularly those trained as generalists—do not always enter the profession with the mathematical content and pedagogical content knowledge needed to teach to rigorous mathematics standards.

Teachers learn a lot on the job—what they know and don't know about the content they have been prepared to teach and what types of teaching practices work and don't work for the student populations they are teaching. But what counts as professional development? The broad term encompasses a variety of activities (e.g., workshops, seminars, study groups, professional learning communities) and areas of focus (e.g., development of content knowledge, use of curricular materials and assessments, implementation of teaching strategies). For this brief, we define professional development as programs designed to improve the teaching and learning of Algebra I or algebraic thinking. The programs include individual and group learning opportunities for teachers that take place inside and outside of schools, with or without the use of technology (Croft, Coggshall, Dolan, & Powers, 2010). We do not include professional development programs with a predominant coaching component—that is, where coaching makes up more than one-third of the intervention—because a separate brief in this series summarizes this topic.

Providing teachers with quality professional development opportunities is especially critical with the implementation of more rigorous College and Career Readiness Standards in mathematics and the wide-scale adoption of the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices [NGACBP] & Council of Chief State School Officers [CCSSO], 2010), which incorporates mathematics standards from high-performing countries (Kober & Rentner, 2012). Just as students are being asked to demonstrate a deeper understanding of mathematics, teachers are being asked to create and sustain learning environments that support this level of understanding, heightening the need for professional development programs that reflect the most current research.

What types of algebra professional development programs have the strongest research base and what are the implications for program developers/administrators? To answer these questions, we conducted a literature review. The process we used is described in the Appendix. Very few of the studies described in this brief meet the highest level of rigor described by the What Works Clearinghouse (WWC).[2] Yoon, Duncan, Lee, Scarloss, and Shapley (2007) found only nine studies of teacher professional development that met WWC high-evidence standards and only two that focused

[2] The What Works Clearinghouse was created in 2002 by the Institute of Education Sciences to be a source of information regarding what works in education. See http://ies.ed.gov/ncee/wwc/DocumentSum.aspx?sid=19 for the standards used to evaluate studies.

exclusively on mathematics—none on algebra in Grades 6–9. A few rigorous, relevant studies of mathematics professional development have occurred since then, and they are included in this brief, but the overall lack of rigorous evidence should not deter program developers/administrators from making informed decisions. A good deal of promising evidence builds on recent research trends in mathematics teacher professional development and advances in technology; these studies are presented and represent the best available evidence on professional development programs targeted to supporting student success in Algebra I.

Recent Trends in Mathematics Professional Development and Technology

This review builds on a research base in mathematics professional development that has been steadily growing for more than a decade. Several studies, using primarily teacher self-report data, indicated that professional development was more likely to be effective if it was sustained and intensive, content focused, collaborative, actively engaging, connected to teachers' daily work, and coherent with other teaching and learning initiatives (Garet, Porter, Desimone, Birman, & Yoon, 2001; Birman, Desimone, Porter, & Garet, 2000; Hawley & Valli, 1999; Wilson & Berne, 1999). During the same time frame, results from the Third International Mathematics and Science Study (TIMSS) revealed not only that U.S. students lagged behind students in other developed countries in mathematics achievement, but also that their teachers lacked structural opportunities for deep, ongoing professional learning (Hiebert et al., 2003; Stigler & Hiebert, 1999; Lewis, Perry, Hurd, & O'Connell, 2006; Lewis, Perry, & Hurd, 2009).

The Japanese lesson study model of job-embedded professional development gained national attention after the TIMSS study was published, spurring new lines of research and development in mathematics teacher professional development. Rapid advances in technology (e.g., computer software programs for conveying mathematics content, advances in video and audio technology and graphing calculators) were also occurring during this period. These technological advances provided opportunities for teachers to represent mathematics concepts—and algebraic concepts particularly—in new, innovative ways; assess their students' progress on a more fine-grained level; and break down the walls of professional isolation by sharing and reviewing videos of mathematics teaching as part of professional development activities. The studies reviewed for this brief reflect these developments.

Synthesis of the Literature

The current research on algebra professional development is summarized in two areas: the content of the professional development and the mechanisms for delivering the content, including programs that use Web- and video-based technology. The brief concludes with key findings and several recommendations for program developers/administrators related to each set of findings.

Professional Development Content

Focus on Mathematical Topics Important to Future Success in Algebra I

Researchers and policymakers widely agree that for most students to succeed in formal Algebra I courses, they need to be exposed to algebraic ideas in earlier grades (e.g., making connections between properties of arithmetic and algebra) and to demonstrate mastery of prerequisite knowledge and skills (e.g., rational numbers, fractions; NMAP, 2008; Kilpatrick, Swafford, & Findell, 2001; National Council of Teachers of Mathematics [NCTM], 2000, 2006). For students to understand these concepts in earlier grades, their teachers need a solid understanding of both the content and the instructional strategies and materials to support this goal. In recognition of this need—especially for elementary teachers, who tend to be generalists rather than mathematics specialists—the Cognitively Guided Instruction (CGI) professional development program was developed and has been widely implemented in recent decades to support teachers in promoting the development of algebraic ideas in the early grades (Carpenter, Fennema, Franke, & Levi, 2011; Carpenter, Fennema, Peterson, Chiang, & Loef, 1989). The CGI program uses the thinking of students—their approaches, conceptions, and misconceptions—as a platform to help teachers understand the foundational properties of numbers and see how algebra is a generalized form of arithmetic. The program has been rigorously evaluated and shown to benefit teachers and students. In one rigorous evaluation of the program, students assigned to teachers who attended a four-week summer CGI workshop plus a one-day follow-up workshop—83 hours of workshops—did significantly better on the Iowa Tests of Basic Skills and in a CGI problem-solving interview than students in the comparison group (Carpenter et al., 2011). CGI is one of very few professional development programs that produced gains in student achievement in a rigorous experimental trial and was one of only two mathematics professional development programs that met WWC standards in the Yoon and colleagues (2007) review cited previously.

Despite the intensity and duration of the study's professional development program, it failed to produce an impact on teacher knowledge or student achievement after one and two years.

Regarding mathematics content that is important for future success in algebra, the Middle School Mathematics Professional Impact Study was a rigorous, experimental evaluation of a professional development program designed to boost Grade 7 teachers' knowledge of rational numbers content in the context of teaching (Garet et al., 2010; Garet et al., 2011). The study's two-year, 114-hour professional development program included both workshops and coaching, with a stronger emphasis on workshops (about two-thirds of the professional development comprised workshops, one-third, coaching). Despite the intensity and duration of the study's professional development program, it failed to produce an impact on teacher knowledge or student achievement after one and two years. The study did find a small difference favoring teachers who participated in the study's professional development program on the frequency of classroom use of particular questioning strategies emphasized in the program, but these strategies did not result in increased student achievement, the ultimate goal of the study. One caveat is that teacher turnover significantly reduced the actual amount of professional development that teachers received.

Saxe, Gearhart, and Nasir (2001) evaluated the impact of an instructional unit designed to improve elementary students' problem solving and reasoning in the domain of fractions, an important algebra prerequisite (NMAP, 2008). Students assigned to teachers who received professional development on the instructional unit plus pedagogical and student motivational approaches demonstrated stronger conceptual knowledge than comparison students. The pedagogical approaches focused on helping teachers assess how students reason and solve problems through the analysis of student work. The study concluded that professional development targeted to understanding how students solve problems and are motivated to learn seemed to make a difference.

Focus on Implementing Larger Algebra Initiatives

Beyond studies of mathematics topics relevant to future success in algebra, algebra-specific professional development programs have focused on supporting the implementation of larger initiatives designed to help struggling students succeed in algebra. One such program was the Talent Development (TD) Middle School Model, which included a professional development program that was linked to the implementation of a curriculum with a strong focus on conceptual understanding and problem solving (University of Chicago's *Transition Mathematics* and *Algebra* texts). Teachers had access to 36 hours per year of summer and Saturday workshops, which were typically led by peer teachers with experience implementing the University of Chicago curricula and emphasized content and pedagogical strategies associated with upcoming lessons and units.

Students in the TD schools outperformed students in non-TD comparison schools on standardized mathematics assessments across Grades 5–8 (Balfanz, Mac Iver, & Byrnes, 2006). The researchers also found that schools with higher levels of implementation performed even better. Although it is difficult to parse out the effects of professional development from the curricular materials and broader whole-school reform model, the professional development program was a key component of this successful program designed to increase the number of students succeeding in Algebra I by Grade 8.

The Chicago Algebra Initiative was a similar, broader initiative that was also implemented during this time frame. The initiative was designed to increase the number of Grade 8 students taking and succeeding in Algebra I and included university coursework, professional development workshops, and coaching for teachers. The university courses were part of a middle school mathematics endorsement program and focused on deepening teachers' knowledge of mathematics content, whereas the professional development focused more on implementing one of the three district-supported algebra curricula. Although the conclusions were not causal and caution should be used because of the small sample size, students assigned to teachers who attended 75 percent or more of the professional development workshops had an algebra end-of-course exam passing rate of 58 percent, which was more than double the passing rate of students assigned to teachers who attended fewer than 75 percent of the workshops (Deiger et al., 2009).

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Focus on Implementing Algebra Programs That Use Technology

Professional development programs have also focused on helping teachers implement technology designed to enhance their algebra instruction. The Classroom Connectivity in Promoting Mathematics and Science Achievement was one such project. It provided algebra teachers with three types of professional development activities over the course of a year—a weeklong, in-person summer workshop; online trainings and discussion forums; and a follow-up, in-person workshop. The professional development focused on helping teachers use the TI-Navigator graphing calculator

Teachers who participated in the professional development were more likely to engage in deeper conceptual discussions with their students than teachers who did not participate in the professional development.

to teach algebra more conceptually and to analyze student work that was instantly uploaded to each teacher's computer. Students in the study's treatment group were assigned to teachers who participated in the professional development and received the technology, and they scored about 10 percentage points higher on an algebra assessment than students in the comparison group. Qualitative analyses also showed that the teachers who participated in the professional development were more likely to engage in deeper conceptual discussions with their students than teachers who did not participate in the professional development (Owens et al., 2007; Owens et al., 2008; Pape et al., 2012; Pape, Irving, Owens, & Abrahamson, 2005).

The Algebra for All project focused on helping teachers use graphing calculator–based instructional materials to help students see the "big picture" of how algebra applies to the real world. The project included ongoing opportunities for algebra teachers to participate in face-to-face and online professional development activities. Unlike the Classroom Connectivity study, this evaluation did not include a comparison group, so the findings are limited. However, the evaluation showed significant pre-post gains in teachers' mathematics knowledge as measured on the Learning Mathematics for Teaching (LMT) assessment—a widely used measure of teachers' knowledge of mathematics content in the context of teaching—and students' scores on an algebra assessment. The study also reported significant gains in teachers' familiarity with and use of graphing calculators to support algebra teaching and learning and their positive impressions of online learning communities as venues to exchange lessons and ideas about teaching (Frost & Everett, 2010; Science and Mathematics Program Improvement, 2012).

Using Technology to Expand and Enhance How Professional Development Is Delivered

Recent developments in Web- and video-based technology allow teachers to learn from one another's practice without being in the same physical location; these technologies have also enhanced face-to-face professional development activities, particularly by incorporating classroom video into small-group meetings. Although studies of programs with these delivery mechanisms have not compared online versus face-to-face formats, they represent another strand of research in algebra professional development and are described next.

The Louisiana Algebra I Online Initiative was designed to provide noncertified algebra teachers with job-embedded professional development by a certified online algebra teacher, with whom they cotaught an online Algebra I course. The noncertified teacher worked in class with students while the certified online Algebra I teacher served as the teacher of record and mentored the in-class teacher. The professional development provided to the noncertified teachers included a two-day summer orientation to the project; an 8-hour online course focused on the use of technology (Blackboard online course system, TI-83 graphing calculator, digital tablet) and classroom management; and a 20-hour online or in-person course on strategies for teaching Algebra I in an online setting. The online teachers participated in a similar set of professional development activities that were tailored to experienced, certified teachers. The reports by both the online and in-person algebra teachers were positive about their professional development experiences, and the in-person teachers reported gains in their algebra content knowledge and benefits from their yearlong partnership with their online mentor (O'Dwyer, Carey, & Kleinman, 2007a). The study included a quasi-experimental evaluation of student outcomes; students taking the online Algebra I course and students taking a traditional face-to-face Algebra I course performed at similar levels (O'Dwyer, Carey, & Kleinman, 2007b).

The Video Cases in Mathematics Professional Development Program (VCMPD) combined face-to-face meetings and exercises for teachers based on classroom videos that focused on the conceptual teaching of linear functions, a foundational concept in Algebra I. A small evaluation of the VCMPD showed that teachers who participated in the program outperformed comparison teachers on mathematics and pedagogical assessment items that were aligned to the professional development. More specifically, teachers who participated in VCMPD improved their ability to compare representations of linear functions and identify potential student misunderstandings (Hill & Collopy, 2003).

Teacher collaboration becomes increasingly productive over time.

Borko and colleagues have conducted a number of studies about the Problem-Solving Cycle (PSC) of professional development, which, like VCMPD, incorporates classroom video as the basis for ongoing, job-embedded professional development for middle school mathematics teachers (Clark & Borko, 2004; Jacobs et al., 2007; Borko, Jacobs, Eiteljorg, & Pittman, 2008; Borko et al., 2005). Each PSC consists of three interconnected workshops that focus on the implementation of a mathematical task designed to promote student thinking. In the first PSC workshop, teachers collaboratively solve the task and plan the lesson before implementing the lesson with their students; this delivered lesson is videotaped. In the second workshop, teachers review and discuss the video with a focus on the role of the teacher. In the third workshop, teachers focus on student thinking related to the big mathematical ideas of the lesson. In an evaluation of a program that began with a two-week summer algebra institute followed by three complete PSC cycles over the next two years using tasks that promoted algebraic reasoning, researchers found that teachers' discussions based on the video became more focused, more in-depth, and more analytic after each PSC cycle (Borko et al., 2008). These results are similar to those that other researchers have documented about teachers' participation in lesson study, noting that teacher collaboration becomes increasingly productive over time (e.g., Lewis, Perry, & Murata, 2006).

Implications for Program Developers and Administrators

The research on algebra professional development has several findings relevant to program developers/administrators who are working to improve the quality of algebra teaching and learning. The concluding table summarizes the key findings from this brief, with potential implications listed. The quality of information available will continue to improve as this emerging body of research expands.

Table 1. Key Findings and Implications for Program Developers and Administrators

Strong algebra professional development programs ...	Program developers and administrators should consider...
Content of the Professional Development	
• Exhibit features of other high-quality professional development programs.	• Supporting professional development programs that are intensive, sustained, collaborative, and tightly linked to practice. This may require altering the supporting structures for such intensive, job-embedded professional development opportunities.
• Recognize that teachers may need support in understanding the mathematical concepts they are required to teach.	• Incorporating an explicit focus on developing teachers' mathematical content knowledge. This focus may be particularly important for teachers at the elementary and middle school levels.
• Focus on strengthening students' reasoning and conceptual understanding, including important prerequisite Algebra I topics.	• Identifying programs with strong supports for stimulating and supporting students' reasoning and understanding, including topics that are important for students to master before they enter a formal Algebra I course. Programs should also ensure that the needs of special populations (e.g., students with special needs, English language learners, etc.) are addressed.
• Can be critical to the successful implementation of broader programs or initiatives designed to improve student success in algebra.	• Supporting larger initiatives with a strong professional development component and collecting implementation data as the initiative is being rolled out.
• Are essential in supporting the implementation of technology designed to improve algebra instruction.	• Providing strong professional development support when introducing graphing calculators and/or software programs designed to improve algebra teaching and learning.
Delivery of the Professional Development	
• Include explicit connections to the classroom, including the use of video or other technologies that support reflections on teacher practice.	• Investing in professional development programs that use classroom video as part of structured, concrete learning opportunities for algebra teachers.
• Provide structured opportunities for algebra teachers to collaborate with one another and with other experts through multiple mediums (e.g., online).	• Including online and face-to-face delivery mechanisms.

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Appendix

To conduct the literature review, we followed the same process used in other briefs in this series by including descriptive, theoretical, and explanatory research on professional development that spans a wide range of methodological approaches (e.g., high-quality experiments, quasi-experimental studies, descriptive studies, case studies), sources (e.g., educational journals, research organizations, national content-specific organizations), and disciplines. In addition to conducting a rigorous search of existing literature, we contacted experts in the field who are conducting research on these educational programs to identify research findings not yet published and included them in this review. We used a four-part, hierarchical selection process as the basis for including the studies summarized in this brief: subject (algebra vs. mathematics vs. other subjects), grade level (Grades 6–9 vs. Grades 1–5), year of publication (since 2005 vs. before 2005), and level of evidence (strong vs. moderate vs. low, based on standards informed by the What Works Clearinghouse; see http://ies.ed.gov/ncee/wwc/). We prioritized studies that focused on algebra or mathematics in Grades 6–9, that were published since 2005, and that had strong or moderate evidence. A fully exhaustive review of the literature is beyond the scope of this brief. Instead, we focus on research studies that are most relevant for professional development as strategies for promoting student success in Algebra I.

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