Applicable Outcomes: An Evaluation of the Investigations Elementary Math Program

Sean Hamer

National achievement data in the United States shows that elementary level students have weak math skills. The 2009 National Assessment of Educational Progress (NAEP) contends that only 39% of all fourth graders demonstrated proficiency in math, and 18% rated below basic (National Center for Education Statistics, 2009). The most instructive elementary math programs develop student knowledge through experiential, hands-on instruction that supports the development of number sense, is grounded in meaningful experiences, and solves real-world and decontextualized mathematics problems. Traditional mathematics curriculum has historically focused on the acquisition of numerical skills such as number order, counting on, addition and subtraction facts, place value, and addition and subtraction algorithms while the constructivist mathematics curriculum, which is grounded in Piaget's theory of child development, is focused on sense-making about number as a primary concern (Goodrow, 1998).

Evidence of the Problem

Math education is essential and most jobs require at least some proficiency in the subject (Nahornick, 2016). A background in math is needed to pursue technological development, to understand political and cultural issues, and simply in everyday life, so it seems evident that mathematical proficiency matters (Nahornick, 2016). Contemporary research revealed that about 20% of students in community colleges' basic math and pre-algebra programs lacked a sense of part-whole relationships with whole numbers (Steinke, 2015). Further, these concepts are needed to understand fraction and percent relationships, carries over to the relationship between details and the main idea in factual prose, in critical thinking in job situations, and on the current high school equivalency tests. The ability to compute, problem solve, and apply concepts and skills in mathematics influences multiple decisions in our lives (Little, 2009). However, mathematics is often challenging for students with, and without, disabilities to master.

Comparison studies have focused on student results that show US students not performing as well in math as students in many other developed countries (USDOE, 2000).

In 1983, the National Commission on Excellence in Education spent 18 months developing a research report, which concluded that schools in the United States were failing (No Child Left Behind [NCLB], 2002). They found that only a third of the country's population had the ability to solve multi-step math problems. These findings ignited the government and other educational organizations to address these issues and improve the country's educational system. In 2001, with the passage of NCLB, the federal government required educators to use research-based programs to ensure students achieved 100% proficiency in reading and mathematics by 2014 (NCLB, 2002). Numerous factors, including research that has documented the importance of early educational experiences on brain development, have given educators and policymakers greater insights to improve young children's learning (Daily, Burkholder, & Halle, 2011). Daily, et al. summarized the state and national initiatives that focused on math and literacy readiness in early childhood and kindergarten programs:

> Readiness programs were supported in 2002 by launching the Bush administration's Good Start, Grow Smart, which urged states to develop voluntary early literacy and early math guidelines for children between the ages of three and five and align them with their K–12 standards. The Obama administration has maintained a focus on early childhood by including $5 billion of new funding for Child Care, Head Start, Early Head Start, and programs for young children with special needs in the American Recovery and Reinvestment Act.

What is taught to students, and how it is taught, are important factors in a school's capability to make gains in student achievement, however, the widespread use of varying approaches to math curriculum and instruction limits the generation of consistent evidence for system wide improvements (Agodini & Harris, 2010).

Evaluation of Elementary Math Programs

The understanding that elementary school students in the United States demonstrate poor math skills on national achievement assessments, specifically those from low socioeconomic backgrounds, and that accumulating evidence indicates an early and lasting difficulty with mathematics is being experienced by many school children, numerous studies of math curricular programs have emerged in recent years (Agodini & Harris, 2010; Doabler, Fien, Nelson-Walker & Baker, 2012). A study by Slavin, Lake, and Groff (2010) assessed 13 studies of elementary mathematics curricula, 40 middle and high school curricula, and found no evidence that different curricula produce different outcomes in terms of achievement. However, they did find strong evidence that using effective teaching strategies can make a real difference. The Doabler et al. (2012) study of three elementary math curricula found that most textbooks were missing opportunities for explicit, systematic instruction, and none offered procedures for linking assessment results with instructional decision-making. The Bhatt and Koedel (2012) study of three elementary math curricula found that major differences could exist between curricula that share the same pedagogical approach. Studies also indicate that teachers' self-efficacy is a key variable in student learning, changes the way that children work together, improves classroom management and motivation, and raises mathematics outcomes for all students (Stronge, 2010). The impact of extensive professional development to help teachers use instructional strategies was found to have the strongest evidence of effectiveness (Slavin et al., 2010).

A feasible strategy to address the low math achievement of U.S. children is to improve the quality of foundational math instruction delivered in elementary classrooms (Doabler et al., 2012). At the core of most math programs are textbooks, which influence the ease of curriculum management in the classroom and assist teachers with guided opportunities to introduce students to critical math content. Often, math programs are offered in full service packages including textbooks, curricular pacing guides, manipulative tools, assessments, and training sessions for teachers. Documenting individual student achievement is a difficult task. Due to the concern that low elementary school performance would limit students' future mathematical capabilities, and their ability to function in an increasingly complex world, legislators constructed mandates for improved performance and accountability in schools (Ding & Navarro, 2004). Therefore it's important to discern whether programs provide teachers with the foundational resources for teaching key math concepts and skills to an inclusive spectrum of exceptional, proficient and struggling students (Doabler et al., 2012).

Program History and Description

The conceptual goals of math education are multifaceted and include viewing mathematics as a language of reasoning. As a particular kind of logical structure, students use math to reason analytically about quantitative and spatial phenomena, make sense of things, and form judgments, inferences, and conclusions (Battista, 1999). When engaged in mathematics, students learn to recognize and describe patterns by manipulating and reflecting on ideas to solve problems. The societal benefits of math education stem from the capabilities of individuals to become articulate in employing the "abstract concepts and mathematical perspectives that our culture has found most useful" in addition to the contributions that "future mathematicians, engineers, and scientists make to the scientific/technical infrastructure of the country" (Battista, 1999, p. 425). These long-term outcomes are initiated in primary/elementary school classroom experiences.

Investigations in Number, Data, and Space (Investigations), a kindergarten to fifth-grade curriculum, was developed by Technical Education research Centers (TERC) under a grant from the National Science Foundation (Agodini & Harris, 2010). The program is based on a constructivist, student-centered approach that emphasizes the use of numerous problem-solving techniques, communicating about mathematics verbally and through writing and drawing, as well as metacognition or thinking about one's own reasoning (U.S. Department of Education, 2013). The goals of the Investigations K-5 curricular program mirror much of the conceptual goals of math education by: supporting students to make sense of mathematics and learn that they can be mathematical thinkers, focusing on computational fluency with whole numbers as a major goal of the elementary grades, emphasizing reasoning about mathematical ideas, communicating mathematics content and pedagogy to teachers, and engaging the range of learners in understanding mathematics (Goals and Guiding Principles, n.d.). In addition to the goals of the curriculum, the three guiding principles that are touchstones for the Investigations K-5 program are that: students possess mathematical ideas; teachers remain engaged in professional development about mathematics content, pedagogy, and student learning; and teachers integrate the students and content materials to create the curriculum as enacted in the classroom (Goals and Guiding Principles, n.d.). Willingham (2009) supported the perspective that students need to develop balanced mathematical understandings as he shared his view that "procedural or factual knowledge without conceptual knowledge is shallow and is unlikely to transfer to new contexts, but conceptual knowledge without procedural or factual knowledge is ineffectual" (p. 14). The Investigations program instructs teachers to guide students to work on a smaller volume of in-depth problems and to select from a variety of materials, both concrete and technological, to find solutions as a regular daily practice. The increased conceptual knowledge assists students to move from bare competence with facts and procedures to the automaticity needed to be a good problem solver (Willingham, 2009). Teachers act as facilitators of student dialogue, assisting them to gain deeper understandings of mathematical concepts, and to express their thoughts (U.S. Department of Education, 2013). Because the developers of the curriculum shared the belief that teachers are critical to the learning process, they designed the program to foster teacher learning (Remillard & Bryans, 2004). Examples of student work, research summaries and assessment samples were included in the program materials.

Each grade level is organized into units that may focus on a single subject, or may revolve around related subjects. For example, addition and subtraction or geometry and fractions could be part of a unit, which usually lasts within a timeframe of two to eight weeks. Each unit is designed around two or more investigations that provide multiple contexts in which students explore mathematical challenges. Some investigations last only two or three days, while others may stretch for multiple weeks. Classroom activities can vary from day to day and are dependent on the type of investigation being studied. For example, an investigation lasting one week may consist of an introduction to the investigation by the teacher through a large group hands-on activity, followed by two or three days where students work in pairs or small groups to explore the concept in depth. The final class meeting during an investigation consists of the students and teacher discussing as a group what they learned during the investigation and the various methods they use to solve problems.

Efficacy of Investigations K-5 Curriculum

The Investigations K-5 Math program is based on constructivist theory, unlike most traditional mathematics instruction and curricula that focus on the transmission, or absorption, view of teaching and learning (Clements & Battista, 1990). In traditional instruction, students passively "absorb" mathematical structures invented by others and scribed in texts by authoritative adults, which depicts teaching as the transmitting of established facts, skills, strategies and concepts to students (Clements & Battista). The constructivist approach to mathematics instruction defines learning as an active process. Cobb (1988) suggested that "constructivism challenges the assumption that meanings reside in words, actions, and objects independently of an interpreter" (p.88). Teachers and students are viewed as active partners who construct understandings and continually give contextually based meanings to each other's words and actions as they interface. Grady, Watkins and Montalvo (2012) cite the following definition of constructivism from Glaserfeld (1989):

> Constructivism is a theory of knowledge with roots in philosophy, psychology, and cybernetics. It asserts two main principles whose application has far-reaching consequences for the study of cognitive development and learning as well as for the practice of teaching, psychotherapy, and interpersonal management in general. The two principles are: (a) knowledge is not passively received but actively built up by the cognizing subject; and (b) the function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality. (p. 162)

A challenge in many constructivist settings, where the teacher is a "facilitator", in contrast to most guided instruction settings, where the teacher is an "activator", is the assumption that "knowledge is best acquired through experience based on the procedures of the discipline" (Hattie, 2009, p. 243). Some constructivists reject strategies, including memorizations, and fail to understand that it's advantageous to have automatic retrieval of knowledge (Quirk, 2013). This outlook can become an impediment to student progress if the teacher focuses on the process of mathematics to the exclusion of teaching the skills of mathematics (Hattie, 2009). Teachers should understand that constructivism is a way of knowing, not a teaching method. The instructional method of constructing conceptual knowledge, however, involves a consideration of the learner's viewpoint and an understanding that what they learn is socially constructed (Hattie, 2009). Goodrow's (1998) study of constructivist versus traditional math methodologies examined (a) the development of number sense and number representation by children in traditional, transitional, and constructivist second grade mathematics classrooms and (b) how different teaching approaches influence the way children deal with computation exercises. The study found that children in constructivist classrooms, who had not learned rote, algorithmic procedures for addition and subtraction but, instead, relied on their own number sense, produced a larger percentage of correct responses through the use of diverse strategies and demonstrated a broader understanding of number relations and of the properties of the decimal system. In contrast, when students rely on procedural knowledge of the standard algorithm, their errors suggest an overgeneralization of rules (Resnick & Omanson, 1987). Conclusions from the Goodrow study support the view that children are more successful at computation when they rely on their own thinking about number sense rather than on taught procedures.

Teacher Orientation Toward Math Curriculum

Teacher behavior is influenced by the teacher's content knowledge, how learners understand that specific content, the teacher's method of instruction, and the teachers' attitudes and beliefs about teaching and mathematics (Van, 2007). Also informed by what Doyle (1993) has named teachers' curriculum processes, is the method by which teachers construct or enact curriculum (cited by Remillard & Bryans, 2004). Studies of teachers' curricular methods include scrutiny of how teachers utilize resources like curriculum guides, and how there is an assumption that teachers inherently understand the intent and meaning of the resources. Remillard and Bryan (2004) view the enacted curriculum as a co-construction between teachers and students as they participate in the daily instructional routines. Their findings revealed that the most significant learning occurred during the process of enacted learning, due to the cognitive stretch that occurs for teachers and student together during those moments. It is in these circumstances, when teachers "examine unfamiliar mathematical tasks and interpret student work on them while teaching" (p. 355), that teachers' ideas about pedagogy are challenged and changed. Researchers have found that a teacher's level of content knowledge and pedagogical beliefs determine how they structure their lessons. As teachers' process similar information from textbooks, and activities differently, there is an assumption that teachers use suggestions in the curriculum differently as well, a situation referred to as "opportunities for learning" by Remillard and Bryans (2004, p. 355).

A negative impact on student achievement develops when there is a lack of instructional level alignment (LeMire, Melby, Haskins & Williams, 2012). In cases where teachers fail to accommodate academically diverse students, the students experience inequitable learning opportunities. Instructional level alignment, where instruction is given at a level that is beneficial to the student, is reliant on specific aspects of the cognitive domain (LeMire et al., 2012). While effective instruction leads to growth in students knowledge, comprehension, and critical thinking, poor instruction may lead to a sense that the student is not valued and that success is not possible in the educational setting. Hackenberg (2012) shares (as cited in LeMire et al., 2012), a student's inability "to reach a valuing state" can result in substantial negative consequences where a student may "affectively shut down" (p. 64). The affective domain has received less attention than the cognitive domain, primarily due to the widespread application of the levels of Bloom's cognitive domain of educational taxonomy (LeMire et al., 2012). However a student's affective response to instruction can play a major role if their interest level is high enough. Subban (2006) found that students continue to see cognitive stimulation if they enjoyed a task at early age, which also helps marginalized students to engage in the classroom. Engaging students actively in the content, and the learning process helps all students to see patterns developing, and to see learning as a positive experience. As noted by Kennedy and Smolinsky (2016), the experiences of African American boys who were successful in mathematics reflected several key factors: recognition of abilities, support systems and a positive mathematical and academic identity.

Achievement Effects

The U.S. Department of Education study (Agodini, Harris, Thomas, Murphy & Gallagher, 2010) presented the findings of a large scale comparison study of four elementary school math curricula in prominent use in classrooms: (1) Investigations in Number, Data, and Space(Investigations); (2) Saxon Math; (3) Math Expressions; and (4) Scott Foresman-Addison Wesley Mathematics (SFAW). The study used randomized controlled trial techniques to compare the effect of each program on math achievement of early elementary school students. The study found student-centered instruction and peer collaboration were significantly higher in Investigations classrooms than in classrooms using the other three curricula (Agodini et al., 2010). Student-centered instruction substitutes active learning for lectures, holding student responsible for their own learning through cooperative learning and assigning open-ended problems that require critical or creative thinking (Felder & Brent, 1996). The Agodini et al. (2010) study also found "that compared to teachers using the other curricula, Investigations teachers should pose more open-ended questions to students, repeat student answers in a neutral way, and probe students for reasoning or justification for their answers" (p. 97). As a teacher-as-facilitator program, the Investigations K-5 curriculum requires teachers to lead the students toward collaborative dialogue. This goal necessitates that teachers will develop effective lines of questioning to drive students' understandings and ownership of content. Both of these findings can be attributed to the constructivist methodology of the Investigations curriculum, which requires teachers to guide, not direct students through the inquiry process. According to the efficacy study of the Investigations program by Gatti (2010), the program assisted students in achieving positive educational attitudes and achievement outcomes. The Investigations student groups showed "dramatic and educationally significant increases at both the early and late elementary grades" (Gatti,2010, p.23), with late elementary Investigations students completing 5th grade testing five months ahead of their counterparts in the comparison group.

Conclusions

The challenge of achieving math proficiency in elementary classrooms persists despite technological developments, curricular innovations, and increased accountability of school systems. Teacher self-efficacy and improved quality of foundational math instruction is the most plausible method to address low math achievement (Stronge, 2010; Doabler et al., 2012). A teacher facilitated, student-centered, constructivist approach to instruction increases students' depth of understanding and their ability to express mathematical concepts (US Department of Education, 2013). This instructional approach increases students' breadth of understanding of number relationships and their intuitive abilities to create diverse problem solving strategies. Teachers with greater content knowledge, and self-efficacy, demonstrate greater competence at supporting constructivist instructional methods. This level of competent instruction supports students' affective domain, which engages marginalized, mainstream, and advanced students alike and helps them to view learning as a positive experience (Subban, 2006). Large-scale studies of major elementary curricula supported the positive impact on student achievement of student-centered and collaborative programs, such as Investigations (Gatti, 2010). Efficacy studies of Investigations also supported the achievement outcomes and positive educational attitudes of students who used the program. Insights from studies in the literature support the premise that experiential, hands-on instruction that develops number sense is the most instructive methodology for elementary math programs. Curriculum and instruction practices that are grounded in meaningful experiences, and provide solutions to real world applications are the most beneficial math programs for elementary students.

References

Agodini, R., Harris, B., Thomas, M., Murphy, R., &Gallagher, L. (2010). Achievement Effects of Four Early Elementary School Math Curricula: Findings for First and Second Graders (NCEE 2011-4001). Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education.

Agodini, R., & Harris, B. (2010). An experimental evaluation of four elementary school math curricula. *Journal of Research on Educational Effectiveness, 3*(3), 199-253. doi:10.1080/19345741003770693

Battista, M. T. (1999). The mathematical miseducation of America's youth. (cover story). *Phi Delta Kappan, 80*(6), 424.

Clements, D. H. & Battista, M. T. (1990). Constructivist learning and teaching. *Arithmetic Teacher*, 38(1), 34-35.

Daily, S., Burkhauser, M., & Halle, T. (2011). School readiness practices in the United States. *National Civic Review, 100*(4), 21-24. doi:10.1002/ncr.20080

Ding, C., & Navarro, V. (2004). An examination of student mathematics learning in elementary and middle schools: A longitudinal look from the us. *Studies in Educational Evaluation, 30*(3), 237-253. doi:10.1016/j.stueduc.2004.09.004

Doabler, C. T., Fien, H., Nelson-Walker, N., & Baker, S. K. (2012). Evaluating three elementary mathematics programs for presence of eight research-based instructional design principles. *Learning Disability Quarterly, 35*(4), 200-211. doi:10.1177/0731948712438557

Felder, R. M., & Brent, R. (1996). Navigating the bumpy road to student-centered instruction. *College Teaching, 44*(2), 43.

Gatti, G. (2010). Pearson investigations in number, data, and space efficacy study. Gatti Evaluation Inc.

Goals and Guiding Principles. (n.d.). Retrieved July 25, 2016, from https://investigations.terc.edu/developing/goals-principles/

Goodrow, A. M. (1998). *Children's construction of number sense in traditional, constructivist, and mixed classrooms*. Tufts University.

Grady, M., Watkins, S., & Montalvo, G. (2012). The effect of constructivist mathematics on achievement in rural schools. *Rural Educator, 33*(3), 38-47.

Hattie, J.A. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. New York, NY: Routledge.

Kennedy, E., & Smolinsky, L. (2016). Math circles: A tool for promoting engagement among middle school minority males. *Eurasia Journal of Mathematics, Science & Technology Education, 12*(4), 717-732. doi:10.12973/eurasia.2016.1223a

LeMire, S. D., Melby, M. L., Haskins, A. M., & Williams, T. (2012). The devalued student: Misalignment of current mathematics knowledge and level of instruction. *Mathematics Educator, 22*(1), 63-83.

Little, M. E. (2009). Teaching mathematics: Issues and solutions. *Teaching Exceptional Children Plus, 6*(1), 1-15.

Nahornick, A. (2016). Math matters: Comparison of the mathematics requirements for Bachelor of Arts and Bachelor of Science degrees in Canada. *Canadian Journal of Higher Education, 46*(1), 109-120.

Quirk, B. (2013). The "parrot math" attack on memorization. *Nonpartisan Education Review, 9*(1), 1-2.

Remillard, J. T., & Bryans, M. B. (2004). Teachers' orientations toward mathematics curriculum materials: Implications for teacher learning. *Journal for Research in Mathematics Education, 35*(5), 352-388.

Resnick, L. B., & Omanson, S. F. (1987). Learning to understand arithmetic. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 3, pp. 41-95).Hillsdale, NJ: Erlbaum.

Steinke, D. A. (2015). Evaluating number sense in workforce students. *MPAEA Journal of Adult Education, 44*(1), 1-8.

Subban, P. (2006). Differentiated instruction: A research basis. *International Education Journal, 7*, 935–947.

U.S. Department of Education, National Center for Education Statistics, *The Condition of Education 2000*, NCES 2000–062, Washington, DC: U.S. Government Printing Office, 2000.

Van, D. S. (2007). Research framework on mathematics teacher behavior: Koehler and Grouws' framework revisited. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(4), 343-350.

Willingham, D. T. (2009). Is it true that some people just can't do math? *American Educator, 33*(4), 14-39.