From the Guest Editors

Introducing the Science of Math

Robin S. Codding, Corey Peltier, and Jared Campbell

U.S. students display chronic underachievement in math. Internationally, U.S. math performance on the Programme for International Student Assessment persistently falls below the average of other OECD countries. Furthermore, the United States has one of the largest achievement gaps when comparing the average performance of the highest (90th percentile) and lowest (10th percentile) performing fourth- and eighth-grade students in the world (Pal et al., 2019; *TIMSS 2019 U.S. Highlights*, 2019). U.S. math performance over the last 20 years on the National Assessment of Educational Progress (NAEP) has also been stagnant (National Center for Education Statistics [NCES], 2019). The most recent data, collected in 2019, identified 59% of fourth graders performed below the NAEP proficiency cut score. Because of the hierarchical nature of math, we see higher prevalence of underachievement among eighth (66% below) and 12th graders (75% below). Resulting from systemic inequities in education broadly and math practices specifically, underachievement in math is not distributed equally across demographic variables related to race and ethnicity, English language proficiency, socioeconomic background, and disability status. Such persistent inequities and poor outcomes behoove educators, school administrators, and school support professionals to assess their math instructional practices and programs in concert with the science of teaching and learning math.

In 2010, Congress created and charged the Equity and Excellence Commission with identifying ways in which federal policies may be used to close the existing achievement gaps. A primary recommendation put forth by this commission was to ensure all students have access to high-quality curricula and instructional practices (The Equity and Excellence Commission, 2013). The Every Student Succeeds Act of 2015 (ESSA) further emphasized the importance of achievement and equity for all students and provided a tiered definition of evidence standards for school considerations. As a general premise, the goal of evidence-based practice as applied to math is to ensure children and youth receive equitable access to the best available education based on scientific knowledge integrated with clinical expertise pertaining to the local school context (Kratochwill et al., 2012). In addition to the evidence base on math instructional practices and programs, the science of learning needs to be considered. The science of learning is a critical component of math education reform because understanding how children learn enhances planned instructional opportunities by informing the most appropriate math instructional practices to use at a given time and context, according to students' current math knowledge and skills (Deans for Impact, 2015; National Mathematics Advisory Panel [NMAP], 2008).

What Is the Science of Math?

The Science of Math is a movement focused on using objective evidence about how students learn math to make educational decisions and to inform policy and practice. This movement, created to mirror the Science of Reading movement, leverages the science of learning and the research base on effective mathematics instruction with the intent to increase outcomes for all students. The original contributors to the Science of Math movement include a group of interdisciplinary researchers, educational consultants, and university trainers. This group of professionals came together to form this movement according to concerns regarding the limited use and implementation of scientifically driven

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evidence-based math practices and the prevalence of pseudoscientific practices in the classroom.

Why Do We Need the Science of Math?

Math reform efforts over the last 30 years addressed concerns regarding the lack of depth and expansive breadth of U.S. math curricula and instruction with efforts to generate more demanding, focused, and coherent standards that can be applied universally across the country (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010; Schmidt & Houang, 2012; Wu, 2011). The National Research Council (NRC; 2001) and the NMAP (2008) engaged in concerted efforts to make national improvements to math achievement by providing recommendations pertaining to curricular content, instructional practices, assessment and data-based decision-making, infusion of learning principles, professional development, and policy changes. These efforts emphasized prevention and early intervention in prekindergarten through eighth grade to secure readiness for algebra, given the critical importance of algebra for advanced math content in high school.

Despite reform efforts, current trends in existing data suggest problems pertaining to curricular focus, mastery of foundational math skills, and equitable access to and use of evidence-based instruction and intervention programs and practices (de Brey et al., 2019; NCES, 2019; Office of Civil Rights, 2021). Unfortunately, regardless of these recommendations, survey data indicate teachers use unsubstantiated math practices as much as or more than evidence-based practices (Hott et al., 2019; Peltier et al., 2021). Furthermore, teachers continue to report regular use of disproven practices, such as learning styles, and less than 50% of teacher-candidates correctly answered survey questions about the basic principles of learning (Deans for Impact, n.d.; Hott et al., 2019; Peltier et al., 2021; van Dijk & Lane, 2020).

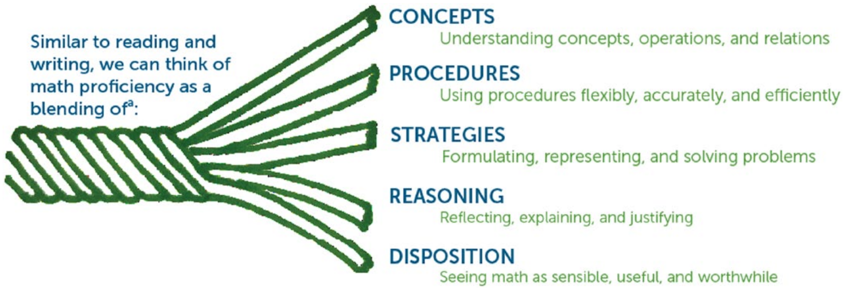
Translating research to practice is impacted by the lack of access to and/or use of evidence-based practices and programs that, along with inaccurate and infrequent implementation, can lead to experiences that foster incorrect beliefs (Fixsen et al., 2009; Odom et al., 2020). Pseudoscientific practices refer to those that lack adequate empirical support with carefully controlled studies to support their claims of positive outcomes (Lilienfeld et al., 2012). These practices can be appealing because they superficially appear to be based in science and often are intuitively meaningful, but the assertions made about the benefits of these practices extend far beyond the evidence for their use. Because of these commonsense features and enthusiastic claims about their benefit, pseudoscientific practices can be hard to identify and persuasive. The failure to implement scientific evidence-based math practices in favor of pseudoscientific practices may result from a confluence of factors, including how math proficiency is defined; limited availability of protocols, materials, and programs; and/or lack of access to information on scientifically proven practices.

The National Research Council (NRC, 2001, p. 408) defined mathematical proficiency as represented by those students who "understand basic concepts, are fluent in performing basic operations, exercise a repertoire of strategic knowledge, reason clearly and flexibly, and maintain a positive outlook toward math" (p. 408). These *five strands of math proficiency* were illustrated in the NRC (2001) document as an intertwined rope (***Figure 1***). The mutual dependence among these strands was also emphasized by the NMAP (2008) when reporting on the available research. This definition contrasts with some circulating theoretical notions that conceptual knowledge should proceed or replace procedural knowledge and is out of sync with more recent evidence supporting a bidirectional relationship between the development of conceptual and procedural knowledge (Baroody, 2003; Canobi, 2009; Hectht & Vagi, 2010; Rittle-Johnson et al., 2001, 2015;Rittle-Johnson & Koedinger, 2009). Furthermore, Kilpatrick et al. suggested mathematical proficiency may only be achieved if changes are made simultaneously to curricula, instructional materials, classroom practices, teacher preparation, and professional development. Perhaps such changes have not been made concurrently, thus impacting implementation of scientifically grounded practices and programs to support math education improvement efforts.

Other experts have suggested interpretation of math education improvement efforts differ among general and special educators and that many of the well-established evidence-based practices, such as fluency building, teaching to mastery, and using the standard algorithm, were left behind (Sayeski & Paulsen, 2010). These challenges might result because there are limited evidence-based examples or programmatic options available that are also relevant to address day-to-day problems experienced by educators attempting to mitigate large and persistent gaps in math achievement. For example, evaluation of math textbooks commonly used in the primary grades indicates that many evidence-based practices, such as systematic and explicit instruction, opportunities for practice and review, procedures for providing immediate and effective academic feedback to correct student errors and misconceptions, and linkages between assessment and instructional decision-making, are consistently missing, inadequate, or limited in scope (Bryant et al., 2008; Carnine et al., 1997; Doabler et al., 2012; Jitendra et al., 2005; Sood & Jitendra, 2007). Although evidence for math teaching and learning continues to expand, this science is developing, and it is well noted there is less available research on math-related interventions and instructional practices than in reading (Frye et al., 2013; Fuchs et al., 2021; Gersten et al., 2009; Mastropieri et al., 2009; Siegler et al., 2010; Star et al., 2015; Villarreal et al., 2017; Woodward et al., 2012).

The research-to-practice gap may also result from a lack of access to information about evidence-based practices. The wealth of information available through textbooks, organizations, clearinghouses, websites, blogs, expert consensus documents, peer-referred scientific journals, and social media can make it challenging to distinguish between scientific and pseudoscientific practices, particularly when conflicting information is presented. General and special education teachers report talking with colleagues and using Facebook, Pinterest, Teachers-Pay-Teachers, or general

Figure 1 **Five strands of math proficiency**



web-based search engines (e.g., Google or Yahoo) for math instructional planning and to identify instructional materials and practices rather than clearinghouses devoted to disseminating evidence-based practices, websites of professional organizations, or practitioner-based and scientific journals (Hott et al., 2019; Peltier et al., 2020).

Finally, failure to implement known evidence-based math practices may result from common teacher-reported barriers to implementation of evidence-based programs and practices, such as (a) time for implementation and planning, (b) access to materials, (c) adequate staffing, (d) support from school leadership, and (e) intervention compatibility (Long et al., 2016). Intervention compatibility can be defined as the appropriateness, fit, or match of an evidence-based program or practice to a school's mission, culture, and history of existing practices. Another implementation issue may be related to errors of how or when to implement effective math practices. Learners may benefit more or less from various instructional strategies or tactics, depending on the learners' stage of skill development (Burns et al., 2010). That is, are learners working on acquiring a math skill or concept, building skill fluency, generalizing or transferring a skill or concept, or using known skills and concepts to solve novel problems? Just because timed practice opportunities have been proven effective to build fluency, for example, does not mean that timed trials always benefit learners (Fuchs et al., 2021). Using timed trials with students who are working to acquire new knowledge or skills is an instructional mismatch; rather, students need to display accuracy with skills and concepts before building fluency. It is not the fault of the strategy; it is an issue with when to implement the strategy.

What Can I Do to Promote the Science of Math?

The following is a list of seven action steps educators can take to meet the challenge of supporting the math proficiency of all students in alignment with the scientific evidence.

1. Collaborate with school leaders and support professionals to conduct an inventory of existing programs, their alignment with evidence-based practices, and fidelity of their use. School-based teams can critically analyze the scientific literature as well as registries of effective programs (e.g., What Works Clearinghouse and National Center on Intensive Intervention) for validity, accuracy, usefulness, efficiency, cost-effectiveness, and compatibility with the local school context (see ***Table 1***). New programs that meet evidence standards and are deemed usable and feasible can be considered for purchase based on a transparent fiscal plan (Kratochwill et al., 2012). As new evidence becomes available, integrate this information into a cumulative and coordinated repository from which better educational decisions can be made about math teaching and learning.
2. Routinely and systematically evaluate the effectiveness of the instructional practices used in your school context. Determining which instructional tactics and activities to use must be situated within knowing students' current skills and knowledge of the content being taught. Thus, as the field identifies instructional practices with compelling evidence of improving student math achievement, this must be situated in the question for whom this practice is going to be the most beneficial and when the practice is most appropriately applied. Answers to *for whom* and *when* require consideration of the currently available best math instructional practices integrated with the science of how children learn math.
3. Supplement existing curricula and programs with evidence-based strategies, tactics, and practices. Identifying effective curricula and programs is important, but it is only one aspect of ensuring evidence-based practices. There is no such thing as a "one size fits all" evidence-based practice; no single curriculum or program will meet the needs of all students, and not all programs incorporate recommended evidence-based practices. Supplement when gaps are identified to strengthen your practices.
4. Be an astute consumer of evidence. Become familiar with sources that disseminate evidence-based practices and learn to differentiate scientific from psuedoscientific claims. Pseudoscientific practices can be spotted by (a) lack of or limited peer-referred literature on the practice (instead most of the "supporting evidence" is anecdotal or testimonial) and (b) the overemphasis on positive results while negative or disconfirming information is explained away or minimized instead of contextualized or used to improve the practice (Lilienfeld et al., 2012).

Table 1 **Resources to Locate Evidence on Mathematics Programs, Strategies, and Tactics**

Resource	*Associated Internet addresses*	*Math-related content*
Center on Multitiered Systems of Support	https://mtss4success.org/	General MTSS guidelines & implementation ideas Examples of implemented MTSS models with math
Institute for Education Sciences Practice Guides	https://ies.ed.gov/ncee/wwc/Publication#/FWWFilterId:1,ContentTypeId:3,SortBy:RevisedDate,SetNumber:1	Practice guides summarizing evidence-based math practices for algebra, young children, elementary students, problem solving, fractions, girls, MTSS K–8
IRISCENTER	https://iris.peabody.vanderbilt.edu/module/rti-math/	MTSS/RTI mathematics (professional development certificate, modules, videos)
National Center for Intensive Intervention	https://intensiveintervention.org/ https://www.youtube.com/channel/UC6W2pma8TiSZvY_GWROkTLA	Math screening and progress-monitoring tool charts, math intervention tool charts, sample math lessons and activities
Project STAIR	https://blog.smu.edu/projectstair/	Instructional resources and videos for various math topics, culturally responsive teaching, and data-based individualization
The Science of Math	https://www.thescienceofmath.com/ https://www.youtube.com/channel/UCMRsvxb-374V-LKNcsW56tQ	Resources on effective, high-quality math instruction

Note. MTSS = multitiered systems of support; RTI = response to intervention.

5. Highlight the connection between your school context and the evidence-based practice. To address concerns about program compatibility with existing classroom or school routines, consider the feasibility and usability of evidence-based practices and programs and select those with the best matches.
6. Make data-based decisions. The expansion of curriculum-based measurement and computer-adaptive assessment tools in math can be used to make a variety of educational decisions, including screening, instructional planning, progress monitoring, and program evaluation. Use of these tools to make such data-based decisions offer the opportunity for school systems to use data more effectively and thoughtfully (Fuchs, 2017; Kratochwill et al., 2012). Notably, allocating less time to screening and more time toward instructional planning, progress monitoring, and program evaluation to distinguish effective from ineffective practices in the local context will facilitate the Science of Math in daily educational practice (Fuchs, 2017; VanDerHeyden & Burns, 2018).
7. Conduct ongoing training and coaching. Work with your school administrators and support professionals to provide ongoing training and coaching to support the accurate use of evidence-based instructional practices. School systems, presented with many topics for professional development, will need to narrow the available opportunities to those most effective for students and after consideration of the most recent available math research recommendations.

Where Do I Find Out More About the *Science of Math*?

More information can be located on the Science of Math website (https://www.thescienceofmath.com/) and via facebook (https://www.facebook.com/groups/484983039154372/), twitter (twitter handle: @4ScienceofMath), and YouTube (the Science of Math channel; https://www.youtube.com/channel/UCMRsvxb-374V-LKNcsW56tQ). Become an affiliate to support the Science of Math movement and the idea that instructional practices in math with a scientific basis is the preferred method of identifying practices in classrooms.

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