THE SCIENCE OF MATH RECONSIDERED: A CRITICAL EXAMINATION OF FOUNDATIONAL CLAIMS

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ABSTRACT

In this critical examination of the "Science of Math" (SOM) document analysis is used to understand the meaning and purpose of the movement. Using reflexive thematic analysis of foundational documents and related sources we determined that, while common ground can be found between the SOM and current research in mathematics education, most arguments made by SOM advocates are poorly constructed or based on scant evidence. Areas of agreement include the need for high-quality instruction, large-scale research of instructional practices, and clear goals and directions for students. However, while proponents of SOM conclude that these goals can only be achieved through the use of direct instruction, they fail to demonstrate that inquiry, discovery, or other student-centered approaches cannot accomplish the same goals.

Keywords: mathematics education, science of math, student-centered approaches, document analysis, reflexive thematic analysis

Introduction

The rise in authoritarianism across the globe is not only concerning, but potentially places public education systems in increasingly vulnerable positions. Political and social scientists have been examining the process in which democratic societies shift toward authoritarianism, which they refer to as democratic backsliding (Levitsky & Way, 2002) for more than two decades. These scholars have documented democratic backsliding in Africa, Asia, Europe, and the Americas (Bano, 2024; Benson, 2024; Bloom & Hudson, 2023; Center for Strategic and International Studies, 2024; Levitsky & Way, 2010; Williamson, 2023). The initial stages of democratic backsliding are identified by increasing governmental restrictions on civic engagement and the undermining of institutions designed to uphold democratic principles (Levitsky & Way, 2002, 2010). Public education is one such vital institution. As such, educational institutions are often the target of anti-democratic policies (Pinckney, 2024). When this occurs, those seeking to reform educational systems often seek to do so through the means of public discourse and governmental agencies and by inauthentic arguments with little scientific evidence.

In the last two years in the US, a movement given the title the "Science of Math" (SOM) by its founders has been garnering attention in popular media (e.g. USA Today, APnews.com/ Christian Science Monitor, EdWeek, and others). Shortly after "The Science of Reading" gained traction in policymaking, the SOM quickly received attention from multiple stakeholders and policymakers (Education Commission of the States, 2025; Whiteboard Advisors, 2025). Yet, organizations such as the Association of Mathematics Teacher Educators (AMTE) have issued position statements that claim the SOM "promotes a one-sizefits-all approach. While this approach, referred to as 'explicit instruction,' is a useful tool for teachers, suggesting that it should be the only tool available is not appropriate" (AMTE, 2025). To better understand the intentions of the SOM, we determined a thorough analysis of the principles foundational to the SOM was necessary to understand the merits of its positions.

One manuscript, published as an analysis paper by The Centre for Independent Studies, serves as a primary source of information and foundational beliefs for the SOM (Powell et al., 2022) and summarizes many of the ideas presented on the SOM website developed by the authors (The Science of Math, n.d.) by introducing seven myths that they claim widely influence mathematics teaching and learning. We conducted a document analysis of that paper and the resources it referenced to understand how they define the ideas discussed, the nature and quality of the claims made about these ideas, and the quality of the references used to support the claims made. Through this analysis, we found three major themes. First, when evaluating the authenticity and relevance of the analysis, we found the proponents of SOM promised a focus on using empirically-proven evidence to determine evidence-based teaching practices in the literature, but failed to deliver on this promise. Second, when evaluating the meaning of the arguments put forth by the proponents of SOM, we find the authors fail to address any potential purposes of mathematics other than procedural skill development. As such, it promotes direct and explicit instructional strategies that support the development of procedural fluency but degrades instructional strategies that support the development of high-order critical thinking or problem-solving skills. In addition, the majority of claims made were not well-supported. For example, terms central to several claims were either left undefined or poorly defined, which set the stage for arguments based on the strawman logical fallacy, in which someone's commitments are misrepresented to refute that person's argument (Walton, 1996). Several additional claims were made without supporting evidence, and evidence offered in support of the so-called myths was often misunderstood or misrepresented. Because of these challenges, we conclude that not only does the paper fail to provide strong evidence of the myths or their influence on teaching and learning, but fails to address the fundamental question of the purpose of school mathematics. As a result, the SOM offers nothing new, but simply reflects the ongoing tension between technocratic and humanistic visions of mathematics education. Further, the claims made by the proponents of SOM are ill-founded and should not be regarded as a reliable basis on which to develop curricular or policy interventions. By sharing our analysis, we hope to equip other mathematics educators and supervisors with important tools needed to engage in academic and political debate regarding the SOM.

The Purpose and Practice of School Mathematics in the United States

One of the purposes of this document analysis is to understand the motivations of the proponents of SOM and what they see as the purpose of mathematics. The purpose of school mathematics has served as a catalyst for a myriad of reform efforts in mathematics education. Informed by shifting political, economic, and ideological forces, different beliefs about the purpose of school mathematics has resulted in persistent debates over two fundamental questions: *what* mathematics should be taught in schools, and *why* (Raymond, 2018).

In the early 20th century, mathematics was seen as essential for developing informed citizens capable of participating in a democratic society. Mathematics was viewed as a means of fostering critical thinking, appreciation of logic and structure, and personal empowerment (National Committee on Mathematical Requirements, 1923). Guidelines stressed the use of mathematics that examined personal, civic, and economic relationships, not just vocational preparation (Commission on Secondary School Curriculum, 1938). Constructivist educational theorists criticized the "inert ideas" of traditional schooling and called for humanistic curricula that engaged students' minds and interests (Whitehead, 1949). As such, learner-centered teaching approaches focusing on cultivating curiosity, creativity, and democratic values and curriculum that attended to students' lived experiences and developmental needs were championed by these theorists (Dewey, 1902; Whitehead, 1949).

The onset of World War II marked a turning point in the evolution in school mathematics. A 1943 U.S. Army report criticized the school system for failing to prepare recruits with the basic mathematical skills needed for military roles (Reeve, 1943). This led to a shift toward procedural, technocratic mathematics focused on rote skills and vocational readiness. For the first time, mathematics education was explicitly tied to preparation for specific professions, rather than universal goals of curiosity, creativity, and democratic values. The Cold War and the space race further shifted the focus on mathematics as a tool for national security and technological advancement. Yet, professional educators continued to resist the narrowing of mathematics curriculum to these technocratic skills. Supported by educators and educational researchers, the "new math" movement of the 1950s and 1960s, aimed to modernize the curriculum by emphasizing problem-solving, abstract reasoning, and conceptual understanding through humanistic approaches rooted in inquiry and discovery (Betz et al., 1944; Bruner, 1960; Kilpatrick, 2014). While these reforms sought to counteract rote learning, the proponents of the movement implicitly adopted the understanding that the purpose of school mathematics was to prepare students for specified careers as they argued that future scientists and technologists would need problem-solving and abstract reasoning skills to win the space race.

It was not long before backlash against new math culminated in the "back to basics" movement, which argued once again that students lacked basic computational skills and blamed new math for this failure (Kline, 1973). As a result, schools returned to traditional, skills-based instruction, emphasizing drills and rote procedures. However, the return to these technocratic approaches also had unintended consequences. While minimal competency improved, higher-order thinking and problem-solving skills declined, and fewer students pursued advanced mathematics or STEM careers (Goertz, 2010; Schoenfeld, 2004). Critics argued that the back-to-basics movement narrowed the curriculum to the point that students were unprepared for both democratic participation and technological innovation.

These philosophical disagreements erupted in the "math wars" of the 1990s, pitting traditionalists against reformers. In an attempt to settle the longstanding disagreements, The National Council of Teachers of Mathematics (NCTM) published the *Curriculum and Evaluation Standards for School Mathematics* (1987), which promoted "mathematics for all" and emphasized mathematical literacy for democratic engagement and aimed to balance conceptual understanding with procedural fluency (Coburn, 1989; Steffe, 1990). Critics labeled curricula based on these reform efforts as "fuzzy math" that lacked rigor and politically-organized groups successfully pushed for a return to traditional curricula (Schoenfeld, 2004). These wars not only reveal that the deep divisions over the purposes of mathematics education were not yet resolved, but also, for the first time, shifted the debate over mathematics curriculum into the political arena. Mathematics curriculum has been increasingly politicized since. For example, the early 2000s saw the rise of the Common Core State Standards, a political effort aimed at unifying educational expectations across states. The mission of the Common Core for mathematics was explicitly framed around college and career readiness, ignoring calls for mathematics education to support democratic citizenship

(National Governors Association, 2010). Additionally, there have been increasing efforts to enact policies at the state level that specify the concepts that can and cannot be taught in classrooms as well as the instructional strategies to be used (Natanson et al., 2024).

Following the Footsteps of the Science of Reading in the United States

Policy and practice regarding reading education in the United States have similarly been embroiled in debate, reminiscent of the back-and-forth swings of the "math wars," which in the last decade has resulted in a focus toward empirical, scientific evidence regarding how people learn to read (Petscher et al., 2020). The cumulative, empirical body of research as well as instructional practices which are applications of that research regarding the instruction of reading have come to be known as the Science of Reading (SOR) (Goodwin & Jiménez, 2020). While sometimes only narrowly considered as the instruction of phonics, SOR is more broadly understood by those in reading education to include more than just foundational reading skills, and applies to how learning to read and the act of reading itself shapes learners across contexts and developmental stages (Goodwin & Jiménez, 2020).

Following yet another cycle in the ongoing, broad debate about reading instruction which correlated with the shift from one set of federal education guidelines to another (Shanahan, 2020), strategies and materials created using SOR were perceived by many education stakeholders as a quick solution to slipping reading achievement scores (Goodwin & Jiménez, 2020). Language or materials explicitly referring to SOR were rapidly integrated into state policies regarding teacher education, licensure, or approved materials. From 2013 to 2019, such adoptions occurred in 16 US states; 13 more occurred in 2021 alone (Schwartz, 2022). Due to this breakneck adoption, some have expressed alarm at the breadth and depth with which the empirical evidence foundational to SOR might be applied (e.g., Goodwin, 2020; National Education Policy Center & Education Deans for Justice and Equity, 2020; Shanahan, 2020).

Regardless of the decades of empirical research that have informed what is currently known as SOR, as popular media, policy makers, and other stakeholders developed interest in the topic, its meaning was affected (Shanahan, 2020; Goodwin & Jiménez, 2020). While some states that enacted policies related to SOR have seen some improvement in reading achievement, it is unclear if this achievement will be widespread, long-term, or even attributable to the adoption of SOR-related policies (Schwartz, 2020). Furthermore, questions remain about how and if pedagogical practices should be enacted solely based on empirical evidence regarding SOR rather than empirical evidence of reading education itself (Shanahan, 2020), how SOR might better reflect issues of equity and diversity (Milner IV, 2020), and the further broadening of SOR to consider that reading instruction extends far beyond primary school (Phillips Galloway et al., 2020; Petscher et al., 2020). These uncertainties are enough to promote caution in mathematics education when considering any new movement that claims to be a solution to a decades-long debate regarding the way forward.

Positionality Statement

As mathematics educators we believe that we cannot be completely objective when discussing matters related to mathematics education; however, we can work to be interpretive in a way that is transparent and disciplined. We came to this study with beliefs, ideas, and philosophies about mathematics and mathematics education that informed our choices in methodology and analysis. In particular, we are social constructivists (Ernest, 1998; Ernest, 2003; Vygotsky, 1978) who believe that the purpose of mathematics education must extend beyond college and career readiness (National Governors Association, 2010) into the mathematical literacy required to navigate the ever "increasing amounts of data and statistics about social and political realities" (Raymond, 2018, p. 10) necessary for participation in democratic society.

Methods

This study employed a qualitative document analysis to examine the policy analysis paper titled *Myths that Undermine Maths Teaching* (Powell et al., 2022) that serves as foundational literature of the SOM movement. The document analysis included all studies cited by the policy analysis paper in our document analysis as well. These documents were appropriate to include in this document analysis as they were selected by Powell et al. (2022) as evidence of claims. Doing so examines the theoretical relevance and alignment of research objectives of the document analysis (Bowen, 2009; Morgan, 2022). After an initial analysis, we determined that we needed to include a second paper by the proponents of SOM (Codding et al., 2023) in our analysis to demonstrate consistency in the arguments made by the advocates of SOM. As such, while the focus of this document analysis is to seek meaning in the claims made in Powell et al. (2022), we draw additional evidence from Coddings et al. (2023) when needed.

The purpose of this analysis was to explore how the developers of the SOM movement describe school mathematics, identify the ideological and epistemological assumptions made by the authors of the paper or the cited literature, and explore the broader implications for mathematics teaching and policy. A document analysis was appropriate in that we sought to investigate the texts to identify implicit meanings, positions, and patterns of representations of both mathematics and mathematics teaching (Bowen, 2009; Morgan, 2022). Throughout systemic evaluations of these documents, we employed thematic analysis to identify strategies used by the authors to construct the "myths" they assert exist in school mathematics and disseminate their perspectives on the teaching and learning of mathematics.

Analysis

Studies identified as empirical, clinical, or school-based studies of mathematics instruction, we flagged and examined separately as Powell et al. (2022) "propose that high-quality mathematics instruction should be instruction that is driven by evidence from clinical studies or school-based studies." (p. 2). The proponents of SOM reiterate this value in (Coddings et al., 2023) when they state that based on "scientific knowledge integrated with clinical expertise" (Codding et al., 2023, p. 6). As such, we sought to identify and understand the meaning of the clinical or school based empirical studies used to support the views of the proponents of the SOM.

After identifying the empirical studies referenced by Powell et al. (2022), both the literal meaning of each cited work and the meaning of the work as interpreted by Powell et al. (2022) was assessed (Bowen, 2009; Morgan, 2022; Salminen et al., 1997). We employed reflexive thematic analysis to assess the meaning of each document. Reflexive thematic analysis views researcher interpretation as a resource rather than a limitation, allowing for the co-construction of meaning between the researcher and the data (Braun and Clarke, 2013; Morgan, 2022). First, all documents were read with attention given to both content and evidence. That is, we sought to identify the claims being made by each work and how those claims were supported in the work. Next, each researcher worked independently to identify relevant segments of each text and inductively code them. Three codes were applied to each segment of text. The first code described the relevant concept (e.g. "direct instruction" or "inquiry"), a second code summarized the claim made about the concept (e.g. "widely used" or “ineffective”), and a third code described the nature of the support provided for the claim in the text (e.g. “theoretical”, “empirical”, or “misinterpreted”). The researchers then met to compare and discuss codes and discuss disparities until agreement was reached. After all segments were coded, codes were clustered into themes to identify patterns of argumentation. Again, each researcher clustered the agreed upon codes independently and then we met to discuss the emergent themes. These themes were refined through recursive rounds of engagement and reflection. Analytical memos were maintained throughout the process to document emerging insights, methodological decisions, and reflexive considerations.

Trustworthiness

Several strategies were employed to ensure the trustworthiness of the study. First, triangulation was achieved because the set of documents analyzed consisted of empirical studies, theoretical contributions, policy analysis, and professional tradebooks (Bowen, 2009; Morgan, 2022). Second, the maintenance of an audit trail consisting of detailed records of the processes of coding and theme development, as well as analytical memos allows for transparency (Tisdell et al., 2025). Third, the researchers engaged in disciplined interpretation. Coding and theming individually and then engaging in collaborative, reflexive conversations that examined our assumptions and interpretive lens allowed for transparency in how our positionalities shaped the analysis (Morgan, 2022). Finally, we recursively engaged in the analytic process until saturation was reached; each emergent theme was well-supported and no additional themes emerged (Bowen, 2009).

Findings

In this section, we will first present a summary of the findings related to the authenticity and representativeness of the literature reviewed in this document analysis before turning our attention to meaning. We then identify the themes and meanings that emerged across multiple myths. To demonstrate how these themes emerged from Powell et. all (2022), we expand on our findings related to meaning in a manner parallel to the way in which the original document was organized. That is, we present the findings related to each myth in turn. By doing so, we demonstrate the ways in which each myth was constructed and supported so that readers can consider their own positions about each myth in isolation.

Authenticity and Representativeness

Each document included in this document analysis was evaluated for authenticity, representativeness, and meaning (Morgan, 2022; Salminen et al., 1997). Authenticity was assessed by verifying the publication source, authorship, and publication date. Representativeness was considered in terms of how typical or influential each cited work was within the broader discourse on mathematics education. Powell et al. (2022) use 89 unique references to support the claims made in the paper. Of those, 30 were not original empirical studies, but rather practitioner articles, books, or book chapters that may have discussed previous research. Nine of the references were longitudinal studies not situated in clinics or schools, and another two studies were empirical studies but did not study instruction. Thus, there were 48 empirical clinical or school-based studies focused on instruction. We conducted a full content analysis of those 48 studies, and reviewed the other 41 sources when needed to develop deeper understandings of the arguments being presented in Powell et al. (2022).

While the 48 empirical studies were from well-established, peer-reviewed sources, 17 of the referenced works appeared in academic journals focused on students with special needs and another three were studies whose populations consisted only of students identified as having special needs and were not conducted with the needs of the full diversity of students typical classroom teachers encounter. Therefore, of the 89 unique references, only 28 (31%) fit the criteria of empirical clinical or school based studies of a broad population of students. Given the limited number of empirical sources used and the populations of students identified in the studies, we concluded that the studies used to support the views of the proponents of SOM were incomplete, raising questions about the representativeness of their analysis.

Themes

There were three themes that emerged through analysis. These were: a focus on empirically-proven evidence, regarding skill development as the product of successful mathematics education, and making claims which were unsupported by the cited evidence. This brief summary will describe these themes with evidence from the text in order to provide context for each theme.

The first theme that emerged was the focus on empirically-proven evidence. There were repeated claims that high-quality mathematics instruction should be derived only from "clinical studies or school-based studies" (Powell et al., 2022, p. 2), based on "scientific knowledge integrated with clinical expertise" (Codding et al., 2023, p. 6) or comprised of scientifically proven practice (Codding et al., 2023) and that doing otherwise amounts to "pseudoscientific practices in the classroom" (Codding et al., 2023, p. 7.).

Second was the promotion of skill development as the sole purpose of mathematics education, with an emphasis that these skills should be developed only through direct or explicit instruction. In Coddings et al. (2023), the proponents of SOM use the definition of mathematical proficiency from the National Research Council (2001), which states proficient students will "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". However, their arguments, and the studies they use to support them, focus entirely on performing basic operations and procedures. They do not engage in questions on developing a repertoire of strategies or choosing between them, learners' ability to reason clearly and flexibly, or how to support a positive outlook towards math. Likewise, in Powell et al. (2022), emphasis is given to teaching algorithms and procedural understanding. Indeed, the first two myths directly address algorithms and procedural fluency, while the fifth myth presented minimizes the importance of affective dimensions of mathematics that support positive outlooks.

Finally, many claims made by Powell et al. (2022) and Codding et al., (2023) either lack definitions or evidence altogether or, even more egregiously, misuse definitions or evidence from extant literature. One example is the use of the phrases "inquiry-based learning" and "inquiry-based instruction" which are never defined in Powell et al. (2022). An example of lacking evidence is the claim that there is a "prevalence of pseudoscientific practices in the [math] classroom" (Codding et al., 2023, p. 7), a statement which has no related citations. Another claim with no citations was that "there are quite a few prevailing myths that are pervasive in conversations about the teaching of mathematics" (Powell et al., 2022, p. 2). In fact, it is in the exploration of these so-called pervasive myths that it became obvious that further analysis into the meaning of the text would be required, as it became clear that definitions and evidence from extant literature were being misused in support of debunking these myths.

Myth 1: Conceptual then procedural understanding

According to Powell et al. (2022), "one commonly-held myth amongst educators is that students should not be exposed to procedural instruction until they have demonstrated adequate conceptual understanding of specific mathematics content" (p. 2). This statement is not supported by citations, and no evidence is provided that this myth exists or is commonly held. "Adequate" conceptual understanding is similarly undefined. Powell et al. (2022) do suggest that "this myth may come from pushback to procedural learning, from resources that state conceptual knowledge should be developed prior to procedural knowledge" (p. 2). This statement implies that *all* conceptual knowledge should be developed before procedural knowledge. The resource which is cited to support this claim is *Principles to Actions* (NCTM, 2014).

Indeed, a chapter of this book is titled *Build procedural fluency from conceptual understanding* (NCTM, 2014, p. 42). This title, at first glance, may be interpreted to imply that all conceptual understanding must be developed first, but the body of the chapter provides a more nuanced understanding of the connection between conceptual understanding and procedural fluency than is suggested by the phrasing of this myth. It states that "when procedures are connected with the underlying concepts, students have better retention of the procedures and are more able to apply them in new situations." (NCTM, 2014, p. 42). Because procedures should be connected to concepts, this statement implies that both should be developed together, an implication that *Principles to Actions* makes explicit when it is said that "effective mathematics teaching focuses on the development of both conceptual understanding and procedural fluency. Major reports have identified the importance of an integrated and balanced development of concepts and procedures in learning mathematics." (NCTM, 2014, p. 42). This idea of an integrated approach is indeed echoed and supported by Powell et al. (2022) when they state, "the truth is that conceptual knowledge and procedural knowledge work in tandem and are often intertwined" (p. 2). Therefore, there may be alignment, rather than disagreement, between Powell et al. and the sources the authors claim to have facilitated the development of a harmful myth. Thus, without evidence to support the claim that significant numbers of teachers believe all knowledge of a concept must be developed before procedural knowledge, the authors have simply created a strawman argument; they have created a myth which is not representative of practitioners' views in order to argue against it.

It is possible that Powell et. al. believe that teachers who read *Principles to Actions* may be misled by the title of the chapter if they do not conduct a close read of the chapter itself. Yet, Powell et al. (2022) also state that, "to use an algorithm well, students have to have a strong understanding of numbers and place value. That is, ensure students have a foundation in understanding what it means to add, subtract, multiply, or divide before introducing an algorithm" (p. 4). That "foundation in understanding" what various operations means is necessarily conceptual in nature. Thus, the authors are inconsistent in their treatment of the need for at least some conceptual understanding before introducing the procedures of an algorithm.

Myth 2: Teaching algorithms is harmful

The use of a strawman argument continues in myth two, in which Powell et al. (2022) claim that "another myth is that students should not be taught algorithms" (p. 3) without evidence that any teachers of mathematics believe this to be true or fail to teach algorithms to students. Indeed, Powell et al. (2022) note "mathematics standards have emphasised that students should learn algorithms alongside the conceptual meaning of each of the algorithms" (p. 3). As mathematics standards are generally written to guide mathematics instruction, it must be questioned how this myth could exist or be pervasive if guidance documents are counter to the ideas in the myth. However, our larger concern is that the authors conflate the teaching of algorithms and the use of direct instruction, implying that students can only learn algorithms through direct instruction. For example, Powell et al. (2022) state "meta-analyses have noted that teaching students explicitly how to solve mathematics problems leads to improved mathematics outcomes over encouraging students to create their own mathematics knowledge" (p. 3). This claim is supported by a single doctoral study consisting of two meta-analyses focused on the relative benefits of unassisted discovery, assisted discovery, and explicit instruction; the word algorithm does not appear anywhere in the body of dissertation (Alfieri et al., 2011). Thus, it appears that Powell et al. conflate the teaching of algorithms with the use of explicit instruction.

Powell et al. (2022) do cite some research focused on the use of algorithms to support claims that algorithms are superior solution strategies. For example, they state that

> In a comparison of standard algorithms to alternate algorithms, Norton worked with students across ages 9 to 12 on a measure of addition, subtraction, multiplication, and division computation. He determined that, across operations, students who employed standard algorithms were more likely to solve each problem correctly than students who used alternate algorithms (p. 3).

While this study does fit Powell et al. (2022) definition of empirically-proven evidence in that it is a "school-based" study (p. 2) there are significant problems with the design of Norton's (2012) study. First, it collected no data about which method or methods participants in the study were taught, nor how they were taught. Nor does it indicate when students participated in the study relative to the instruction they received or even if all students received the same amount or quality of instruction. Indeed, Norton (2012) states:

> No school possessed a comprehensive school-wide mathematics program that stipulated which resources ought to be used or even which concepts ought to be emphasized. Rather, teachers selected their own resources and tended to teach independently. Thus, it was very difficult to attribute a child's response to the use of a particular resource. The student response could have been a reflection of what the current teacher had taught or a previous learning experience. The school-based specific data reflected a clustering of the use of particular methods in some classes, but there was no overall school-based pattern that could be reliably linked to a specific approach. It could only be inferred that students would respond in a way that they had been taught at some point in their learning of mathematics (p. 8).

Thus, there is no way to tell if the participants' performance was a reflection of the superiority of a strategy or simply their familiarity with it.

The other article used to support the claim that teaching algorithms is superior to teaching other methods (Torbeyns & Verschaffel, 2016) also has design flaws related to participants' familiarity with different strategies. Powell et al. (2022) state:

> In a research study, Torbeyns and Verschaffel demonstrated that students, after a year of practising an algorithm, could apply the algorithm correctly and preferred using the

> algorithm. When students did not use an algorithm, they often employed inefficient strategies to solve computation problems (p. 3).

In fact, Torbeyns and Verschaffel (2016) tested students for whom, after being "taught varying strategies including compensation" in grade two, revisited only the standard algorithm in grade three:

> the teachers did not stimulate and help the pupils to actively construct the standard algorithm gradually out of their available mental calculation strategies, but almost immediately presented the algorithm in its final shortest form. After intensive practice of the standard algorithm in 3rd grade, children briefly rehearsed it during the first months of 4th grade (p. 105).

After a year of "intensive practice" with the standard algorithms, their findings showed that only 52 percent of the participants relied only on the standard algorithm. While Torbeyns and Verschaffel (2016) interpreted this finding as demonstrating a preference for the standard algorithm, the effects of the different timing and intensity of instruction is not considered; students could have simply been replicating the method they were most often and most recently asked to use in schools. The more recent and intensive focus on algorithms could also explain the increased speed and accuracy of the participating children when using the algorithm. Regardless, that only 52 percent relied on such an intensely studied method is cause for caution.

Thus, Powell et al. fail to provide evidence that the myth that algorithms should not be taught exists and also fail to substantiate their own claims about the superiority of teaching algorithms. Indeed, Powell et al. (2022) demonstrate a challenge in the use of algorithms, stating that "In a study with university students, many had difficulty with the algorithms after years of not practising them" (p. 4). While Powell et al. conclude that students need even more practice with and modeling of the standard algorithm, we wonder if there may be other methods which would not require years of remediation, or if the teaching of multiple methods in ways that connect the methods to foundational conceptual understandings of what operations mean may allow learners to move to another method if they fail to recall a standard algorithm, or even recreate a method based on their conceptual understanding when their memory of a procedure fails them.

Myth 3: Inquiry learning is the best approach

A third myth that Powell et al. (2022) assert is that "inquiry-based learning is the best approach to introduce and teach mathematics" (p. 4). International assessments (e.g., PISA) are referenced to suggest that many students face challenges in learning mathematics, but evidence is not provided that inquiry-based learning is the norm or prevalent in K-12 mathematics classrooms for the students assessed. Rather, a single source (Tan et al., 2022) is cited as evidence of this alleged myth. However, upon examining Tan et al.'s references to inquiry, it is clear that the importance of students developing inquiry skills is the emphasis rather than advocating for or against inquiry-based teaching methods. Tan et al. (2022) highlight that "mathematical knowledge and inquiry-based skills constitute a crucial gatekeeping stumbling block for students to thrive in and out of schools" (p. 873). This statement underscores the significance of inquiry skills but does not address inquiry-based instruction. Furthermore, Tan et al. (2022) stress the need for awareness of social forces perpetuating ableism in mathematics education. They advocate for cultivating emancipatory forms of inquiry and practices (e.g., Lewis & Lynn, 2016; Gutstein, 2003). Again, this emphasizes the development of inquiry skills without prescribing either a particular or singular teaching method. Simply put, this evidence simply does not address methods of teaching, or teacher beliefs.

Regardless of either the existence of this belief or its status as a myth, it is also important to examine the evidence used to support Powell et al. (2022) claim that inquiry-based learning is less effective than more guided forms of instruction. The evidence provided to support this claim is not as definitive as they suggest. Powell et al. (2022) state that “decades of research evaluating effects of inquiry-based learning and guidance demonstrated that more specific supports and guidance have been more effective than inquiry without supports in a wide range of contexts” (p. 4). Five studies are cited to support this claim. Each of these five references are discussed below.

Two of the references used (Carbonneau et al, 2013; De Jong and Van Joolingen, 1998) do not address inquiry learning versus other types of learning, which indicates a misalignment between the claims made by Powell et al. and the evidence they present. Moreover, Powell et al.’s (2022) interpretation misconstrues De Jong and Van Joolingen's (1998) definition of inquiry learning, as the study discusses different forms of inquiry-based learning, rather than inquiry versus non-inquiry approaches. Powell et al. (2022) state “De Jong and Van Joolingen reported that the forms of inquiry that were most beneficial were those that also included access to relevant information, in addition to support to structure inquiry and monitor progress - all elements that align with explicit instruction” (p. 4). While these supports may align with explicit instruction, it is clear that DeJong and Van Joolingen (1998) framed these elements as aligning to some forms of inquiry-based learning as well. Further, Powell et al. presented no evidence that explicit instruction requires these elements or that these elements are used more routinely in explicit instruction.

The third study cited to support the claim that inquiry-based instruction is inferior to explicit instruction, Alfieri et al. (2011), provides evidence that the opposite may be true. Alfieri et al. found that enhanced discovery learning, which includes supports such as feedback, worked examples, scaffolding, and elicited explanations, has favorable outcomes compared to other forms of instruction, including explicit instruction. This suggests that inquiry-based learning, when implemented with appropriate supports, can be beneficial for students. However, Powell et al. fail to engage with this evidence.

Powell et al (2022) also misconstrue the work of Hermann (1969). This study, the fourth cited to support the contention that explicit instruction is a superior approach, offers a critical review of the methods of studies investigating discovery approaches rather than the effectiveness of discovery approaches themselves. Hermann (1969) states “many results are suspect due to limitations in experimental design and analysis, as is demonstrated in a critical analysis of the studies. Also, direct comparison of experimental findings is difficult due to differing ideas concerning the nature of discovery learning. Hermann (1969) concluded that “progress in this field will be limited until the experimental methodology is improved, and until acceptable operational definitions of discovery learning variables are used” (p. 58). In other words, Hermann determined that the field, in 1969, did not yet have enough evidence to definitely determine the relative benefit of discovery-based approaches and other methods. However, the article does not present any evidence to suggest that discovery-based methods are inferior to explicit instruction methods.

Likewise, the last article Powell et al. (2022) used to support the claim that explicit instruction is superior to inquiry-based instruction, Lazonder and Harmsen (2016), examines what supports are most effective in inquiry-based instruction. Lazonder and Harmsen (2016) conclude: "Which types of guidance are appropriate cannot be determined on the basis of the existing reviews and meta-analyses. This seems at least in part due to the fact that guidance is often classified ad hoc on the basis of the included studies. Using an a priori classification based on a theoretical framework might be more fruitful and ease interpretation of the findings" (p. 684). Again, this is a critical review of the research studying inquiry-based learning, not of inquiry-based learning itself. Lazonder and Harmsen do not provide any critique of the merits of inquiry-based instruction, only of the research of those methods. Yet, the Powell et al. (2022) state "Lazonder and Harmsen noted that many of the supporting scaffolds reported in studies in their meta-analysis were added 'ad hoc'" (p. 4). In doing so, the discussion of ad hoc classifications is misapplied to the work of teachers, rather than the work of researchers.

Based on the treatment of these sources, one might conclude that Powell et al., who do not clearly define either explicit instruction or inquiry-based learning, view only those approaches that offer no supports or guidance to students as "true inquiry" while suggesting that "built-in scaffolds and support for student success" are only offered in "modified" inquiry learning, This is a narrow view of inquiry-based instructional approaches and ignores a wealth of literature that investigates the effectiveness of various supports and scaffolds within inquiry-based learning experiences, including Alfieri et al. (2011), DeJong and Van Joolingen (1998), and Lazonder and Harmsen (2016). By artificially narrowing inquiry-based instructional approaches in this way, the authors once again have created a strawman argument.

Myth 4: Productive struggle is important

Perhaps the clearest example of the conflation of terms and definitions by Powell et al. comes in their discussion around productive struggle. They claim that it is a myth that productive struggle is important, but their discussion focuses instead on *un*productive struggle. The reference to unproductive struggle is quite explicit, as Powell et al. state "the struggle many students experience is frustrating and wasteful rather than productive" (p. 5). By definition, these experiences are not productive struggles, yet these are the experiences focused on throughout the discussion of this so-called myth.

As evidence, Hiebert and Grouws (2007), are quoted as stating they "do not use struggle to mean needless frustration or extreme levels of challenge created by nonsensical or overly difficult problems" (p. 387), but Powell et al. (2022) fail to acknowledge that Hiebert and Grouws (2007) define such struggles as *un*productive in their attempt to distinguish unproductive struggle from productive struggle. To be clear, in the sentence that directly precedes the one quoted above, Hiebert and Grouws (2007) define productive struggle as expending "effort to make sense of mathematics, to figure something out that is not immediately apparent" (p. 387). Unproductive struggle, on the other hand, occurs when students "make no progress towards sense-making, explaining, or proceeding with a problem or task at hand" (Warshauer 2011, p. 21). No one is advocating for engaging students in unproductive struggle. However, students who productively struggle in their attempts to make sense of a problem or explain their thinking can develop stronger reasoning and communication skills, which are both key skills in mathematics learning.

We agree with Powell et al. (2022) when they state that "Much of the difficulty with productive struggle is how educators interpret the level of struggle" (p. 5). However, this does not mean productive struggle is unimportant, unnecessary, or counterproductive. Instead, this insight supports further teacher development focused on recognizing when struggle is or is not productive and identifying experiences that will engage students productively based on their prior knowledge and readiness.

Because Powell et al. (2022) conflated unproductive and productive struggle, it is no surprise that they cite studies that engaged students in unproductive struggle. For example, Powell et al. (2022) claimed that, in a study by Ashman et al. (2020), "productive struggle and explicit instruction were compared in two randomised controlled trials, which are the 'gold standard' in research design" (p. 6). However, in the article by Ashman et al. (2020), the focus was comparing the results when elements of a single lesson were presented in different orders. That is, all participants in the study received explicit instruction and all participants in the study were given problems to solve. While Ashman et al. (2020) claim to have developed the research protocol to allow for "productive failure" (which is not the same as productive struggle), there were no measures of struggle, productive or unproductive, in the study.

Additionally, the study contained a segment described as "problem-solving", but not problem-centered instruction. The study focused on the order in which students received different elements of a lesson, including the use of a 6-problem booklet that contained problems which required participants to calculate the energy efficiency of light globes. Participants had not yet engaged in instruction related to calculating energy efficiency. For the problem-solving element of the lesson, Ashman et. al. (2020) state that students:

> were given the booklet of problems to solve, with the following instructions: 'This booklet contains some problems to try to solve. They are set in everyday situations so think how you would solve the problem in real life. You are not expected to solve all of the problems. Just do what you can.' They were given 15 min to work on these problems (p. 236).

Given this description, any struggle the students engage in was likely unproductive, as they were not provided a definition of energy efficiency and there is no reason to believe the participants would have encountered this term outside of school. Regardless, this description of the participants' experiences simply does not align with problem-centered instruction, and there is no evidence that participants actually engaged in any problem solving.

In a problem-centered learning experience, students work collaboratively to develop strategies and test them as the teacher poses questions to guide and support student thinking. Students are often provided time to review the strategies of others, compare strategies (which may or may not be strategically chosen by the teacher), and refine their thinking and their work (Ridlon, 2009). Here, students had limited time to problem-solve, were not able to work collaboratively, and had no opportunity to compare, discuss, or refine their problem-solving strategies, and absolutely no guidance or support from their teacher. Effectively, participants received no instruction during the so-called "problem solving" portion of the lesson, and any claims that this study compared teaching pedagogies is false.

Myth 5: Growth mindset increases achievement

As with other myths, Powell et al. (2022) leaped from a theoretical construct, in this case, growth mindset, to assuming that teachers are spending instructional time focused solely on "mindset training" with no evidence. Additionally, even if we accept their assumption that teachers both believe growth mindset 'training' is important and spend significant time on it, Powell et al. (2022) failed to provide evidence that such a use of instructional time is any less effective than the methods they promote. The study used as an example of the evidence which demonstrates the lack of effectiveness of "mindset training" is described as follows:

> A recent randomised control trial assigned third graders who demonstrated need for mathematics intervention to three separate conditions: (a) business as usual, (b) fraction intervention, and (c) fraction intervention plus growth mindset training. Results revealed no difference in mathematics learning gains between the stand alone fraction intervention in comparison to the fraction intervention plus growth mindset (Powell et al., 2022, p. 6).

At best, the cited study (Fuchs et al., 2021) demonstrates no significant difference in the methods used. However, upon closer inspection of the study itself, it becomes clear that the participants who received "fraction intervention plus growth mindset training" were given no additional instructional time above the other two groups. As such, this group of participants necessarily received less instructional time focused on mathematics, because some of their allotted time was focused on developing mindsets; both intervention groups received interventions for 35-minute three times a week for 13 weeks (Fuchs et al., 2021). Therefore, this group had equal learning gains with less instruction focus on fractional content. That being the case, the only conclusion that can be reached is that the mindset training did not harm the participants in this study. If the mindset training were to allow participants to continue achieving equal gain in less time in future lessons, then it may in fact be beneficial. Indeed, Fuchs et al. (2021) state their study showed only that mindset "may not be necessary in the context of strong intervention' (p. 163). This implies that no conclusions can be reached when students are not receiving strong interventions.

Myth 6: Executive Training Function is important

Powell et al. stated that "there is a belief that executive functioning is more influential on students' mathematics achievement than other academic domains" and that there is also a belief "that stand-alone interventions targeting executive functioning will transfer to improvements in mathematics outcomes." (p. 7). Like the other so-called myths presented in this paper, there is no evidence that significant numbers of teachers of mathematics believe executive function training is important nor that this belief influences teachers of mathematics to focus on executive function training in any way. However, what becomes confusing in their discussion of this myth is that Powell et al. (2022) state that "It is likely cognitive factors, such as executive functioning, will be correlated with mathematics achievement" (p. 7), but then encourage teachers to teach explicitly because "explicit instruction reduces the likelihood student differences in executive functioning will impact learning" (p. 8). This suggests that the intent of Powell et al. is not to maximize student achievement but to equalize achievement across all students. By doing so, they contradict their own premise that the SOM movement is intent upon increasing "outcomes for all students" (Codding et al., 2023, p. 6).

Myth 7: Timed Assessments Cause Mathematics Anxiety

Unlike many of the other myths presented in Powell et al. (2022), this myth is not focused on promoting specific methods or tools in mathematics teaching, but instead is focused on negative views of a specific method. As such, Powell et al. inverted the usual process of creating a strawman argument, and instead clearly explained how and why educators who question the use of timed assessments may have reason to because of a lack of clear understanding what is meant by a timed assessment, what its purpose is, and how to implement such assessments. Powell et al. (2022) stated "teachers are rightfully wary of timed assessment because when used ineffectively it yields useless data and is an ineffective instructional technique" (p. 8). In other words, it is not the construct of timed tests that is problematic, but the ineffective use of such a construct. Powell et al. (2022) go on to provide a vignette of a poorly-implemented timed assessment:

> *An educator administers a maths multiplication fact sheet to all students in the class. All students get the same exact sheet. Before the educator starts the timer, they say, "It is important to master our maths facts. If you get below [X] correct, then we will spend the first 5 minutes at recess practising." As students work on the sheet you see students quickly slapping their pencil down and flipping their paper over to signify, they finished. Other students quickly look at them and frantically get back to their sheet. As the timer rings the educator yells, "Times up, trade with your shoulder partner." The educator has students exchange sheets with a peer. As the educator reads off the answers the peer scores the sheet. The educator then posts everyone's score on a classroom board to track student progress (p. 8,* emphasis in original*).*

If this is what one thinks of when considering the use of timed assessments, then we agree with Powell et al. (2022) that teachers should be wary of such uses. Powell et al. (2022), however, explained that this is a poor use of timed assessments and stated that teachers should "Administer timed assessments as low-stakes activities. For example, do not tie the assessment to a grade, consequences of scores should not include removal of desired activities, and avoid peer-to-peer comparisons" (p. 9). In other words, when done well, timed assessments can provide high quality data about student learning, but when done poorly, such assessments may cause anxiety. We do not disagree; when teachers implement timed assessments, they should be extremely careful not to implement timed tests in ways that may increase students' mathematical anxiety. Moreover, the authors fail to show that significant numbers of teachers would disagree with this statement.

Discussion

Throughout our analysis the SOM proponents' emphasis on empirically-proven evidence to support best practice was clear. However, it should be noted that Powell et al. (2022) and Codding et al. (2023) use sources that are not empirically-proven as evidence for the practices as recommended by the SOM, as only 48 of the 115 cited sources in Powell et al. (2022) were of this type, with only 28 that studied large populations of students with varied abilities. Therefore, the claims made by Powell et al. (2022) are not representative of the field of mathematics education. Furthermore, their focus on empirically-proven evidence stated that only clinical or school based studies should be examined. This eliminates the consideration of longitudinal or other studies that examine measures of student success outside of standardized assessments.
As described in the discussion of the seven so-called myths, SOM advocates also emphasize the promotion of skill development as the primary purpose of mathematics education. Specifically in the discussion related to procedural understanding (Myth 2), algorithms (Myth 3), and executive functioning (Myth 6), the primary argument formed against what Powell et al. (2022) claimed as prevalent teaching practice was to support explicit or direct instruction to develop specific mathematical skills to promote student success.

Finally, the majority of claims made by Powell et al. (2022), provide no evidence to support their claim that the practices they described were prevalent in US classrooms (Myths 1, 2, 5, 6). Definitions were either not provided for key terms, like "adequate conceptual understanding" (Myth 1), "explicit instruction" (Myth 3), and "inquiry-based learning" (Myth 3) or misconstrued from established use, as was the case with "productive struggle" (Myth 4). Evidence provided to support what Powell et al. (2022) are promoting as best practice is often misused (Myths 1, 2, 3, 4, 5) regardless of whether the source was empirical in nature or not. Some studies used, such as, Torbeyns and Verschaffel (2016) reported minimally significant findings that were not clearly presented in Powell et al. (2022). This extensive misrepresentation of extant literature should be critically examined further, as this has provided the stage for supporting arguments based on logical fallacies that should not be convincing to any mathematics educator.

The nuanced and differentiated way in which Powell et al. discussed what timed assessments are meant to be, on one hand, versus how they are often implemented, on the other, illustrates awareness of two key ideas: the importance of clear definitions and the difference between the a methodological tool and the use of that tool. This understanding is not applied to any of the other myths presented in this paper. We would maintain that the value of tools such as inquiry-based learning, productive struggle, and other constructs dismissed as ineffective throughout Powell et al. (2022) lies in the quality with which they are implemented. However, in citing research Powell et al. claimed to assess the effectiveness of such tools, they do not include any consideration of how well these tools were implemented in the chosen studies. As we have shown throughout this paper, studies cited by Powell et al. also failed to ensure that the tools in question were being implemented in ways that aligned with the definition of those tools. Indeed, we have described many instances in which the tools being investigated simply were not implemented in the cited literature. In addition, the authors failed to demonstrate that any of the so-called myths presented are believed by significant numbers of teachers of mathematics, nor that the methodological tools at the heart of each myth are used by significant numbers of teachers of mathematics. Simply put, there is little to no scientific evidence presented to support the SOM.

Conclusion

The emergence of the SOM as a contemporary contribution to the discourse on mathematics education represents a new chapter in the century-long debate over what mathematics should be taught and how it should be taught in United States schools. Yet, the themes of the debate remain the same. What is new is that the originators of the SOM, while researchers themselves, have sought to promote their vision for mathematics education not through disseminating empirical research, but instead through popular media sites and local legislative bodies. This shift in approach is reflective of the increasingly authoritarian rule of the United States government in relation to education. Additionally, authoritarian governmental actors may be inclined to support SOM because of its focus on procedural fluency rather than sense-making, reasoning, or problem-solving. While we do not imply any relationship between creators of SOM and those seeking authoritarian rule, the emergence of SOM at a time when authoritarian rule is increasing is both a significant concern and an explanation for the rapid dissemination of the ideas of the SOM among policy-makers.

The foundational difference between the developers of the SOM and ourselves is a new verse of the old song, but there is still common ground. We agree that more evidence is needed to determine how mathematics is being taught in classrooms across the country. What is working and what is not? It is difficult to have a discussion about what prevalent or effective practices are without updated data. The last long-term and representative mathematics education study with data in the United States was completed by Silver and Stein (1996), and even that study was limited to urban middle schools. Until adequate funding is available for the mammoth undertaking of examining a representative sample of teaching across the United States, definitive, empirically-based evidence will not be forthcoming. Additionally, if we look for common ground rather than dismiss others' perspectives, we see that there is much to agree on about the use of timed assessments, and the need for students to understand what an operation or other mathematical concept is and does before procedural fluency can be built.

Surprisingly, when we investigated the definition of explicit instruction, there is significant agreement as well. Though the term is not defined in the paper we investigated, Powell et. al (2023) use Hughes et al. (2017) definition: "an instructional design and delivery approach characterized as unambiguous, structured, systematic, and scaffolded" (p. 140). We agree that instructions should be thoughtfully designed and delivered such that it is unambiguous, structured, systematic and scaffolded. However, we do not agree that such qualifications are antithetical to inquiry, problem-based learning, or other student-centered approaches. On the contrary, we believe that such approaches require systems and scaffolds that are not only unambiguous and structured, but also responsive and flexible to individual learning needs. As such, we do not consider many of the activities described as inquiry or problem-based learning to be appropriate examples of such methods. Similarly, we do not believe proponents of the SOM would accept the example of a teacher simply replicating a problem from a textbook and then passing out a worksheet as an appropriate example of explicit or direct instruction. It is simply inappropriate to make conclusions about an instructional strategy based on evidence that does not represent high-quality implementation of the strategy. However, judging the quality of implementation requires a deep understanding of the strategy and its purposes. In other words, it would be beneficial for researchers from different disciplines, theoretical backgrounds, and knowledge traditions to work together to first understand the different perspectives before making conclusions or assessing blame.

It is imperative that as scholars and educators we do our due diligence with all new ideas, examining each critically. The quick adoption of SOR and the speed with which the SOM garnered attention in popular media means that we must consider that it is time to work to improve the image of mathematics and mathematics education outside of our academic institutions and innovative ways in which to do so.

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