RCMOS – Revista Científica Multidisciplinar O Saber. ISSN: 2675-9128. São Paulo-SP.

Ano VII, v.2 2026 | submissão: 25/10/2026 | aceito: 30/10/2026 | publicação: 04/11/2026

O impacto da abordagem de ensino híbrido no desempenho em matemática nos anos iniciais e finais do ensino fundamental

The impact of the hybrid learning approach on mathematics performance in elementary and middle school

El impacto del enfoque de aprendizaje híbrido en el rendimiento en matemáticas en la educación primaria y secundaria

Tulika Samal

RESUMO

O ensino híbrido, também conhecido como blended learning, combina a instrução presencial em sala de aula com atividades de aprendizagem on-line nas quais os estudantes exercem algum controle sobre o tempo, o lugar, o percurso ou o ritmo de estudo. Nas últimas duas décadas, e especialmente após as rupturas provocadas pela pandemia de COVID-19, os arranjos híbridos se difundiram amplamente nas escolas de ensino fundamental dos Estados Unidos. Este artigo examina o impacto da abordagem híbrida sobre o desempenho em matemática de estudantes do jardim de infância ao 8º ano. Do ponto de vista metodológico, trata-se de uma revisão integrativa de literatura, de natureza qualitativa, que sintetiza meta-análises, ensaios controlados randomizados, estudos quase experimentais e dados de avaliações nacionais publicados principalmente entre 2006 e 2023. Os resultados indicam que modelos híbridos bem planejados, sobretudo aqueles que integram softwares adaptativos, sistemas tutores inteligentes e feedback imediato com mediação ativa do professor, tendem a produzir efeitos positivos pequenos a moderados sobre o desempenho em matemática, em comparação com o ensino tradicional isolado. Contudo, as evidências também mostram que o ensino híbrido adotado de forma emergencial durante a pandemia esteve associado a quedas expressivas no desempenho em matemática, especialmente entre estudantes de baixa renda e alunos mais novos. Conclui-se que a eficácia do ensino híbrido depende menos da modalidade em si do que da qualidade do desenho instrucional, da formação docente, da fidelidade de implementação, das habilidades de autorregulação dos estudantes e do acesso equitativo a dispositivos e à conectividade.

Palavras-chave: Ensino híbrido. Blended learning. Desempenho em matemática. Ensino fundamental. Anos finais.

ABSTRACT

Hybrid learning, also known as blended learning, combines face-to-face classroom instruction with online learning activities in which students exercise some control over time, place, path, or pace. Over the past two decades, and especially after the disruptions caused by the COVID-19 pandemic, hybrid arrangements have become widespread in elementary and middle schools across the United States. This article examines the impact of the hybrid learning approach on mathematics performance among students in grades K–8. Methodologically, it is a qualitative, integrative literature review that synthesizes meta-analyses, randomized controlled trials, quasi-experimental studies, and national assessment data published mainly between 2006 and 2023. The findings indicate that well-designed hybrid models, particularly those that integrate adaptive software, intelligent tutoring systems, and immediate feedback with active teacher mediation, tend to produce small to moderate positive effects on mathematics achievement when compared with traditional instruction alone. However, the evidence also shows that hybrid schooling adopted as an emergency response during the pandemic was associated with substantial declines in mathematics performance, particularly among low-income students and younger learners. The effectiveness of hybrid learning therefore depends less on the modality itself than on the quality of instructional design, teacher preparation, implementation fidelity, students' self-regulation skills, and equitable access to devices and connectivity. The article concludes that hybrid learning can be a powerful tool for improving mathematics outcomes in the elementary and middle grades, provided that schools treat it as a deliberate pedagogical model rather

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Ano VII, v.2 2026 | submissão: 25/10/2026 | aceito: 30/10/2026 | publicação: 04/11/2026

than as a simple substitute for in-person teaching.
Keywords: Hybrid learning. Blended learning. Mathematics achievement. Elementary education. Middle school.

1 INTRODUCTION

Mathematics occupies a central place in the elementary and middle school curriculum. The concepts that students build between kindergarten and eighth grade, including number sense, place value, operations with whole numbers and fractions, proportional reasoning, and the foundations of algebra, serve as the basis for virtually all later work in science, technology, engineering, and mathematics. Students who leave middle school without a solid command of these ideas face well-documented obstacles in high school coursework, in postsecondary education, and in the labor market (NATIONAL MATHEMATICS ADVISORY PANEL, 2008). For this reason, any instructional innovation that promises to strengthen mathematics learning in the K–8 years deserves careful and critical examination.

Among the innovations that have gained ground in American schools over the past two decades, hybrid learning stands out for its scale and its visibility. Also referred to as blended learning, the hybrid approach combines teacher-led instruction in a physical classroom with online learning experiences, frequently supported by adaptive software that adjusts tasks to each student's level of performance (STAKER; HORN, 2012). Before 2020, hybrid models were typically adopted by schools and districts that deliberately sought to personalize instruction, such as charter networks, innovation zones, and schools participating in foundation-funded initiatives. With the onset of the COVID-19 pandemic, however, hybrid schedules became a mass phenomenon: during the 2020–2021 school year, millions of students attended school in person on some days and learned remotely on others, often with little preparation on the part of schools, teachers, or families.

This dual history creates an important tension for researchers and practitioners. On the one hand, a growing body of rigorous research suggests that carefully designed hybrid programs can improve mathematics achievement, sometimes substantially, by giving students more practice, more immediate feedback, and more individualized pathways than a single teacher can provide to a class of twenty-five or thirty children (PANE et al., 2014; ROSCHELLE et al., 2016). On the other hand, national data collected after the pandemic show the steepest declines in mathematics performance ever recorded by the National Assessment of Educational Progress (NAEP), and several studies associate those declines with the amount of time that students spent in remote or hybrid schooling (NATIONAL CENTER FOR EDUCATION STATISTICS, 2022; GOLDHABER et al., 2022; JACK

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et al., 2023). The same label, “hybrid learning,” thus describes both a promising pedagogical model and an emergency arrangement associated with significant learning loss.

Against this background, the central question guiding this article is the following: what does the available evidence reveal about the impact of the hybrid learning approach on mathematics performance in elementary and middle school, and under what conditions does this approach tend to succeed or fail? The general objective is to analyze the relationship between hybrid learning and mathematics achievement among students in grades K–8. The specific objectives are (a) to define hybrid learning and describe its main models in K–12 education; (b) to present the theoretical foundations that support hybrid mathematics instruction; (c) to synthesize empirical findings from meta-analyses and large-scale studies; (d) to examine the lessons learned from the COVID-19 period; and (e) to identify the factors that moderate the effectiveness of hybrid approaches in mathematics.

The relevance of this study is both academic and practical. Academically, it seeks to reconcile two strands of research that are often discussed separately: the literature on intentionally designed blended programs and the literature on pandemic-era schooling modes. Practically, school leaders across the United States continue to make decisions about software licenses, device programs, schedule designs, and teacher professional development that will shape how millions of children learn mathematics. Federal pandemic relief funds financed large purchases of digital tools, and districts now face the question of which of these investments are worth sustaining. A clear, evidence-based understanding of when hybrid learning helps and when it harms mathematics performance is therefore essential.

The article is organized in five sections. Following this introduction, Section 2 presents the theoretical framework, including definitions, models, and learning theories relevant to hybrid mathematics instruction. Section 3 describes the methodology adopted. Section 4 presents and discusses the results of the literature review, organized around meta-analytic evidence, large-scale program evaluations, pandemic-era findings, moderating factors, equity concerns, and implications for practice. Finally, Section 5 offers concluding remarks and suggestions for future research.

2 THEORETICAL FRAMEWORK

This section establishes the conceptual basis of the study. It begins by defining hybrid learning and distinguishing it from related terms, then describes the principal models used in elementary and middle schools, discusses the learning theories that help explain why hybrid instruction may affect mathematics achievement, and closes with a brief characterization of mathematics learning in the K–8 years.

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Saber. ISSN: 2675-9128. São Paulo-SP.

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2.1 DEFINING HYBRID AND BLENDED LEARNING

The terms “hybrid learning” and “blended learning” are frequently used interchangeably in the educational literature, and this article follows that convention. Early definitions, developed mainly in the context of higher education, described blended learning in broad terms as the combination of face-to-face instruction with computer-mediated instruction (GRAHAM, 2006). Garrison and Kanuka (2004) proposed a more demanding conception, arguing that genuine blended learning involves the thoughtful integration of classroom experiences with online experiences, rather than the mere addition of technology to an otherwise unchanged course.

In K–12 education, the most influential definition was developed by researchers at the Clayton Christensen Institute (formerly the Innosight Institute). According to Staker and Horn (2012), blended learning is a formal education program in which a student learns at least in part through online delivery of content and instruction, with some element of student control over time, place, path, or pace; at least in part in a supervised brick-and-mortar location away from home; and in such a way that the online and face-to-face components are connected to provide an integrated learning experience. Three elements of this definition deserve emphasis. First, the online component must deliver content and instruction, not merely host assignments or worksheets. Second, the student must exercise some control over the learning process. Third, the modalities must be integrated, meaning that what happens online informs what happens in the classroom and vice versa.

This definition helps distinguish hybrid learning from two neighboring practices. The first is technology-rich instruction, in which teachers use interactive whiteboards, educational videos, or digital worksheets while the entire class proceeds at the same pace and along the same path. Although such practices involve technology, they do not give students meaningful control over their learning and therefore do not constitute hybrid learning in the strict sense. The second is fully remote or online schooling, in which students do not attend a supervised physical location. The hybrid approach occupies an intermediate position, combining the social, relational, and supervisory advantages of the physical school with the flexibility and personalization made possible by digital tools.

The pandemic added a third, more colloquial meaning to the term. In 2020 and 2021, “hybrid” commonly referred to a scheduling arrangement in which students were divided into cohorts that alternated between in-person days and remote days in order to reduce classroom density. This arrangement did not necessarily involve integrated online instruction, student control over pace, or adaptive technology; in many cases, remote days consisted of synchronous video lessons or

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independent assignments with limited teacher interaction. As Section 4 shows, distinguishing between intentional hybrid learning and emergency hybrid scheduling is crucial for interpreting the research on mathematics outcomes.

2.2 MODELS OF HYBRID LEARNING IN K–8 SETTINGS

Staker and Horn (2012) and Christensen, Horn and Staker (2013) proposed a taxonomy that has become the standard reference for classifying hybrid learning in American schools. The taxonomy identifies four main models: the Rotation model, the Flex model, the A La Carte model, and the Enriched Virtual model. The Rotation model is further subdivided into Station Rotation, Lab Rotation, Flipped Classroom, and Individual Rotation. Table 1 summarizes these models and indicates their typical use in elementary and middle schools.

Table 1 – Main models of hybrid learning in K–12 education

Model	Description	Typical use in K–8
Station Rotation	Students rotate within the classroom among stations, at least one of which is online learning; other stations may include small-group instruction and collaborative work.	Very common in elementary grades
Lab Rotation	Students rotate between the classroom and a computer lab where online learning takes place.	Elementary and middle schools
Flipped Classroom	Students access online instruction and content at home; class time is devoted to guided practice and problem solving.	Mainly middle school
Individual Rotation	Each student follows an individualized schedule of modalities set by an algorithm or by the teacher.	Less common; some middle schools
Flex	Online learning is the backbone of instruction; students move on fluid, individually customized schedules with on-site teacher support.	Rare in K–8
A La Carte	Students take one or more entire courses online while attending a physical school for other courses.	Occasional in middle school
Enriched Virtual	Students complete most coursework online and attend required in-person sessions with a teacher.	Rare in K–8

Source: prepared by the author based on Staker and Horn (2012) and Christensen, Horn and Staker (2013).

In the elementary grades, the Station Rotation model is by far the most common. Its popularity stems

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from its compatibility with the self-contained classroom and with the small-group instruction that many elementary teachers already practice in reading and mathematics. In a typical station rotation mathematics block, one group of students works directly with the teacher on a targeted concept, a second group engages in collaborative problem solving or hands-on work with manipulatives, and a third group practices on an adaptive software platform. Students rotate through the stations during the class period, so that every child receives some direct instruction, some peer interaction, and some individualized online practice.

In middle schools, where students typically change classrooms and teachers by subject, a wider variety of models appears. Some schools adopt Lab Rotation, in which students leave the mathematics classroom for a computer lab session; others experiment with the Flipped Classroom, in which students watch short instructional videos at home and devote class time to problem solving and discussion (BERGMANN; SAMS, 2012). A smaller number of schools use Individual Rotation or Flex arrangements, in which each student follows a customized playlist of learning modalities determined by software algorithms and teacher judgment. These models are more disruptive to traditional school organization, because they require flexible use of space, time, and staffing (HORN; STAKER, 2015).

The choice of model has important consequences for mathematics learning. Rotation models preserve a substantial amount of teacher-led instruction and peer interaction, while Flex and Enriched Virtual models shift a larger share of responsibility to the student and to the digital platform. Given that younger learners are still developing the self-regulation skills needed to manage independent work, it is reasonable to expect that models with stronger teacher presence will be more appropriate for elementary students, whereas models with greater autonomy may become feasible as students mature through the middle grades.

2.3 THEORETICAL FOUNDATIONS OF HYBRID MATHEMATICS INSTRUCTION

Several theoretical perspectives help explain why hybrid learning might influence mathematics performance. The first is mastery learning. Bloom (1984) famously reported that students who received one-to-one tutoring combined with mastery learning procedures performed about two standard deviations above students taught in conventional classrooms, a finding he called the “2 sigma problem.” The challenge Bloom posed to educators was to find methods of group instruction that could approach the effectiveness of individual tutoring. Adaptive mathematics software can be understood as one attempt to answer this challenge: by diagnosing each student’s current level,

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presenting tasks of appropriate difficulty, and requiring demonstrated mastery before advancement, such software reproduces some features of individual tutoring at scale. Although no technology has come close to achieving a two-sigma effect in regular classrooms, the mastery principle remains a central rationale for hybrid mathematics programs.

The second perspective is sociocultural theory. Vygotsky (1978) emphasized that learning occurs most productively within the zone of proximal development, the space between what a learner can accomplish independently and what the learner can accomplish with guidance from a more knowledgeable other. From this perspective, the value of hybrid learning lies not in replacing the teacher but in freeing the teacher to work more closely with small groups and individuals at the edge of their understanding. When software handles routine practice and immediate correctness feedback, the teacher can devote more time to questioning, explaining, and scaffolding, which are precisely the interactions that sociocultural theory identifies as essential for conceptual growth.

The third perspective is cognitive load theory. Sweller (1988) demonstrated that problem-solving activities can impose a heavy burden on working memory, especially for novices, and that instructional design should reduce extraneous load so that learners can devote cognitive resources to building schemas. Well-designed digital mathematics environments can support this goal by presenting worked examples, breaking complex problems into manageable steps, and providing hints at the moment of difficulty. Poorly designed environments, by contrast, may increase extraneous load through cluttered interfaces, distracting gamification features, or confusing navigation, thereby undermining learning.

The fourth perspective concerns self-regulated learning. Zimmerman (2002) describes self-regulated learners as individuals who set goals, select strategies, monitor their progress, and reflect on their performance. Hybrid learning places greater demands on these capacities than traditional instruction does, because students must often manage their own progress through online activities. This creates both an opportunity and a risk. Hybrid environments can help students develop self-regulation through dashboards, progress indicators, and goal-setting routines; however, students who lack these skills may disengage, rush through tasks, or engage in behaviors such as guessing and hint abuse that produce the appearance of progress without genuine learning.

Finally, the Technological Pedagogical Content Knowledge (TPACK) framework proposed by Mishra and Koehler (2006) highlights that the effective use of technology in teaching requires the integration of three bodies of knowledge: knowledge of content, knowledge of pedagogy, and knowledge of technology. A teacher implementing a hybrid mathematics model must understand not only the mathematics being taught and the pedagogical strategies appropriate for it, but also how

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particular digital tools represent mathematical ideas, what kinds of data they generate, and how those data can inform instructional decisions. This framework anticipates one of the central findings of the empirical literature: the impact of hybrid learning depends heavily on teacher knowledge and professional preparation.

2.4 THE NATURE OF MATHEMATICS LEARNING IN THE ELEMENTARY AND MIDDLE GRADES

To evaluate the impact of hybrid learning on mathematics performance, it is necessary to clarify what mathematical proficiency entails. The National Research Council (2001), in the influential report Adding It Up, described mathematical proficiency as composed of five intertwined strands: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. These strands develop together and support one another; a student who can execute procedures without understanding them, or who understands concepts but cannot apply them fluently, has not achieved full proficiency.

This multidimensional view has direct implications for the analysis of hybrid learning. Many adaptive mathematics platforms are particularly effective at building procedural fluency, because they can provide large amounts of practice with immediate feedback. Their capacity to develop strategic competence, adaptive reasoning, and productive disposition is less clear. These strands often depend on rich tasks, mathematical discussion, justification of reasoning, and a classroom culture that values effort and sense-making, elements that the National Council of Teachers of Mathematics (2014) identifies as essential to effective teaching. A hybrid model that relies exclusively on software for mathematics learning may therefore improve some dimensions of proficiency while neglecting others.

The K–8 years also encompass important developmental transitions. In the early elementary grades, children build foundational number sense and rely heavily on concrete representations, manipulatives, and verbal interaction with adults. In the upper elementary grades, the curriculum introduces multi-digit multiplication, division, and fractions, the last of which the National Mathematics Advisory Panel (2008) identified as a critical foundation for algebra and a persistent area of difficulty. In the middle grades, students move toward ratio and proportional reasoning, negative numbers, expressions and equations, and early functional thinking, as reflected in the Common Core State Standards for Mathematics adopted by most states (NATIONAL GOVERNORS ASSOCIATION CENTER FOR BEST PRACTICES; COUNCIL OF CHIEF STATE SCHOOL

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OFFICERS, 2010). Each of these stages presents different opportunities and challenges for hybrid instruction, a point to which the discussion returns in Section 4.

3 METHODOLOGY

This study adopts a qualitative approach and is classified, with respect to its objectives, as exploratory and descriptive research. With respect to technical procedures, it is an integrative literature review, a method that allows the combination of empirical and theoretical studies with different designs in order to produce a comprehensive understanding of a phenomenon. The integrative review was chosen because the research question involves heterogeneous forms of evidence, including meta-analyses, randomized controlled trials, quasi-experimental evaluations, descriptive reports, and national assessment data, which would not be adequately captured by a narrower systematic review restricted to a single study design.

The literature was identified through searches in academic databases and repositories commonly used in educational research, including ERIC (Education Resources Information Center), Google Scholar, JSTOR, and the publication archives of research organizations such as the RAND Corporation, the National Bureau of Economic Research, and the Institute of Education Sciences of the U.S. Department of Education. The search combined terms such as “blended learning,” “hybrid learning,” “online learning,” “computer-assisted instruction,” “intelligent tutoring,” “personalized learning,” “mathematics achievement,” “elementary,” “middle school,” and “COVID-19.”

The inclusion criteria were as follows: (a) studies published in English between 2006 and 2023, with the exception of classical theoretical works; (b) studies that addressed hybrid, blended, or technology-supported instruction in mathematics, or that addressed schooling modes during the pandemic; (c) studies focused on K–12 students, with priority given to those involving grades K–8; and (d) studies that reported measures of mathematics performance or offered theoretical contributions directly relevant to the research question. Meta-analyses and syntheses from higher education were included only when they provided context that is useful for interpreting K–12 findings, and this limitation is explicitly acknowledged in the discussion.

The analysis proceeded in three stages. First, the selected studies were read in full and their main characteristics were recorded, including design, population, intervention, and results. Second, the findings were grouped into thematic categories: meta-analytic evidence, large-scale program evaluations, pandemic-era evidence, moderating factors, and equity. Third, the categories were interpreted in light of the theoretical framework presented in Section 2. Because the review is

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interpretive rather than statistical, it does not calculate a new pooled effect size; instead, it reports the effect sizes published by the original authors and discusses their meaning and limitations.

4 RESULTS AND DISCUSSION

This section presents and discusses the main findings of the review. The results are organized into six thematic subsections, moving from the broadest forms of evidence to the most specific implications for schools and policymakers.

4.1 EVIDENCE FROM META-ANALYSES

Meta-analyses provide a useful starting point because they aggregate results across many individual studies. One of the most frequently cited syntheses is the meta-analysis commissioned by the U.S. Department of Education and later published in revised form by Means et al. (2013). The authors found that, on average, students in conditions involving online learning performed modestly better than students receiving face-to-face instruction alone, and that the advantage was considerably larger for blended conditions than for purely online conditions. This pattern has been interpreted as evidence that the combination of modalities, rather than the online component in isolation, is responsible for the gains. Nevertheless, the authors themselves cautioned that relatively few of the included studies involved K–12 students and that blended conditions often provided additional learning time and materials, which may partly explain the observed advantage.

Bernard et al. (2014), in a meta-analysis of blended learning in higher education, likewise reported a moderate positive average effect of blended instruction compared with classroom instruction, with stronger effects when technology was used to support cognitive activities and interaction rather than merely to deliver content. Although this study did not involve elementary or middle school students, it reinforces the principle that the pedagogical function of technology matters more than its mere presence.

Research focused specifically on K–12 mathematics presents a more cautious picture. Cheung and Slavin (2013), in a meta-analysis of educational technology applications for mathematics in K–12 classrooms, found a positive but modest average effect of about 0.15 standard deviations. Importantly, they observed that studies with more rigorous designs, larger samples, and standardized outcome measures tended to report smaller effects than studies with weaker designs, and that programs in which technology was integrated with classroom instruction tended to outperform those in which it

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was used as a supplementary add-on. This finding is especially relevant for hybrid learning, whose defining feature is precisely the integration of online and face-to-face components.

Syntheses of intelligent tutoring systems (ITS), a category of software that often serves as the online component in hybrid mathematics models, report larger effects. Ma et al. (2014) found that ITS produced a moderate advantage over teacher-led large-group instruction, while Kulik and Fletcher (2016) reported a median effect that was considerably larger across the evaluations they reviewed. Both groups of authors noted, however, that effects were smaller when outcomes were measured with standardized tests rather than with tests developed by the researchers, and when the software was compared with other forms of individualized instruction. In a broad review of experimental research in education technology, Escueta et al. (2020) concluded that computer-assisted learning programs, particularly in mathematics, are among the most consistently effective technology interventions, whereas simply providing students with devices or internet access, without accompanying pedagogical changes, generally produces little improvement in achievement.

Taken together, the meta-analytic evidence supports three preliminary conclusions. First, hybrid and technology-supported mathematics instruction tends to produce positive effects on average. Second, these effects are generally small to moderate in rigorous K–12 studies, not transformational. Third, the size of the effect depends strongly on how technology is integrated into instruction, a theme that recurs throughout this review. To put the magnitude of these effects in perspective, Hattie (2009) argued that many educational interventions produce some positive effect and suggested that effects around 0.40 standard deviations represent a meaningful threshold for judging influences as particularly worthwhile. By this criterion, the average effect of educational technology in K–12 mathematics is positive but falls below the level that would justify treating it as a solution in itself.

4.2 EVIDENCE FROM LARGE-SCALE STUDIES OF HYBRID MATHEMATICS PROGRAMS

Beyond meta-analyses, several large-scale studies conducted in the United States offer detailed evidence about specific hybrid mathematics programs. Table 2 summarizes the main studies discussed in this subsection.

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RCMOS – Revista Científica Multidisciplinar O Saber. ISSN: 2675-9128. São Paulo-SP.

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Table 2 – Selected studies on hybrid and technology-supported mathematics instruction

Study	Design and context	Main finding
Pane et al. (2014)	Randomized trial of Cognitive Tutor Algebra I in middle and high schools in seven states	No effect in year one; positive effect of about 0.2 SD in high school in year two; no significant effect in middle school
Roschelle et al. (2016)	Randomized trial of ASSISTments online homework with seventh graders in Maine	Positive effect of about 0.18 SD, larger for students with lower prior achievement
Pane et al. (2015; 2017)	Quasi-experimental studies of personalized learning schools using hybrid models	Positive mathematics gains, but smaller and more variable in the larger later sample
Muralidharan, Singh and Ganimian (2019)	Randomized trial of adaptive software with instructional support for middle school students in India	Large gains in mathematics in less than five months, especially for students far behind grade level
Goldhaber et al. (2022); Jack et al. (2023)	Analyses of pandemic-era test data across schooling modes in the United States	Larger mathematics declines with more remote or hybrid instruction, concentrated in high-poverty districts

Source: prepared by the author based on the cited studies (2026).

Pane et al. (2014) conducted one of the largest randomized evaluations of a blended mathematics curriculum, studying Cognitive Tutor Algebra I across more than 140 schools in seven states. The curriculum combined textbook-based classroom instruction with sessions on intelligent tutoring software. The researchers found no significant effects in the first year of implementation, but in the second year high school students in the treatment group outperformed their peers by approximately one-fifth of a standard deviation, an effect large enough to move an average student from the 50th to roughly the 58th percentile. In middle schools, the effects were not statistically significant. The authors attributed the delayed effect in high schools to the time teachers needed to adapt their practice to the new model, an interpretation that underscores the importance of implementation maturity. The absence of significant effects in middle school is a reminder that results obtained with older students cannot simply be generalized to younger ones.

Roschelle et al. (2016) evaluated ASSISTments, an online platform that provides students with immediate feedback on mathematics homework and gives teachers detailed reports on student performance. In a randomized controlled trial involving seventh-grade students in Maine, schools assigned to the platform achieved significantly higher end-of-year mathematics scores than control schools, with an effect of approximately 0.18 standard deviations. The effect was larger for students with lower prior achievement, suggesting that the intervention helped to narrow achievement gaps. A

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distinctive feature of ASSISTments is that it does not replace classroom instruction; instead, it strengthens the connection between independent practice and teacher decision-making, because teachers review the data and use them to plan instruction for the following day. In this sense, ASSISTments exemplifies the integrative principle emphasized by Staker and Horn (2012).

The RAND Corporation also conducted a series of studies of schools implementing personalized learning, most of which relied on hybrid models. Pane et al. (2015) found that students in these schools made significantly greater gains in mathematics than comparable students nationally, with a cumulative effect over two years of roughly one-quarter of a standard deviation. A subsequent report with a larger sample, however, found smaller and more variable effects, and noted that many schools implemented personalized learning practices only partially (PANE et al., 2017). This variation suggests that the label “personalized” or “hybrid” can mask substantial differences in actual practice.

International evidence adds further perspective. Muralidharan, Singh and Ganimian (2019) evaluated a technology-aided after-school program in India that combined adaptive software with small-group instructional support. Middle school students who attended the program achieved large gains in mathematics over a period of less than five months. The authors highlighted that the software was particularly beneficial for students who were far behind grade level, because it identified and addressed their actual level of knowledge rather than the level assumed by the grade-level curriculum. Although this context differs substantially from that of American schools, the finding reinforces the potential of adaptive hybrid models to address wide within-class variation in mathematics readiness, a problem that American teachers also face.

The large-scale evidence therefore confirms the pattern suggested by the meta-analyses. Hybrid mathematics programs can produce meaningful gains, and in some cases these gains are concentrated among lower-achieving students. However, effects are rarely immediate, vary considerably across schools, and appear to depend on the degree to which the online and face-to-face components are genuinely connected through teacher use of data and targeted instruction.

4.3 LESSONS FROM THE COVID-19 PANDEMIC

The COVID-19 pandemic created an unplanned natural experiment in which schools across the United States adopted in-person, hybrid, and fully remote modes of instruction for extended periods. The consequences for mathematics performance were severe. In 2022, the NAEP mathematics assessment recorded a decline of five points among fourth-grade students and eight points among eighth-grade students compared with 2019, the largest decreases in the history of the assessment in

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that subject (NATIONAL CENTER FOR EDUCATION STATISTICS, 2022). Declines were observed across nearly all states and demographic groups, but students performing at the lower end of the distribution experienced particularly steep drops.

Researchers had anticipated that mathematics would be especially vulnerable. Kuhfeld et al. (2020), projecting the effects of school closures on the basis of prior research on summer learning loss and absenteeism, estimated that students would return to school with substantially smaller gains in mathematics than in reading. Studies conducted in other countries confirmed the pattern: Engzell, Frey and Verhagen (2021), analyzing national assessment data from the Netherlands, a country with high levels of broadband access and a relatively short closure period, found measurable learning losses, with larger losses among students from less-educated households.

Of particular relevance to this article are studies that compared outcomes across schooling modes. Goldhaber et al. (2022), using test data from millions of students in multiple states, found that students in districts that remained remote for longer periods experienced larger declines in mathematics achievement, and that hybrid instruction was associated with losses that were generally intermediate between those of fully remote and fully in-person instruction. They also found that the negative consequences of remote instruction were concentrated in high-poverty schools, thereby widening existing achievement gaps. Jack et al. (2023), examining state test results from districts across the United States, similarly reported that declines in pass rates were larger in districts with less in-person instruction during the 2020–2021 school year, with stronger effects in mathematics than in English language arts and in districts serving larger proportions of low-income and minority students.

At first glance, these findings appear to contradict the positive evidence presented in the previous subsections. The contradiction dissolves, however, once the distinction drawn in Section 2.1 is taken into account. Pandemic hybrid learning was, in most cases, a scheduling arrangement adopted under crisis conditions, not an intentional pedagogical model. Teachers typically received little preparation; curricula were not redesigned for integration; many students lacked reliable devices or connectivity; remote days often involved reduced instructional time; and students, families, and teachers faced extraordinary stress and disruption. None of the features that the research associates with effective hybrid learning, such as adaptive practice tightly connected to teacher-led small-group instruction, was systematically present.

Reich (2020), writing about the history of educational technology, argued that new technologies tend to be absorbed into existing institutional routines rather than transforming them, and that technology alone rarely changes educational outcomes without corresponding changes in pedagogy, organization, and support. The pandemic experience provides a striking illustration of this argument.

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The mere availability of online tools did not produce effective hybrid learning; on the contrary, when those tools were used as an emergency substitute for in-person teaching, mathematics performance declined. The lesson for schools is not that hybrid learning is ineffective, but that the effectiveness of any hybrid model depends on intentional design, adequate time for implementation, and sufficient human support.

4.4 FACTORS THAT MODERATE EFFECTIVENESS

The reviewed studies converge on a set of factors that moderate the impact of hybrid learning on mathematics performance. The first and perhaps most important is the role of the teacher. In the most successful programs, teachers do not step aside while students work on computers; rather, they use the data generated by digital platforms to identify misconceptions, form flexible groups, and plan targeted instruction. The ASSISTments study illustrates this mechanism clearly (ROSCHELLE et al., 2016). Conversely, when software is used as an isolated activity disconnected from classroom teaching, its effects tend to be weaker (CHEUNG; SLAVIN, 2013). The TPACK framework (MISHRA; KOEHLER, 2006) explains why: effective integration requires teachers to combine knowledge of mathematics, pedagogy, and technology, and this combination must be developed through sustained professional learning.

The second factor is implementation fidelity and maturity. Pane et al. (2014) observed effects only in the second year of implementation, and later RAND reports documented wide variation in how thoroughly schools implemented personalized learning practices (PANE et al., 2017). Hybrid models require changes in routines, classroom management, scheduling, and assessment, and these changes take time. Evaluations conducted during the first months of implementation may therefore underestimate the potential of well-established hybrid programs, while decisions to abandon a program after a single year may discard an intervention before it has had a fair opportunity to work.

The third factor is student age and self-regulation. As discussed in Section 2.3, hybrid learning places significant demands on students' capacity to manage their own learning (ZIMMERMAN, 2002). Younger elementary students generally require more structure, more adult interaction, and more concrete experiences than older students, and pandemic-era research suggests that remote and hybrid schooling was particularly difficult for them. At the same time, the middle school null results reported by Pane et al. (2014) caution against assuming that older students automatically benefit more. What seems to matter is the alignment between the degree of autonomy demanded by the model and the self-regulatory capacity of the learners, together with explicit support for the development of that

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capacity.

The fourth factor is the design quality of the digital content. Cognitive load theory predicts that interfaces cluttered with distracting elements, or tasks that present too much information at once, will hinder learning (SWELLER, 1988). Research on intelligent tutoring suggests that features such as step-by-step feedback, well-sequenced problems, and worked examples contribute to effectiveness (KULIK; FLETCHER, 2016). Moreover, platforms differ considerably in how they represent mathematics. Some emphasize rapid procedural practice, while others incorporate visual models, number lines, and tasks that require explanation. Given the multidimensional nature of mathematical proficiency described by the National Research Council (2001), schools should evaluate whether the digital component of a hybrid model supports conceptual understanding and reasoning, and not only procedural fluency.

The fifth factor is the balance between online and face-to-face time. Hybrid learning is not synonymous with maximizing screen time. The evidence reviewed here suggests that the most effective models allocate a meaningful but bounded portion of mathematics time to adaptive online work, while preserving substantial time for teacher-led instruction, collaborative problem solving, and mathematical discourse. This balance aligns with the National Council of Teachers of Mathematics (2014), which calls for tasks that promote reasoning and problem solving, meaningful mathematical discussion, and the use of multiple representations, practices that depend heavily on human interaction.

4.5 EQUITY AND ACCESS

Equity is a transversal concern in the literature on hybrid learning. On the positive side, several studies suggest that well-designed hybrid mathematics programs can benefit lower-achieving students disproportionately. Roschelle et al. (2016) found larger effects for students with lower prior achievement, and Muralidharan, Singh and Ganimian (2019) reported that adaptive software was particularly valuable for students who were far behind grade level. These findings suggest that personalization can help teachers address the wide range of readiness levels found in typical classrooms, a challenge that is especially acute in schools serving disadvantaged communities.

On the negative side, hybrid learning depends on access to devices, reliable internet connectivity, and a supportive environment for independent work, resources that are unequally distributed across American households. Even before the pandemic, a significant share of teenagers reported being unable to complete homework at least sometimes because of a lack of reliable internet access, a

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phenomenon often called the “homework gap,” which disproportionately affected lower-income, Black, and Hispanic students (ANDERSON; PERRIN, 2018). During the pandemic, these disparities became more consequential, and the evidence reviewed in Section 4.3 shows that remote and hybrid schooling produced the largest mathematics losses in high-poverty schools (GOLDHABER et al., 2022; JACK et al., 2023).

The equity implications of hybrid learning therefore depend on where the online component takes place and how it is supported. Models in which online work occurs primarily at school, under teacher supervision and with school-provided devices, such as Station Rotation and Lab Rotation, are less dependent on home resources than models that rely heavily on work completed at home, such as the Flipped Classroom or the Enriched Virtual model. For elementary and middle schools serving low-income communities, this consideration should weigh heavily in the choice of model. Furthermore, schools must consider students with disabilities and English language learners, who may require specific accommodations, accessible interfaces, and additional teacher support to benefit from digital mathematics tools.

4.6 IMPLICATIONS FOR PRACTICE AND POLICY

The findings of this review lead to several practical implications for teachers, school leaders, and policymakers. First, hybrid learning should be adopted as a deliberate instructional model with clear goals, not as a scheduling solution or as a way to reduce the need for teachers. Schools should define which dimensions of mathematical proficiency the online component is expected to strengthen and how its data will inform classroom instruction.

Second, investment in professional development should accompany investment in technology. Teachers need opportunities to learn how to interpret platform data, organize rotations, manage small-group instruction, and select digital tasks that align with the curriculum. Professional learning is most effective when it is sustained, content-specific, and collaborative, rather than limited to one-time training on software features. The broader research on the science of learning and development also emphasizes that supportive relationships and learning environments are essential to academic growth (DARLING-HAMMOND et al., 2020), which reinforces the central role of teachers in any hybrid model.

Third, school leaders should allow sufficient time for implementation and evaluate programs with appropriate measures. Given that effects may emerge only in the second year (PANE et al., 2014), decisions about continuing or discontinuing a hybrid program should be based on multi-year data and

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on evidence of implementation quality, not solely on first-year test scores. Districts can strengthen these decisions by piloting programs in a subset of schools, collecting comparison data, and consulting independent evaluations, such as those catalogued by the What Works Clearinghouse of the Institute of Education Sciences.

Fourth, policymakers should address the infrastructure and equity conditions on which hybrid learning depends. Ensuring that every student has access to a suitable device and reliable connectivity is a necessary, though not sufficient, condition for equitable hybrid learning. As Escueta et al. (2020) observed, access to technology alone does not raise achievement; it must be combined with effective instructional programs and support.

Fifth, the choice of hybrid model should be sensitive to grade level. For the early elementary grades, models that preserve a strong teacher presence, abundant hands-on work with concrete materials, and limited, well-structured online practice appear most appropriate. For the upper elementary and middle grades, schools may gradually introduce greater student autonomy, provided that they explicitly teach self-regulation strategies and monitor engagement closely. In all grades, online practice should complement, rather than replace, rich mathematical tasks and discussion.

5 FINAL CONSIDERATIONS

This article set out to examine the impact of the hybrid learning approach on mathematics performance in elementary and middle school. Through an integrative review of theoretical and empirical literature, it sought to reconcile two bodies of evidence that appear, at first, to point in opposite directions: research on intentionally designed blended mathematics programs, which generally reports positive effects, and research on schooling during the COVID-19 pandemic, which documents severe declines in mathematics achievement associated with remote and hybrid arrangements.

The review allows the research question to be answered in the following terms. When hybrid learning is implemented as a deliberate pedagogical model, integrating adaptive online practice with teacher-led instruction and using data to guide targeted support, it tends to produce small to moderate positive effects on mathematics achievement in the K–8 grades, with some programs showing especially promising results for lower-achieving students. When hybrid learning is adopted as an emergency scheduling arrangement, without instructional redesign, teacher preparation, or equitable access to resources, it is associated with significant learning losses, particularly among low-income students. The modality itself is therefore not the decisive variable. What determines the impact of hybrid

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learning on mathematics performance is the quality of its design and implementation.

The specific objectives of the study were also achieved. The article defined hybrid learning and distinguished it from related practices; described the principal models used in K–8 settings; presented theoretical foundations drawn from mastery learning, sociocultural theory, cognitive load theory, self-regulated learning, and the TPACK framework; synthesized evidence from meta-analyses and large-scale studies; examined the lessons of the pandemic period; and identified the main moderating factors, namely the role of the teacher, implementation fidelity and maturity, student age and self-regulation, the design quality of digital content, the balance between online and face-to-face time, and equitable access.

This study has limitations that should be acknowledged. As an integrative literature review, it does not produce new empirical data or a new pooled effect estimate. Much of the meta-analytic evidence on blended learning comes from higher education, and relatively few rigorous studies focus specifically on the early elementary grades. In addition, the rapid evolution of educational technology, including the emergence of artificial intelligence tools capable of generating explanations and tutoring dialogue, means that the software evaluated in many of the reviewed studies differs considerably from the tools now available to schools.

These limitations point to directions for future research. There is a need for rigorous, long-term studies of hybrid mathematics models in grades K–5, for research that examines outcomes beyond standardized test scores, such as conceptual understanding, reasoning, and mathematical disposition, and for studies that investigate how the new generation of AI-based tutoring tools can be integrated into classroom practice without displacing the human relationships that remain at the heart of learning. Research that follows the post-pandemic recovery will also be valuable in determining whether the digital infrastructure built during the crisis can be converted into intentional, effective hybrid learning.

In conclusion, hybrid learning should neither be celebrated as a technological solution to the challenges of mathematics education nor dismissed on the basis of the pandemic experience. It is best understood as a set of instructional possibilities whose value depends on the professional judgment of teachers, the quality of the tools they use, the support provided by schools and policymakers, and the attention given to equity. When these conditions are in place, the hybrid approach can help realize an old aspiration of education: to give every child the time, feedback, and support needed to master mathematics.

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