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Post-Pandemic Mathematical Learning Recovery: A Narrative Review of Targeted Intervention Strategies in United States Secondary Education

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ABSTRACT: The COVID-19 pandemic left the United States with the mathematics learning crisis of a generation, in which deficits in mathematics learning by secondary students corresponded to the loss of multiple months of learning, and were most severe for low-income, Black, Hispanic, and Native American students. These losses have since been well studied, but the recovery literature presents pedagogy, sociodemographic inequality, and data-driven monitoring as distinct fields, with an increasing number of 'catch-up' programs each time, which are invariably weakened by the very structures that they did not consider. This narrative review presents a unifying thesis: mathematical recovery after the pandemic is a single coordination problem that can only be solved by working with the inequalities it aims to offset and the predictive processes for assessing its impact. The review begins by establishing the empirical scale and sociodemographic patterning of pandemic-era learning loss; it shows that there is no one-size-fits-all approach to catch-up that will equalize the harms that have been unevenly distributed. It then considers the current generation of pedagogical interventions (adaptive personalization, AI-enhanced platforms and small-group instructional models), and how their demonstrated advantages for lower-performing students are indistinguishable from access conditions that differentiate who gets which and who does not. Next, the review considers the structural filters that influence the effectiveness of interventions: socioeconomic status, racial inequality, and digital access, as they are not background factors, but rather critical factors shaping the chance of any pedagogical approach reaching the students it was designed to serve. The review then rates diagnostic assessment and predictive modeling, not as tools to be used in conjunction with instruction, but as coordinating tools that enable schools to determine who, in the aggregate, is underperforming and to focus interventions on these disparities while continually adjusting dosage. Lastly, the review identifies methodological gaps, the ethical dangers of algorithmic bias and data privacy, and the multi-level policy levers by which districts will need to coordinate integrated diagnostic-pedagogical architectures to support equitable continuity of recovery response, suggesting that a lack of consideration for equity in a way will be a lack of concern for how to improve teaching and learning.

KEYWORDS: post-pandemic learning recovery, secondary mathematics education, adaptive learning; educational equity, artificial intelligence in education, small-group instruction, predictive modelling.

1.0 INTRODUCTION

The COVID-19 pandemic triggered unprecedented disruptions in secondary mathematics education, with students experiencing learning losses equivalent to three to four months of typical academic growth (Çevikbaş & Kaiser, 2022). This impact is especially acute in secondary mathematics, where the transition to abstract algebraic reasoning was severely interrupted (Bettauser et al., 2023). The compounded effects of fragmented instruction and entrenched socioeconomic disparities have widened achievement gaps in critical STEM pathways. Addressing these challenges requires moving beyond generic remediation toward evidence-based, equity-centered instructional reforms that integrate pedagogical innovation with technological advancement. This review synthesizes recent literature to explore how accelerated learning models and personalized instructional technologies can restore conceptual fluency among disadvantaged secondary learners (AMIR & ANSARI, 2026). It also highlights the disconnect between quantitative literacy research focused on higher education and the pressing needs within K-12 secondary contexts (Grawe, 2022). To develop effective recovery strategies, it is vital to first understand the historical context and current academic impacts of the pandemic on mathematics proficiency.

The impact of the 2019-2020 school disruptions remains; data for mathematics performance in early adolescence, at the U.S national level, show that performance has dipped to multi-decade lows, as students suddenly moved to under-prepared remote learning environments (Asogwa et al., 2023). This deep achievement loss is still apparent years after closure began and serves as a reminder that a one-size-fits-all approach to classroom recovery simply does not work for complex and multi-layered numeracy gaps. Furthermore, evidence suggests that social inequalities are worsening and that the use of remedial activities as a universal approach is not working well enough to decrease the growing gap in secondary mathematics relative to subjects that are based in literacy. It has been found that marginalized student groups, especially those from families with a low level of education, saw their performance drop by almost 60 per cent compared with their peers, requiring a shift towards higher-level interventions on a one-to-one basis (Donnelly & Patrinos, 2021). To "close the gap" on these systemic inequities, there has been a development of a promising framework to adapt to individual student skills: Equity-Centered Adaptive Learning. There has been a development of a promising framework for adapting individual student skills to “close the gap” on these systemic inequities: Equity-Centered Adaptive Learning. These platforms implement cutting-edge algorithmic architectures, enabling tailored learning journeys to suit individual cognitive abilities and different prerequisite knowledge sets among today's learners (Dagunduro et al., 2024). These digital tools do have great potential, but they must be integrated into the classroom curriculum, which requires teacher professional development to ensure effective use and usage; otherwise, there are disparities in the use of the digital tools (Arhimah & Cudjoe-Mensah, 2025). Awareness of these systemic issues leads to an exploration of specific pedagogical and technological interventions for addressing learning losses.

2.0. PEDAGOGICAL CATCH-UP STRATEGIES

With such stratified mathematics loss comes the natural question: What instructional strategies have been proven to drive mathematics recovery, and what conditions are in place for the impact of these strategies? Over the past few years, however, multifaceted pedagogical approaches have become a focus, with cognitive and social factors of learning gaps being central: problem-based interactive learning, individual learning pathways supported by high-dosage tutoring and extended learning opportunities through summer academic camps, which are difficult to recover in schools (Asogwa et al., 2023; Betthäuser et al., 2023; Carbonari et al., 2024). Of these, AI-based personalized learning pathways have received special attention, as the ability to customize learning content and pacing to individual learners' paths has been linked to lower-order knowledge gaps and improvements in mathematics achievement on the order of 0.42 standard deviations compared to traditional instruction (Chen, 2025). The latter – that is, the negative effect of school closures – has been buffered by intelligent tutoring systems which have been demonstrated to encourage students to practice personalized and continuous practice during time-outs of in-person learning, and to benefit struggling students (Madaan et al., 2025), and adaptive systems such as AIDA or iTalk2Learn are shown to give incremental guidance, identifying and remediating misconceptions as they emerge and preventing them from becoming permanent gaps in student knowledge.

These gains, however, do not arrive in a vacuum. Pedagogical personalization, high-dosage tutoring, and AI-driven adaptation each presuppose a stable instructional environment, a meaningful degree of learner agency, and responsive feedback loops; whatever benefits these designs have demonstrated in efficacy trials are therefore conditioned on a prior question that instructional design alone does not answer — whether the students for whom these models were designed actually receive them (Hannan & Eynon, 2025). Once stated, this question immediately redirects attention from the internal architecture of the strategy to the delivery architecture: the digital infrastructure, the classroom configuration, and the professional capacity through which a strategy either reaches its intended student or fails to do so. It is to those delivery architectures that the next section turns.

3. DIGITAL MATH TOOL INTEGRATION AND SMALL GROUP INSTRUCTIONAL MODELS

The pedagogical strategies of the previous section will only reach students in the concrete context in which they are taught in secondary classrooms, and in practice, a lot of the possibilities of the recovery program have been reduced. Two different logics have to be aligned to use digital tools for mathematics learning: Dynamic visualization environments that allow students to ask questions and make sense of concepts based on Vygotsky's "Zone of Proximal Development (ZPD)", and intelligent scaffolding systems that are able to provide formative assessment and offer personalized learning experiences on the fly (Akçay & Çilingir, 2025). There are structural relationships between both logics, with the relationship between device access, broadband connections, and the interpretation and utilization of the signals generated by these tools being unevenly distributed until now across school districts in the United States (Dwivedi et al., 2024).

Small group instructional models provide an alternative delivery architecture when digital tools are unavailable or not functioning to provide adaptive software for managing P2P discourse to translate individual performance data to target and time intervention. In small groups models, the teacher adopts a new role as a facilitator of collaborative sense making, shifting from the role of total mathematical authority to one in which the teacher collaborates with students, generating mathematical ideas. These models align with conceptual practices that have been found to be a central part of high-quality mathematical competence (Lee & Paul, 2023; Madaan et al., 2025). There are also a number of small group models that make assumptions about how instructional time is allocated to provide instruction in small groups, the training of teachers to facilitate small group instruction, and the flexibility of structuring the curriculum to provide instruction in small groups that are not necessarily homogeneous, all of which rely on the same set of structural variables that are being studied next (Costello et al., 2023; Hannan & Eynon, 2025). So, what about the students for whom the pedagogical possibility with delivery architectures is a reality?

4.0. EQUITY CONSIDERATIONS: SOCIODEMOGRAPHIC DISPARITIES AND TECHNOLOGY ACCESS

Achievement gaps are deeply rooted in socioeconomic and racial disparities, with the digital divide limiting access to high-quality instruction and adaptive technologies in marginalized communities (Tang, 2025). Addressing these systemic disparities requires a strategic redistribution of resources to ensure that underserved student populations benefit from adaptive, technology-enhanced pedagogical frameworks that extend beyond basic connectivity (Engelbrecht et al., 2023).

Furthermore, to close the achievement gap, designing an inclusive environment means that students need language interactional resources to explain their thinking and participate in productive mathematical conversations. The evidence indicates that developing these scaffolds within the community is a critical component to reducing the impact of ongoing challenges including inequitable access to digital tools and workload pressures that disproportionately impact student persistence in mathematics (A, 2025). Educational recovery, therefore, requires that school districts consider how to incorporate pedagogical practices like the flipped classroom, and establish structured feedback loops that can help to remove obstacles to learning and strengthen students' sense of self-efficacy.

Beyond organizational shifts, leveraging artificial intelligence offers transformative potential to address mathematics anxiety by enhancing students' internal sense of competence and control (Gabriel et al., 2025). However, developers must proactively mitigate algorithmic biases and ensure data privacy to prevent the replication of existing socioeconomic disparities in these automated learning environments (Luzano, 2025). Comprehensive professional development is essential to equip teachers to balance human judgment with data-driven insights, ensuring equitable implementation (Çevikbaş & Kaiser, 2022). These equity challenges underscore the importance of data-driven educational interventions supported by transparent and ethical predictive modeling.

5.0. DATA-DRIVEN EDUCATIONAL INTERVENTIONS AND PREDICTIVE MODELING

Modern pedagogical frameworks are increasingly pivoting toward assessment systems that utilize formative data to tailor instruction in real time, moving beyond traditional summative metrics that fail to capture individual student growth. By integrating predictive analytics and AI-driven diagnostic tools, educators can identify specific misconceptions early, allowing for precise and targeted scaffolding to support learners who have historically been underserved by static curricula (Roshanaei et al., 2023). These adaptive platforms should be implemented in conjunction with comprehensive pedagogical training to ensure that digital interventions emphasize conceptual understanding over problem-solving efficiency (Arhimah & Cudjoe-Mensah, 2025).

Indeed, the efficacy of these technological implementations depends heavily on the collaborative integration of digital tools with human-centric instructional strategies. Proactive measures, such as comprehensive digital literacy training and community-based Internet access points, are essential to ensure that these sophisticated tools do not unintentionally widen the achievement gap (Nang et al., 2024). Therefore, policy initiatives must prioritize funding for infrastructure while establishing standards that promote digital equity, ensuring that technology acts as a bridge rather than a barrier to academic inclusion. These technological and ethical considerations inform critical policy decisions necessary for sustainable educational transformation.

6.0. SMALL GROUP INSTRUCTIONAL MODELS

Small group instructional models have emerged as critical pedagogical interventions to address the heterogeneous learning gaps exacerbated by pandemic-era disruptions. These collaborative configurations leverage peer-to-peer discourse to move instruction away from rote rule-following toward active sense-making, a transition that is essential for cultivating mathematical proficiency (Bowers et al., 2023). By shifting the classroom dynamic from passive reception to collaborative inquiry, these models provide a structural framework for students to articulate their reasoning and critique their peers' arguments, directly aligning with the core mathematical practices required for high-level competency.

Further, these models enable the strategic implementation of adaptive learning software in microenvironments, empowering teachers to offer personalized interventions based on students' performance data (Redmond-Sanogo et al., 2025). This entices a redefinition of the teacher authority as facilitator of collaborative sense-making, and not as the sole source of truth (Canonigo, 2025). The changing landscape requires teachers to develop new skills including how to operate in blended settings where AI tools work side-by-side with human teaching, (Jita et al., 2025). Co-construction and collaborative learning belong to this category, especially collaborative learning and project-based learning that allows students to work together to build their knowledge and solve real-world problems together. This transformation of the classroom into a place where "productive discourse" is occurring combines the use of new technologies with student interaction, thereby focusing student interactions and learning on the generation of sustainable and peer supported knowledge of mathematics.

Moreover, intelligent applications of intelligent agents and chatbots can help support these collaborative efforts with the appropriate just-in-time guidance to ensure that the students, with their complex problem-solving, get personalized feedback. These areas can be structured to foster independent and collaborative learning, thus allowing for deeper and more shared understanding of mathematical concepts and content, rather than just procedural fluency (Cohen et al., 2024). These spaces foster a culture of asking questions and frequently involve students in owning mathematical ideas rather than merely following a mathematical course of study, making the classroom a site of sense-making and exploration. Empirical data collected in recent years indicates that a virtual AI-generated peer can further stimulate students to create viable arguments and persist with complex problems in such collaborative environments (Yue et al., 2024). The movement towards this shift promotes a sense-making and collaborative process where students do not merely take on a role but actively engage in reflecting on the experts' actions, as well as with the various cognitive demands of today's mathematics curriculum.

7.0. SOCIOECONOMIC STATUS AND PERFORMANCE

There are deep-seated links between home income, living location, and mathematical ability that indicate that standardized interventions frequently do not consider the distinctive systems that limit access for marginalized groups of students. Structural inequities and post-pandemic disruptions are also found to drive achievement gaps even further, often by more than 1.8 standard deviations, by socioeconomic and disability status groups (Huang et al., 2025), as evidenced by longitudinal analyses. The digital divide is exacerbating these gaps as students in under-resourced communities may not have the equipment or high-speed Internet connections needed to access advanced digital tools for remediation.

Furthermore, these systemic barriers are exacerbated by not having affect-aware support, which leads to increased mathematics anxiety and a lack of tools to close the achievement gap that increases the difficulty of cognitive problem-solving tasks (Polydoros et al., 2026). Schools need to adopt pedagogies that are flexible and adapt to the situation, involving strategic interventions that incorporate artificial intelligence to foster academic resilience and cognitive self-regulation (Polydoros et al., 2025). Such interventions need to be more than just quantitative; high-SES students may also have access to a combination of external private support systems that are not as likely to be available for their low-income counterparts (Lee & Albert, 2026). As a result, current interventions need to focus on a more holistic model that includes non-cognitive components, acknowledging that mathematical success is not only about performance, but also about how opportunity structures in the outside world affect it. This calls for future policies that support equitable resource allocation and are data-driven to meaningfully reduce the deep socioeconomic status (SES) achievement gap (Huang et al., 2025).

8.0. RACIAL ACHIEVEMENT GAP TRENDS

Systemic disparities in mathematical attainment are deeply stratified by racial identity, reflecting historical patterns of inequity that persist despite contemporary reform efforts. These persistent divides are frequently reinforced by entrenched institutional biases and a lack of equitable access to high-quality academic support, which disproportionately disadvantages minoritized student populations (Otero et al., 2024). These structural impediments are further compounded by negative stereotyping and institutional expectations of lower academic performance, which actively undermine the self-confidence and longitudinal growth of students from marginalized backgrounds.

In addition, schools with a high concentration of Black, Hispanic, and Native American students show that academic achievement is attainable where institutional barriers are addressed with targeted support strategies that are specifically designed to reverse environmental inequities (Yang et al., 2024). More specifically, empirical research with the 2025 graduating class suggests intentional efforts to improve teacher education and strict adherence to culturally responsive pedagogy (CRP) is needed to address these systemic barriers (Etheridge, 2026). Beyond this, although some interventions (e.g., accelerated course placement) yield modest gains, they tend to yield smaller gains for Black and Hispanic students, underscoring the need for structural policy change rather than a single course path (Etheridge, 2026).

Prioritizing systemic change acknowledges that post-COVID-19 declines in math achievement, which have persisted into late secondary education, cannot be rectified by individual course-taking adjustments (Kuhfeld et al., 2025). Instead, initiatives must address the underlying "opportunity to learn" frameworks comprising both structural tracking and the quality of instructional experiences that continue to gatekeep advanced mathematics coursework from historically marginalized student populations (Franks & McGlamery, 2021). In particular, the disproportionate underrepresentation of Black and Hispanic students in gateway mathematics courses, such as Algebra I by the ninth-grade year, serves as a primary driver of long-term achievement deficits (Park et al., 2025). This institutional sorting often relies on deficit-based assumptions that conflate linguistic diversity or racial identity with lower mathematical aptitude, effectively channeling students into remedial tracks that emphasize rote memorization over conceptual discourse (Kitchen et al., 2021). By replacing these deficit-oriented frameworks with pedagogies that frame students as "abundantly mathematical," educators can disrupt the construction of harmful personhood narratives that currently govern school-based mathematical outcomes (Dahlgren, 2024). Transitioning toward such inclusive environments requires dismantling rigid tracking systems, as research demonstrates that heterogeneous classrooms organized around equitable instruction can yield significant achievement gains while simultaneously narrowing disparities between ethnic subgroups (Boaler & Staples, 2008).

9.0. EQUITABLE TECHNOLOGY ACCESS

The digital divide remains a significant barrier to mathematical equity, as students in marginalized communities frequently contend with unequal access to high-quality instructional materials and essential connectivity (Thomas & Larwin, 2023). This technological stratification persists even when schools provide baseline digital resources, as systemic discrimination frequently limits access to advanced coursework or personalized tutoring that high-SES students leverage to augment their learning (Castle et al., 2024).

To bridge this divide, schools must transcend basic hardware provisioning by ensuring that all students have equitable access to experienced educators and rigorous curricula that foster conceptual development rather than passive digital consumption (Thomas et al., 2024). Policy frameworks must move toward sustainable models that integrate high-quality, equity-directed instructional tools into the standard curriculum, ensuring that technological deployment serves as a catalyst for deeper engagement rather than a surrogate for expert teaching. Ultimately, addressing these inequities necessitates a transition away from resource-deprivation models, which unfairly locate the impetus for success within the student, toward systemic equity approaches that target institutional barriers limiting postsecondary transitions (Remillard et al., 2017). To facilitate this shift, schools must replace exclusionary ability grouping with inclusive pedagogical models that foster a growth mindset across all student populations (Alam & Mohanty, 2023).

10.0. FUTURE RESEARCH AND GAPS

Despite the promise of these technological advancements, significant empirical lacunae remain regarding the long-term impacts of algorithmic intervention on student agency and the mitigation of inherent systemic biases within predictive models. Current research remains disproportionately centered on technologically advanced school systems, leaving a critical need for studies that evaluate algorithm performance in diverse, resource-constrained environments (Haileslassie & Tegegne, 2025).

Future investigations must prioritize the development of ethical guidelines for algorithmic accountability, ensuring that predictive variables, such as socioeconomic status or demographic background, do not perpetuate existing inequities (Khan & Samad, 2024). Additionally, longitudinal inquiries are required to track how these AI-driven systems influence student motivation and self-efficacy over extended durations rather than focusing solely on immediate performance metrics.

11.0. TECHNOLOGICAL AND ETHICAL CHALLENGES

Incorporating predictive systems requires moving beyond algorithm optimization to real-world, ethical, and human-centric feedback loops; this is important (Ouyang et al., 2023). To realize this evolution, the multimodality of information (both behavioral and emotional) must be considered in the learning environment. The rigor of data privacy and algorithmic transparency must be preserved (Nguyen et al., 2024). Further, the institutions need to be dedicated to further improving these algorithms, reducing algorithmic bias to the extent that the automated profiling is not seen to limit student opportunities or to perpetuate socioeconomic inequalities (Maulana et al., 2023; Onesi-Ozigagun et al., 2024).

These challenges should be tackled by focusing on human-centered explainability in the AI-generated predictions to make them actionable and transparent for educators (Turkmenbayev et al., 2025). To bridge the interpretability gap, attention needs to be paid to architectures that offer rationales for pedagogical recommendations, which goes beyond the "black-box" approach (Villegas-Espinoza & Necochea-Chamorro, 2025). Furthermore, to harmonize these automated insights with well-established pedagogical best practices, it is of paramount importance to foster interdisciplinary collaboration between computer scientists, cognitive psychologists, and educators (Katiyar et al., 2024). It is also critical to build strong policy frameworks to keep data protection at the heart of a digital change in mathematics teaching (Ifraheem et al., 2024).

12.0. POLICY IMPLICATIONS FOR DISTRICTS

District leaders should create committees that include data scientists, pedagogues, and ethicists to review the fairness of algorithms and make sure that automated decisions to support student learning do not exacerbate the digital divide. These committees should also incorporate strict anonymization measures and differential privacy to preserve student confidence while adhering to changing regulatory requirements and practices ("AI-Driven Student Performance Prediction Models in EdTech," forthcoming).

In addition, districts need to make investing in XAI systems a priority to ensure algorithmic decision-making is transparent, so teachers can continue to fulfill their important role as facilitators of critical metacognitive engagement. In addition to compliance, districts need to provide comprehensive professional development to help teachers understand the output of the system and to use it to inform their rich, human-based pedagogical practices. This professional capacity building is crucial if students are not to become over-reliant on the automated tools but rather become supported by and scaffolded by AI to undertake independent problem solving (Ansari & Qamari, 2025). Ultimately, the successful integration of such systems requires a shift toward a collaborative framework where AI serves as a diagnostic assistant, allowing educators to engage in the more complex aspects of mathematical reasoning, such as social and emotional considerations (Henkel et al., 2025).

13.0. CONCLUSION

A post-pandemic recovery must shift the focus on remediation to a proactive model and use of data to inform instruction, one that integrates the precision of technology with the expertise of the human teacher. In order to achieve this vision, educational institutions need to invest significantly in digital infrastructure and inclusive curriculum development, and the research program needs to be oriented towards the conduct of longitudinal studies of the effectiveness of these tools in a variety of socio-cultural settings. The integration of algorithmic diagnostic capacities and pedagogical intentionality has the potential to create a more equitable future where AI is a tool that can amplify personalized, high-quality mathematical education in schools. Creating this resilient educational system will depend on the resilience of human-in-the-loop decision-making, with AI-generated insights complementing, not replacing, professional pedagogical decisions. This paradigm shift requires a strong structure for AI literacy, enabling teachers to interrogate and customise algorithmic suggestions to align with their students' cognitive differences and socioeconomic backgrounds. This shift in paradigms demands a strong framework for AI literacy, empowering teachers to question and tailor algorithmic recommendations to the cognitive diversity and socioeconomic contexts of their students.

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