Dismantling barriers in the middle grades: the relationship between multimodal digital inquiry and science equity

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Abstract

Purpose – This study aims to examine the relationship between the use of a multimodal, inquiry-based digital science platform and grade 8 student performance on a statewide assessment. Grounded in a systemic equity framework, the study investigates whether multimodal inquiry experiences are differentially associated with outcomes for students who have historically encountered structural and linguistic barriers in middle grades science classrooms.

Design/methodology/approach – Using a quasi-experimental design across 32 middle schools (n = 7,555), researchers utilized multi-level modeling to account for the nesting of students within schools. Engagement was measured by the number of completed investigations during a spring implementation period. Regression analyses estimated the relationship between platform use and standardized state science assessment scores.

Findings – While no significant difference was found between users and non-users overall, regression analyses revealed a statistically significant positive relationship between the number of investigations completed and assessment scores for the full student sample (p = 0.006). Subgroup analyses revealed stronger positive associations for emergent multilingual learners (ML), Black, Hispanic and female students. Findings suggest that even limited access to multimodal inquiry experiences may address critical opportunity and access gaps and are associated with higher levels of science performance. Since the middle grades represent a pivotal period for the development of science identity, these associations carry developmental significance for young adolescents.

Originality/value – This study contributes to middle grades research by examining multimodal digital inquiry and state assessment outcomes through a lens of systemic equity, highlighting how inclusive instructional design may expand access to rigorous science learning during a critical developmental period for young adolescents.

Keywords Access and opportunity gap, Inquiry-based science, Middle-level science, Middle-level technologies, Multimodal inquiry

Paper type Research article

Introduction

Science proficiency among U.S. middle school students remains a persistent concern largely caused by systemic inequity in opportunity to learn. These patterns of inequality are often masked by a national focus on aggregate test scores that overlook the uneven distribution of resources and the impact of racial-economic segregation on student outcomes (Parsons, Dibner, & Schweingruber, 2025; Smith, Trygstad, & Banilower, 2016). Since the middle grades represent a critical developmental window for STEM identity (McQuillan, Hill, Jochman, & Kelly, 2023), students may disengage if they are denied an equitable quality of experience through restrictive tracking policies or under-resourced learning environments (Alexander, 2024). This study aligns with the Association for Middle Level Education (AMLE) principle that curriculum must be challenging, exploratory, and relevant (Bishop & Harrison, 2021) to ensure that young adolescents have the opportunity to see themselves as capable scientific thinkers.

Theoretical framework: multimodal inquiry and equity

The study is grounded in two complementary frameworks: Inquiry-Based Learning (IBL) and Multimodal Learning. Young adolescents seek autonomy and the need to feel capable of mastering challenging tasks. IBL satisfies these developmental needs by asking young

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adolescents to be active investigators who construct and test explanations of scientific phenomena through engagement with evidence and disciplinary practices (Hmelo-Silver, Duncan, & Chinn, 2007). Traditional science instruction often creates barriers to access through a reliance on text focused instruction that does not reflect the multidimensional nature of scientific practice (National Academies of Sciences, Engineering, and Medicine, 2025).

Multimodal learning addresses these inequities by providing varied representations (e.g. visuals, simulations, and interactive data) that offer multiple entry points to rigorous content (National Academies of Sciences, Engineering, and Medicine, 2025). Here, multimodality functions as an epistemic resource, a tool supporting how learners construct, represent, and justify knowledge, rather than a scaffold for comprehending dense texts, letting learners engage with and make meaning of complex scientific phenomena (Lim, Cope, & Kalantzis, 2022; Nichols, Neal, & Hand, 2025). By integrating IBL with multimodal experiences, digital platforms create hybrid learning environments that expand participation in disciplinary reasoning and challenge tracking policies and systemic barriers (Grapin *et al.*, 2023). Throughout this study, science equity refers not only to equity as access, defined as providing high-quality science learning opportunities, but also to equity as transformation, in which the meaning-making resources that historically marginalized students bring to science are treated as legitimate within the discipline (Grapin *et al.*, 2023; Lee, Quinn, & Valdés, 2013). Systemic equity extends this view by locating barriers within structures, such as student tracking, the uneven distribution of resources, and text-centric instruction, rather than within students themselves (Calabrese Barton & Tan, 2020). Multimodal digital inquiry has the potential to advance science equity by addressing structural constraints, such as expressing and accessing scientific reasoning through visual, interactive, and multimodal means. This allows full participation in rigorous scientific inquiry without depending primarily on dense academic text.

Literature review

The state of science in the middle grades

Science proficiency among U.S. middle school students has plateaued. According to the most recent National Assessment of Educational Progress (National Center for Education Statistics (NCES), 2024), only 31% of grade 8 students scored at or above proficiency level in science in 2024. This is a notable decline from previous years (NCES, 2024) and is particularly critical because the middle grades represent a developmental window where students either solidify their identity as science learners or disengage from science (McQuillan *et al.*, 2023).

Systemic inequity and opportunity gaps

National averages mask deep patterns of inequality and systemic inequity in opportunity to learn. Students from historically marginalized communities, including Black and Hispanic students and emergent multilingual learners, continue to face structural barriers such as racial-economic segregation and restrictive tracking policies that limit their access to high-quality scientific instruction. Researchers (e.g. Deehan, MacDonald, & Morris, 2024) have documented that interventions in middle grades science are often unevenly distributed, particularly in schools in systemically underserved communities which lack the material resources necessary for deep, exploratory inquiry.

When science instruction relies on dense texts, it effectively locks many emergent multilingual learners out of STEM opportunities by conflating scientific proficiency with reading proficiency (Lee *et al.*, 2013). As noted by recent research, when these structural barriers are removed through visual, interactive, or multimodal supports, meaningful participation increases (Grapin *et al.*, 2023).

The role of digital multimodal tools as epistemic resources

To address these gaps, schools are increasingly turning to digital platforms that utilize Universal Design for Learning (UDL) principles. Li and Kim (2023) found that multimodal learning environments had a strong positive effect on STEM achievement when they offered multiple entry points. A broader body of research on multiple representations helps explain why such environments support learning. Presenting scientific ideas through complementary visual, symbolic, and textual forms can give learners more than one route into a concept and reduce the demands placed on any single mode of communication (Ainsworth, 2006). In science specifically, well-designed representations scaffold disciplinary practices such as asking questions, analyzing data, and constructing explanations, and these affordances are strongest when representations are interactive and dynamically linked rather than static (Wu & Puntambekar, 2012). Within digital platforms, these affordances allow students to engage with a single phenomenon through simulations, models, and data displays, distributing meaning across modes rather than concentrating it in dense print.

This framework treats multimodal tools as resources for meaning-making rather than remedial aids for struggling readers. Even so, technology use alone does not guarantee learning. Successful digital interventions must be designed for active learning and provide the necessary structure and tools for students to engage in rigorous scientific reasoning and develop a sense of belonging in the STEM community (Singer, Montgomery, & Schmoll, 2020; Martin-Hansen, 2018).

The gap in current research

While the potential of multimodal science tools is increasingly recognized, a significant gap remains in understanding their impact on state-level assessments through the lens of systemic equity. Much of the current literature focuses on general student engagement or "learning loss" narratives rather than examining how inclusive design can dismantle systemic gatekeeping (National Academies of Sciences, Engineering, and Medicine, 2025). Furthermore, recent national data indicates that middle school tracking policies and racial-economic segregation continue to be the primary drivers of the science proficiency plateau, yet few studies investigate how digital platforms function as epistemic tools to overcome these structural barriers in a high-stakes assessment context (National Academies of Sciences, Engineering, and Medicine, 2025).

This study addresses this gap by utilizing a large-scale, quasi-experimental design to analyze the relationship between the use of a multimodal digital science platform and grade 8 science scores on a standardized state assessment. By focusing specifically on emergent multilingual learners and students from systemically underserved communities (Grapin *et al.*, 2023), this research examines how equitable access to multimodal science inquiry can promote positive learning outcomes (National Academies of Sciences, Engineering, and Medicine, 2025).

Methods

Study design and context

This study employed a quasi-experimental design within a large, urban school district in the southeastern U.S. The sample included grade 8 students ($n = 7{,}555$) nested within 32 schools. The intervention took place between February and May 2024, representing a supplemental spring semester intervention rather than a full-year curriculum. This context is characterized by the patterns of inequality inherent in large urban systems, where racial-economic segregation often results in an uneven distribution of resources for science instruction.

Implementation

The digital science platform examined in this study functioned as a supplemental instructional tool integrated into grade 8 science classrooms during spring 2024. Each completed investigation represented a structured, multi-step inquiry experience centered on a real-world scientific phenomenon and a guiding question.

Investigations included multimodal components such as short readings, interactive simulations, visual diagrams, data manipulatives, embedded videos, and scaffolded prompts. Students engaged in guided observation, analysis of evidence, and structured reasoning tasks aligned with disciplinary core ideas and scientific practices. Each investigation culminated in the construction of a written explanation using a Claim–Evidence–Reasoning (CER) framework.

Teachers determined when and how investigations were incorporated into classroom instruction. The platform was used to supplement, rather than replace, core curriculum materials. Engagement levels varied across classrooms and students, reflecting differences in instructional pacing and integration during the February–May implementation window. Since teachers retained discretion over how frequently and how deeply investigations were used, implementation was not uniform across classrooms. The platform did not prescribe a fixed pacing or sequence, and the study did not collect direct observational measures of implementation fidelity. The number of completed investigations reflects the combined influence of teacher decisions and student engagement during the study timeframe, a point discussed in the study limitations.

Measures and analysis

Usage Metric. Engagement was measured by the number of completed investigations, which indicates a student's quality of experience with inquiry-based content. We acknowledge that usage in this implementation window was variable (Mean = 1 investigation; Range = 1–12). This count serves as a proxy for engagement rather than a direct measure of it. It does not capture the teachers' approach, quality, or instructional framing of each investigation, and identical counts may represent qualitatively different learning experiences. We treat the number of completed investigations as an indicator of opportunity to engage with multimodal inquiry and interpret the associated estimates accordingly.

Outcome Measure. The primary outcome measure was students' spring standardized state science assessment score. This criterion-referenced assessment evaluates proficiency across disciplinary domains including physical science, life science, earth and space science, and the nature of science. Because the assessment is administered only in the spring, prior science achievement was measured using a district-level standardized science assessment administered earlier in the academic year to establish baseline equivalence and serve as a covariate in outcome models.

Demographic Variables. Student-level demographic data were obtained from district administrative records. Variables included gender, race/ethnicity (e.g. Black, Hispanic, White, Asian, and Multiracial), emergent multilingual learner (ML) status, disability status, and gifted designation. These variables were used both as covariates in analytic models and to conduct subgroup analyses examining whether associations between platform engagement and science achievement differed across historically underserved student populations.

Analytical approach

Consistent with rigorous middle grades research designed to account for the nested nature of school structures, we utilized multilevel modeling (MLM) to estimate the relationship between platform engagement and state science scores. MLM was necessary to account for the nested structure of the data (students within schools), reducing the risk of Type I errors. Furthermore, this approach addresses how structural barriers at the school level relate to individual achievement outcomes.

All models controlled for prior science achievement and demographic covariates. Overall and subgroup analyses were conducted to examine whether the relationship between completed investigations and assessment performance varied across all students and student groups. Standardized coefficients were calculated to estimate effect sizes and facilitate interpretation of the magnitude of observed associations.

Results

Overall outcomes

The comparison between users and non-users overall yielded no statistically significant difference ($p = 0.461$). However, among platform users, students demonstrated a statistically significant positive relationship between the number of investigations completed and state science scores ($p = 0.006$). The standardized effect size ($b = 0.05$) translates to an increase of 1.7 percentile points per investigation completed using the What Works Clearinghouse (WWC)'s improvement index (What Works Clearinghouse, 2022; See Table 1 and Figure 1). This pattern suggests that increased access to multimodal, inquiry-based learning opportunities was associated with higher levels of science proficiency across the student population. As shown in Table 1, this overall association ($\beta = 0.05$, $p = 0.006$) was modest in magnitude but consistent in direction, and Figure 1 illustrates how scores rose steadily with each additional investigation completed rather than only above a single threshold of use. Together, the table and figure suggest a cumulative benefit that even incremental increases in access to multimodal inquiry were associated with measurable gains, consistent with the platform widening opportunity rather than as a one-time intervention.

Outcomes by subgroup

Subgroup analyses revealed significant associations between platform use and state science scores for Black and Hispanic students, emergent multilingual learners (ML), and grade 8 girls (See Table 1 and Figure 1).

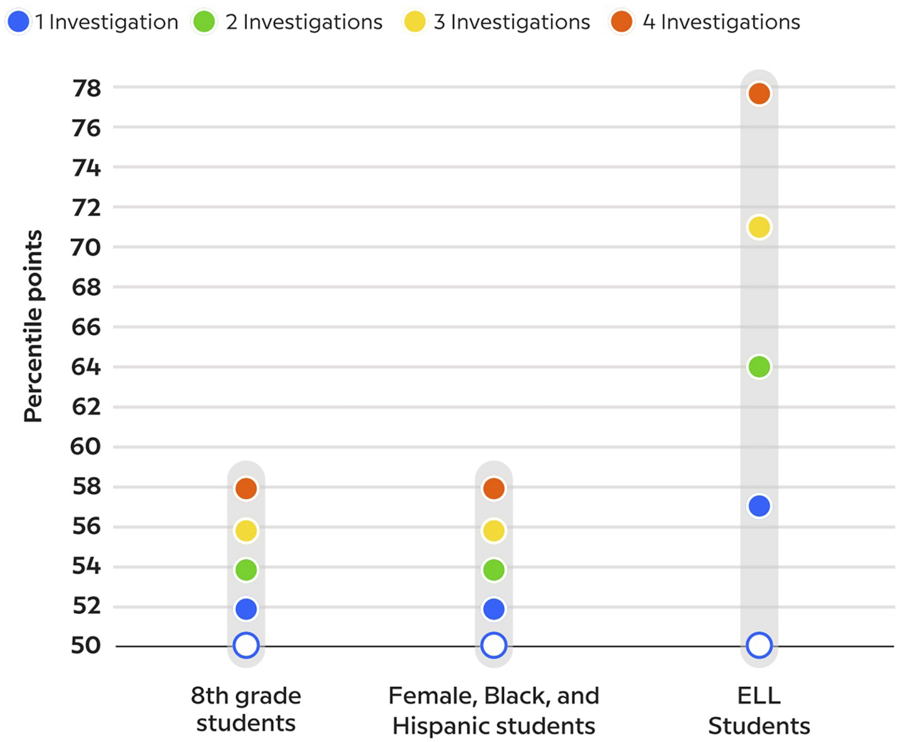
Black and Hispanic Students: Significant positive associations were found for Black ($p = 0.028$) and Hispanic ($p = 0.042$) students, corresponding to increases of roughly 2 percentile points per investigation. For these groups, each additional completed investigation was associated with an increase of approximately 2 percentile points on the statewide assessment. These findings indicate that engagement with multimodal inquiry experiences was differentially associated with assessment outcomes for students who have historically experienced systemic inequity in opportunity and constrained access to high-quality science learning.

Emergent Multilingual Learners (ML): ML students demonstrated a statistically significant positive relationship between the number of investigations completed and assessment scores ($p = 0.009$). The standardized effect size ($b = 0.18$) translates to an increase of 6.7 percentile points per investigation completed. This pattern suggests that when provided with epistemic resources that move beyond text-centric barriers, ML students demonstrated higher levels of science performance. As Table 1 and Figure 1 show, this was the largest association observed in the study: the estimate for ML students ($\beta = 0.18$; approximately 6.7 percentile points per investigation) was more than three times

Table 1. Multi-level model results: relationship between investigations completed and spring 2024 science scores, by student subgroup

Subgroup	β (coefficient)	p-value	Percentile point increase (WWC index)
Overall	0.050	0.006**	+1.7
Female	0.048	0.045*	+1.8
Male		0.061	
Asian		0.144	
Black	0.061	0.028*	+2.3
Hispanic	0.056	0.042*	+2.1
Multiracial		0.464	
White		0.354	
ELL	0.182	0.009**	+6.7
Students with Disabilities		0.410	
Gifted		0.810	

Note(s): $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***)
Source(s): Authors' own work



Source: Authors' own work

Figure 1. More investigations lead to higher scores on the science assessment

the overall estimate, and Figure 1 displays a markedly steeper trajectory for ML students than for the full sample. This reinforces the interpretation that reducing text-centric barriers may matter most for students whose access to science has been most constrained by the language demands of traditional instruction (Lee *et al.*, 2013).

Gender: For grade 8 girls, platform engagement was significantly associated with higher science assessment scores ($p = 0.045$). The relationship for grade 8 boys was not statistically significant ($p = 0.061$), suggesting the platform served as a critical support for girls' identity and competence as science learners during this developmental window.

These findings indicate the relationship between engagement and science achievement was stronger for specific student groups. In particular, students who have historically faced structural and linguistic barriers in science education demonstrated higher scores associated with participation in multimodal, inquiry-based investigations.

Discussion

Multimodal inquiry and access to science learning

This study examined the relationship between engagement with a multimodal, inquiry-based digital science platform and grade 8 science performance. While no statistically significant difference was observed between the digital science platform users and non-users overall, regression analyses revealed a significant positive relationship between the number of investigations completed and assessment scores for the full sample of students ($p = 0.006$) as well as for Black and Hispanic students, emergent multilingual learners (ML), and grade 8 girls. These findings suggest that the frequency of engagement with multimodal inquiry plays a critical role in expanding access to meaningful science learning, particularly for those who have historically encountered structural and linguistic barriers.

For emergent multilingual learners, the relationship between investigations completed and higher science scores was particularly robust ($b = 0.18$). Middle grades science instruction frequently relies on linguistically dense texts, which can limit students' ability to demonstrate scientific understanding. The use of simulations, visual representations, and interactive investigations supported students' engagement with scientific phenomena and practices by providing multiple ways to access and communicate understanding. In this context, multimodality functioned as a resource for participation in scientific inquiry rather than as a remedial support.

The significant positive associations between platform use and science performance for Black and Hispanic students indicate similar equity-oriented considerations. Students from these groups are more likely to experience systemic inequity in opportunity due to factors such as tracking policies and uneven distribution of instructional resources. The observed relationships suggest that participation in multimodal inquiry experiences may help broaden access to core scientific practices that are often limited in traditional middle grades classrooms. These findings align with research emphasizing the importance of instructional designs that support multiple entry points into rigorous content for students.

Instructional context and middle grades implications

The platform was implemented within a limited instructional window which reflects the realities of middle grades classrooms shaped by time constraints. Even within these constraints, the positive associations indicate that grade 8 students are responsive to instructional environments that reduce barriers.

These findings underscore the importance of instructional approaches that are exploratory, developmentally responsive, and inclusive, and to the role digital learning experiences can play in supporting engagement, meaning making, and a sense of belonging. Multimodal inquiry platforms may offer a practical way for educators to provide equitable access to science learning opportunities within existing curricular and structural constraints.

For practitioners, these findings translate into several concrete instructional moves. Teachers do not need to adopt the platform as a full curriculum to see benefits. Even integrating one or two investigations per unit, used as the anchoring phenomenon for a lesson, appears worthwhile. Within a typical class period or block, an investigation can launch a Claim–Evidence–Reasoning task, with the simulations and visual data serving as the shared evidence base for classroom discourse. Because the associations were strongest for emergent multilingual learners (ML), teachers can deliberately pair multimodal investigations with talk-based routines, such as partner sense-making and structured discussion, so that students reason scientifically before being asked to produce written text. Within common middle grades structures, interdisciplinary teams can coordinate so that science investigations reinforce literacy and language goals shared across content areas, and pacing guides can designate specific units in which an investigation replaces, rather than supplements, a text-heavy lesson. At the school and system level, these patterns suggest that professional learning should help teachers select, sequence, and facilitate multimodal investigations rather than treat the platform as a self-guided supplement, and that decisions about who receives consistent opportunities to engage in inquiry are equity decisions with measurable consequences for historically underserved students.

Limitations and future research

Several limitations should be considered when interpreting the findings of this study. First, the quasi-experimental design limits causal claims about the relationship between engagement with the multimodal inquiry platform and science assessment outcomes. Although multilevel modeling was used to account for the nested structure of students within schools, unmeasured factors, such as classroom instructional practices or teacher implementation choices, may have influenced student engagement and performance.

Second, the implementation occurred during a limited spring intervention period. As a result, levels of engagement varied and were generally modest, reflecting the instructional realities of middle grades classrooms shaped by competing curricular demands. Relatedly, engagement was operationalized solely as the number of completed investigations. This did not capture differences in how teachers approached instructional practices and framing of the investigation. Because no direct measures of implementation fidelity were collected, the estimates should be read as associations between opportunity to engage in multimodal inquiry and assessment outcomes rather than as effects of a uniformly delivered intervention. Future implementations would benefit from pairing usage counts with classroom observation and fidelity measures.

Future research should build on these findings by examining how multimodal inquiry platforms are integrated into daily instruction across longer time frames and varied middle grades contexts. Mixed-methods studies that incorporate classroom observations, student work artifacts, and student perspectives would provide deeper insight into how multimodal features support engagement and meaning making for learners.

Conclusion

This study contributes to middle grades research by examining how engagement with a multimodal, inquiry-based digital science platform relates to science assessment outcomes through a lens of systemic equity. Although overall comparisons between users and non-users did not yield statistically significant differences, regression analyses revealed positive associations for the full student sample, emergent multilingual learners, Black and Hispanic students, and female students. These findings highlight the importance of examining how instructional opportunities are experienced differently by young adolescents.

The results suggest that multimodal inquiry can function as an equity-oriented intervention by expanding access to scientific meaning making for students who have historically encountered barriers. By providing multiple ways to engage with complex phenomena, such approaches may support more inclusive participation during this critical developmental period.

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