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Lowell et al. (2024) extend the practitioner needs report with their case study methodology and use of an organizational sensemaking framework. This approach enabled the researchers to look across organizational levels of their participating districts and examine the extent to which district adoption and implementation practices exhibited coherence across these levels. For example, leaders and teachers in one district described tensions related to implementation fidelity differently. Leaders described challenges teachers had shifting their practice from traditional to storyline-based approaches, while teachers expressed uncertainty about being asked by the district to teach OpenSciEd "with fidelity" while also needing to adapt the materials to support multilingual learners.

## Opportunities for Further Research

While empirical research on the middle school units has both grown and matured, a large portion of papers on high school units have a design focus, with empirical research studies emerging in recent conference proceedings. With the high school field test now complete and materials fully released, we expect more rigorous empirical research on the high school units to be published in the coming years. For the elementary units, as of this writing, one unit has been released for each grade of kindergarten through fifth, with release of the remaining units scheduled through 2026. Research on the design, enactment, and implementation of the elementary units stand to differ in particular ways from middle and high school units for several reasons, such as (1) the extent the design of those units will necessarily integrate other disciplines such as math and literacy, (2) the limited instructional time many elementary schools devote to science, and (3) the nature of elementary teachers' expertise as cutting across all disciplines, rather than focusing more exclusively on science. Future research should investigate these differences.

Two doctoral dissertations had a particular focus on comparing student learning outcomes from OpenSciEd to other science curricula (Kelly, 2023; Vick & Blanton, 2023). While the findings from these studies show some promise, they exhibit limitations such as employing a small convenience sample or using state assessments, whose alignment to the NGSS performance expectations are yet unclear, as the outcome measure. There remains a need for OpenSciEd studies on student learning that use validated measures of three-dimensional science proficiency.

As noted above, Lowell et al. (2024) is the first study we are aware of to systematically study implementation at the district level. Implementation studies are especially important because OpenSciEd is frequently adopted at the district level (and not just by individual teachers). As such, teachers' enactment and PL opportunities will necessarily be shaped by policies and

practices implemented by their districts. Teachers' organizational contexts must be considered in order to fully understand teachers' needs, enactment decisions, and (ultimately) student outcomes. These studies will also help articulate deep and sustainable models for district adoption and implementation that meet the needs of students and their communities.

One area we observed limited research activity was on assessment in the context of OpenSciEd unit enactment. Based on surveys and focus group interviews, the practitioner needs report (McElhaney et al., 2024) identified enabling formative assessment practices and access to assessment resources as salient areas of need for practitioners. For example, we conjectured that formative assessment could be enabled by positive classroom culture around assessment (e.g., viewing assessment as a mechanism for ongoing improvement rather than summative evaluation). Aspects of existing classroom culture such as grading and individual student accountability can also constitute obstacles to assessment practices that are informative to teachers and coherent with storyline-based instruction. These assessment-related issues merit further research.

Combined with the logic model (Figure 1), the new OpenSciEd studies collectively continue to strengthen the Every Student Succeeds Act (ESSA) Tier 4 argument for OpenSciEd (McElhaney, Mills, et al., 2022). The emerging body of design and empirical research points to the need for efficacy studies of OpenSciEd that answer at least one research question at the Tier 1 level of rigor (i.e., entailing a randomized, experimental design). A successful efficacy study would require a validated student outcome measure of three-dimensional science proficiency—another salient need for the science education research community.

## Conclusion

The initial synthesis of OpenSciEd-enabled research supported two specific claims about classroom enactment and teacher supports for the middle school curriculum materials. Since then, the scope of this research has progressed in numerous ways, such as encompassing the high school units, increasing in methodological rigor and depth of findings, addressing new contexts (such as district implementation and preservice teacher education), and including more science education research community members who are not part of the OpenSciEd development consortia. This growth reflects OpenSciEd's potential to enable transformative science education research at multiple system levels.

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## Appendix: Summary of Research Papers on OpenSciEd

Citation	Article Type	Focus	Data Sources / Methods	Participants	Demographics	Grade band & unit(s) MS = middle school, HS = high school
Andersen et al. (2024)	Journal Article	Classroom Enactment	Case study; teacher interviews, teacher learning artifacts, curriculum materials, classroom video recordings	One middle school teacher and 14 participating 7th grade students	N/A	MS: Chemical Reactions & Matter
Benedict-Chambers & Sherwood (2024)	Journal Article	Teacher Supports	Mixed methods analysis of preservice teacher lesson plans	36 preservice teachers	33 Female 3 Male  34 Undergraduate 1 Post-Baccalaureate 1 Master's	N/A
Cherbow et al. (2024)	Journal Article	Design	N/A	N/A	N/A	MS: Magnets
Garner (2024)	Dissertation /Related	Design	Qualitative content analysis of the curriculum materials	N/A	N/A	MS: All Grade 7 Units

Kelly (2023)	Dissertation /Related	Classroom Enactment	Quantitative analysis of students' standardized test scores in science, mathematics, and English language arts	~1600 students 23 teachers	Students: 76% FRPL 23% MLs 15% have IEPs	MS: Various
Lee et al. (2024)	Journal Article	Classroom Enactment	N/A	N/A	N/A	MS: Contact Forces
Lowell (2024)	Journal Article	Teacher Supports	Case study using teacher interviews and video recordings of PD sessions	32 teachers	66% Women 34% Men 75% From large city 25% From small city	MS: Light & Matter, Contact Forces, Chemical Reactions & Matter
Lowell et al. (2024)	Journal Article	System Level	Contrasting case study based on in-person semi-structured interviews, teaching artifacts and reflections	9 MS teachers and 6 leaders across 2 schools	Teachers: Between 2 and 28 years of science teaching experience  Leaders: Between 8 and 20 years of teaching experience and between 3 and 16 years of administration experience  School student demographics varied	MS: Various

Lowell & McNeill (2023)	Journal Article	Teacher Supports	Quantitative analysis of teacher surveys	322 teachers	72% Women 77% White	MS: Light & Matter, Contact Forces, Chemical Reactions & Matter
McNeill, Affolter, & Reiser (2023)	Book Chapter	Design	Illustrative examples from whole group teacher PD sessions	30 teachers	Experience: 24% 1–6 years 52% 7–15 years 24% 16+ years  Gender: 73% Female 24% Male 3% Unknown  Race/Ethnicity: 76% White 7% American Indian/Native Alaskan 7% Native Hawaiian/Pacific Islander 7% Multiracial 3% African American	MS: Various



McNeill, Fine, et al. (2023)	Proceedings	Classroom Enactment	Mixed methods analysis of teacher survey responses and interviews	169 middle school science teachers from 41 US states	80% Women 19% Men  0.5% Non-binary 0.5% Did not identify their gender  86% White 6% Other 3% African American/Black 2% Latinx or Hispanic 0.5% Native Hawaiian/Pacific Islander 0.5% Asian or Asian American 2% None specified	MS: Various
McNeill et al. (2024)	Proceedings	Teacher Supports	Qualitative analysis of artifacts from teacher professional learning community meetings	7 middle school teachers in PLCs	N/A	MS: Various
Mohan et al. (2023)	Journal Article	Design	Mixed-methods analysis of student online exit tickets and end-of-unit surveys.	~240 students	N/A	HS: COVID-19

Penuel, Henson, et al. (in press)	Journal Article	Design	N/A	N/A	N/A	HS: Various
Penuel et al. (2024)	Journal Article	Classroom Enactment	Quantitative analysis of student survey responses	10,194 students in 146 classrooms as part of a 10-state field test	46% White 17% Latinx 10% African American/Black 7% Asian/Asian American 3% Native American (<0.5% Native Hawaiian/Pacific Islander) 15% Multiple  52% Female <0.5% Gender Non-binary  10% EL 4% Migrant 13% Special Ed	MS: Various
Penuel et al. (2023)	Proceedings	Design	N/A	N/A	N/A	HS: Ecosystems
Penuel, Rubin, et al. (in press)	Journal Article	Design	N/A	N/A	N/A	HS: Biology

Pomian Bogdanov (2022)	Proceedings	Design	Discourse analysis of design team meeting recordings	3 high school teachers, 3 researchers, 1 district science curriculum specialist	N/A	HS: Waves
Pomian Bogdanov (2024)	Proceedings	Classroom Enactment	Discourse analysis of semi-structured teacher interviews and recordings of classroom enactment	One high school teacher	N/A	HS: Wave Unit
Singleton et al. (2024)	Journal Article	Classroom Enactment	Quantitative analysis of student survey responses	847 students of 34 teachers located in nine different states	Students: 6.88% African American/Black 2.65% Native American 3.62% Asian/Asian American 17.25% Latinx/Hispanic 15.32% Multiple 54.28% White	MS: Cells, Earth's Resources, Natural Selection
Vick & Blanton (2023)	Dissertation /Related	Classroom Enactment	Quantitative analysis of student attitudes survey and student science outcome measure	44 eighth grade students at a large, suburban, Midwestern, public middle school	2.8% White 89.8% African American 0% Asian 3.4% Hispanic 4% Other or multiple races	MS: Earth in Space

Vick et al. (2024)	Journal Article	Design	Descriptive analysis of 1,061 student-generated questions from Driving Question Boards	High school students in 32 classrooms across 10 states	N/A	HS: Zombie Fires in the Arctic, Lightning Formation, Surface Changes in the Afar Region of Ethiopia
Watkins & Penuel (2023)	Journal Article	Teacher Supports	Descriptive analysis of self-report surveys	More than 300 HS teachers	N/A	HS: Various
Wingert & Ko (2024)	Proceedings	Teacher Supports	Qualitative analysis of 60 hours of video recordings, photos, and teacher artifacts	6 high school science teachers (3 biology and 3 chemistry)	N/A	HS: Biology and Chemistry