# A Summary and Synthesis of Initial OpenSciEd Research

Draft Version

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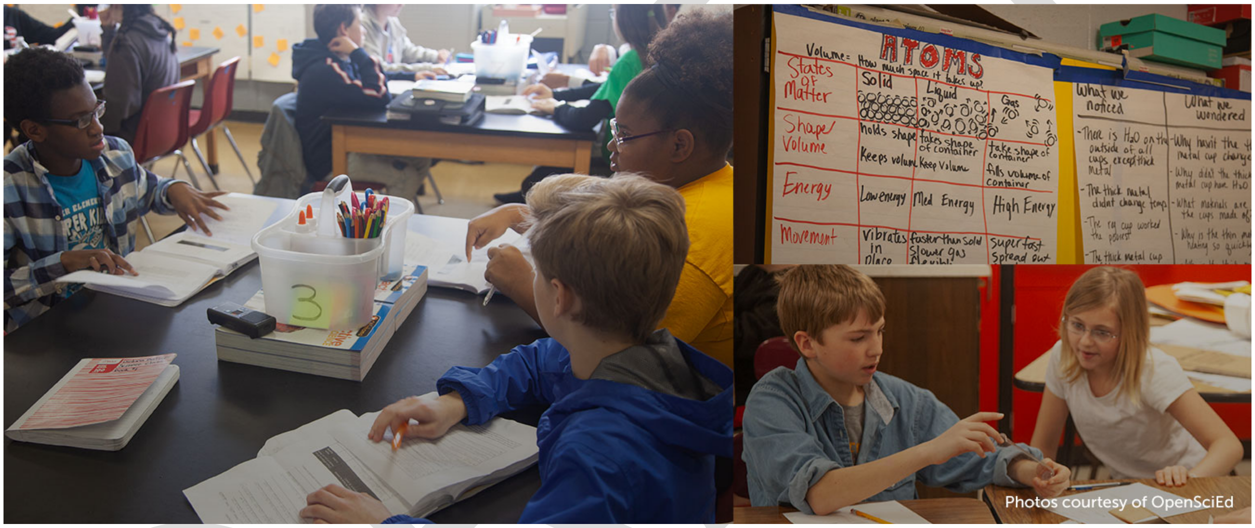

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**Note on the draft version.** We are releasing an early version of this document so that it can inform the development of upcoming research proposals. Based on feedback from readers, we will revise this report and release the revised version in late 2022. Please send feedback to Kevin McElhaney at the address listed above.

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## Introduction

OpenSciEd (2022) is a set of Creative Commons licensed, freely available curriculum and professional learning materials addressing the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). OpenSciEd is based on a set of distinctive instructional principles (Reiser et al., 2021) and professional learning approach (McNeill & Affolter, 2020) that uniquely enable research to address important knowledge gaps about science learning, teaching, and implementation. Rigorous research on these materials is urgently needed in order to answer questions about the equitable design of materials, impacts on student learning, effective and equitable classroom teaching practices, teacher professional development (PD) approaches, and models for school adoption and adaptation that address the diverse needs of historically marginalized students in STEM in K-12. These findings have the potential to advance the knowledge, skills, and practices that educators need to support student success. The OpenSciEd leaders anticipate eventual adoption by 40% or more of the nation's schools. Because of this potentially large adoption, research centered on OpenSciEd has the possibility to make important contributions to improvements in teaching and learning.

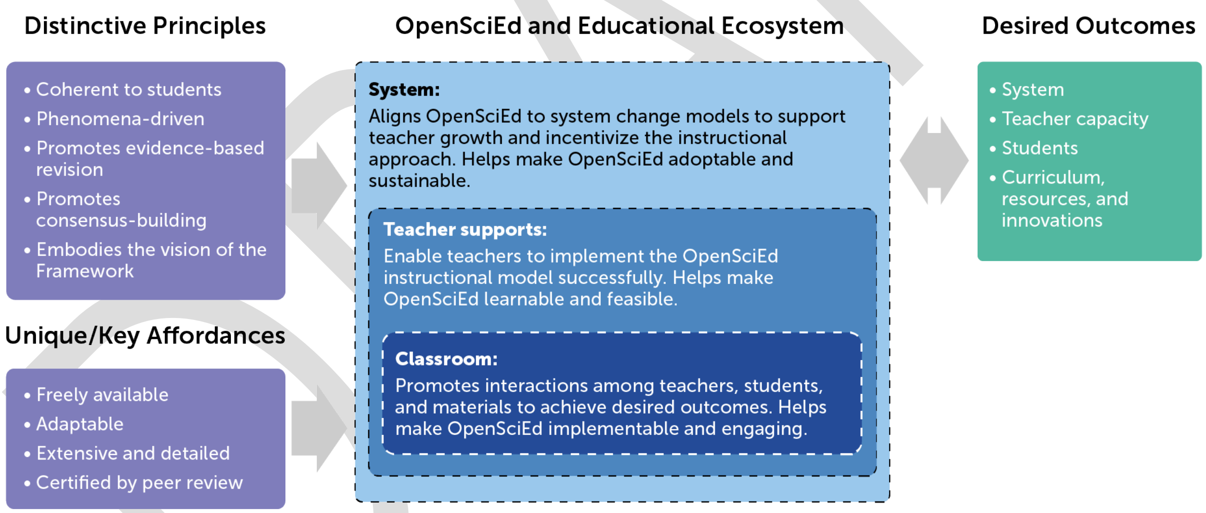
The purposes of this paper are to summarize and synthesize currently published OpenSciEd research. The synthesis aims to provide preliminary answers to two questions about OpenSciEd: (1) To what extent do teachers enact OpenSciEd units with integrity to its distinctive principles? and (2) To what extent do OpenSciEd teacher tools and professional learning experiences support teachers to enact OpenSciEd with integrity? This synthesis addresses three main audiences who are in a position to act on knowledge about OpenSciEd research published to date: (1) researchers who are conducting (or wish to conduct) OpenSciEd enabled research and writing OpenSciEd-related research proposals; (2) practitioners, such as science teachers, curriculum specialists, or instructional coaches; and (3) science policymakers, such as state officers.

We build on two white papers that elaborate OpenSciEd's affordances for research. The first white paper (McElhaney, et al. 2022a) articulated a logic model for OpenSciEd (Figure 1). A logic model describes the expected outcomes from an intervention and details the rationale for expecting impact, based on learning sciences principles. The logic model frames this research synthesis specifically by clarifying intended relationships between (1) OpenSciEd's distinctive principles and (2) how OpenSciEd is intended to be implemented at multiple organizational levels. OpenSciEd's distinctive principles include being coherent to students, being phenomena-driven, promoting iterative refinement and consensus-building (particularly around explanatory models), and embodying the vision of the K-12 Framework for Science Education (Framework) (NRC, 2012). Our synthesis questions emerge from the need for OpenSciEd to be implemented with integrity to these principles at every organizational level, including classroom enactment, supporting structures for teachers, and at broader "system" levels such as districts and states. The two questions map onto the classroom and teacher supports organizational levels articulated in the logic model, as no currently published studies address OpenSciEd implementation at either district or state level contexts.

The second white paper (McElhaney, et al., 2022b) articulated a Research Agenda for OpenSciEd research. To articulate the Research Agenda, we engaged 79 science education community members in a series of workshops to elicit research questions that each center equity issues, leverage OpenSciEd distinctiveness, and address salient gaps and needs in science education. In synthesizing the working group outputs, we identified the following four themes that were prevalent across all questions in each topic area: (1) student agency and participation, (2) promoting the Framework vision, (3) materials customization and adaptation, and (4) sustainable adoption and implementation. We observed that themes (1) and (2) broadly concern student outcomes of interest, while themes (3) and (4) broadly concern processes or approaches for achieving those outcomes. This research synthesis examines the progress of current research along these emergent themes, while identifying future research opportunities consistent with these themes.

**Figure 1**

*An initial logic model to guide OpenSciEd research*

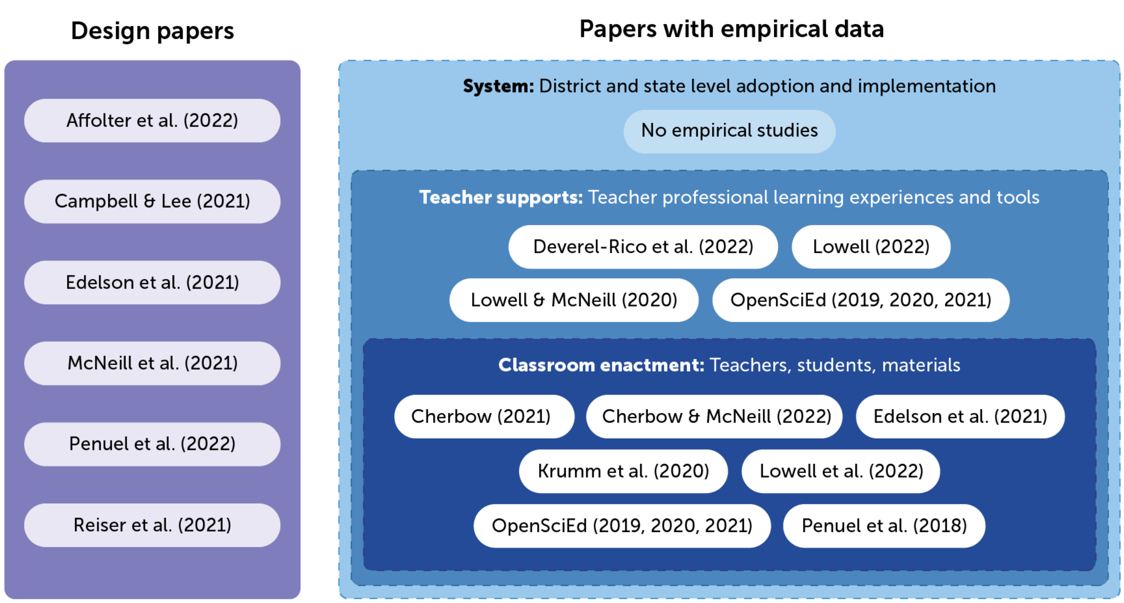



## Overview of the Papers Included in the Review

This review includes 16 publications, which are listed in the references section and summarized in the Appendix. The publications consist of seven journal articles, two peer-reviewed conference proceedings, two conference papers, two doctoral dissertations, and three OpenSciEd published reports. Of these papers, five of them focus on the design of OpenSciEd materials and do not have an empirical focus (Affolter et al., 2022; Campbell & Lee, 2021; Edelson et al., 2021, Penuel et al., 2022, and Reiser et al., 2021). We categorized the remaining empirical articles based on our logic model levels according to whether their primary focus was around classroom enactment or teacher supports. As noted above, there were no papers focusing on district or state contexts, as analyses of these data from the OpenSciEd field tests are still underway. Figure 2 includes a map of the papers according to these criteria. In this review, we provide summaries of the non-empirical design papers to provide background context for our subsequent synthesis of the empirical papers.

### Figure 2

*Map of the papers to the OpenSciEd Logic Model, based on their primary area(s) of focus*




*Notes*. (1) The primary focus of the paper by Edelson et al. (2021) is design, but it reports a few classroom-level findings from the OpenSciEd field test study. (2) The OpenSciEd summary reports (2019, 2020, 2021) focus on both classroom enactment and teacher supports.

All the papers except for Campbell and Lee (2021) were co-authored by members or affiliates of the OpenSciEd middle school development consortium. All the papers we review here except for Penuel et al., (2022) have a focus on the middle school grade band because these were the first set of materials to be developed and released to the general public, so these are the materials on which initial research studies are based. The two doctoral dissertations (Cherbow, 2021; Lowell, 2022) are by former graduate students at Boston College. Each dissertation has a "three-paper" format, which we indicated as Paper 1, Paper 2, and Paper 3 where we discuss the details of specific papers in the dissertations.

## Paper Summaries

In this section, we summarize each paper in the categories identified in the map (see Figure 2) around design, classroom enactment, and teacher supports.

### Design Papers

Initial publications about OpenSciEd primarily discussed the principles and processes used to design and develop the student and teacher OpenSciEd instructional materials. Three of these papers (Campbell & Lee, 2021; Edelson et al., 2021; Reiser et al., 2021) appear in a special issue of *Journal of Science Teacher Education* (JSTE) about designing instructional materials for the Next Generation Science Standards. One (Penuel et al., 2022) describes processes that inform the development of the forthcoming OpenSciEd high school units. Two other papers (Affolter et al., 2022; McNeill et al., 2021), both published in *Science Scope,* target primarily practitioner audiences.

In "Some of You Are Smiling Now:" Supporting Trust, Risk Taking, and Equity in Your Classroom," **Affolter et al. (2022)** describe four features of classroom culture that support equitable sensemaking. These features are presented as questions for teachers to consider such as, "What ways of knowing are privileged in the classroom?" and "Who is engaged in (or excluded from) classroom activity?" The papers provide examples of instructional strategies that support equitable classroom culture, such as establishing classroom norms, using different activity structures to share ideas, and supporting discussions with talk moves.

In "Instructional Materials Designed for A Framework for K-12 Science Education and the Next Generation Science Standards: An Introduction to the Special Issue," **Campbell & Lee (2021)** synthesized articles about NGSS-aligned instructional materials as an introduction to the JSTE special issue, which include the above papers by Edelson, et al., (2021) and Reiser et al., (2021). Campbell and Lee noted the following themes across articles: (1) leveraging an instructional approach that emphasizes students "figuring out" a phenomenon, rather than direct instruction (2) relating science instruction to students' interests and identity as an equity focus (3) prioritizing professional learning and teacher support to transform science learning.

In "Developing Research-Based Instructional Materials to Support Large-Scale Transformation of Science Teaching and Learning: The Approach of the OpenSciEd Middle School Program," **Edelson et al. (2021)** discussed the participants, processes, and products involved in the design and development of OpenSciEd resources, including instructional materials for students and supplementary professional learning materials for teachers. They describe a diverse group of community members (e.g., state-level education leaders, educational researchers, instructional materials developers, teachers, and students) that were engaged in the design and development of OpenSciEd resources, and the opportunities they had to contribute to the instructional and professional learning materials. They also describe design frameworks for both instructional materials and professional learning with design specifications and design principles provided for guidance and consistency. The paper also reports a handful of preliminary findings from the OpenSciEd field test study that indicate positive uptake of the materials, but the empirical results are not the primary focus of the paper.

In “Shifting From Learning About to Figuring Out: PD Resources to Support Classroom Change,” **McNeill et al. (2021)** introduced five key instructional elements for teachers to use during professional learning to support a shift in their science classroom practice from "learning about" to "figuring out." These instructional elements are phenomenon based, coherent for students, driven by evidence, collaborative and equitable. Examples of teachers engaging in each element during a professional development session include examining video to operationalize the instructional elements and identify strategies, facilitating teachers' reflection on their own classroom practice, and analyzing curriculum and resources for alignment with each element.

In “Learning Practical Design Knowledge through Co-Designing Storyline Science Curriculum Units,” **Penuel et al. (2022)** explored tools and processes for co-designing high school storyline science curriculum units that are aligned to NGSS standards and connected to students’ interests and experiences. Twenty-seven participants (19 teachers, 7 researchers, and 1 district science coordinator) engaged in codesign strategies and reflection before, during, and after a week-long co-design workshop. A collaborative analysis revealed strategies that participants perceived to be most closely aligned to the goals of the curriculum and their suggested refinements to the co-design process. The authors synthesized the findings to identify three mechanisms to support collective learning of co-design: deliberation, anticipation of learner participation, and reflection. This design process comprises the basis for the OpenSciEd high school units.

In “Storyline Units: An Instructional Model to Support Coherence from the Students’ Perspective,” **Reiser et al. (2021)** describe the storyline instructional model, which centers on coherence from the students’ perspective. This approach emphasizes students' epistemic agency, with the instructional sequence driven by student and peer questions regarding a topic, rather than a premeditated sequence determined by disciplinary experts, typically represented by textbooks and teachers. The paper describes four teaching routines to promote coherence from the students' perspective: anchoring phenomenon, navigation, putting pieces together, and problematizing.

## Classroom Enactment

In addition to the design paper by Edelson et al. (2021) described above, and the OpenSciEd summary reports described below, there were five publications having an empirical focus on classroom enactment – one conference paper presented at the American Association of Educational Research Annual Meeting (Penuel et al., 2018), two journal articles (Cherbow & McNeill, 2022; Lowell et al., 2022), one conference proceedings paper (Krumm et al., 2020), and one doctoral dissertation (Cherbow, 2021). Each of these papers supports its claims by analyzing data, such as observation of instruction and student surveys, gathered as part of OpenSciEd classroom enactment.

In “Planning for Epistemic Agency in Storyline Discussions: A Revelatory Case of Student-Informed Curricular Sensemaking” and “Planning for Student-Driven Discussions: A Revelatory Case of Curricular Sensemaking for Epistemic Agency,” **Cherbow (2021) (Paper 1) and Cherbow & McNeill (2022)** used a case study analysis to examine tensions and ambiguity that arose as one middle school science teacher pilot tested an OpenSciEd storyline unit. In the studies, a tension that arose was that storyline units follow a premeditated sequence of knowledge building that may not be what organically arises from students. Another tension observed was between equitable participation and incremental building of ideas. That is, the teacher wrestled with and tried different strategies to open up space to promote all student voices, while still incrementally building disciplinary ideas in a time-efficient manner. A source of ambiguity was whether students’ epistemic agency was similar across discussion types (initial ideas, building understandings, and consensus). Performing a planning-reflection cycle helped the teacher increase the sophistication of his understanding of epistemic agency and the goals of different types of discussions.

In “Responsive Instructional Design for Students’ Coherence-Seeking: Documenting Episodes of Principled Improvisation in Storyline Enactment,” **Cherbow (2021) (Paper 2),** examined how one teacher supported students’ epistemic agency through his use of principled improvisation while enacting an OpenSciEd unit. The study illustrates how students’ coherence-seeking can deviate from the premeditated coherence in the storyline unit. However, through the use of instructional moves, the teacher used different strategies to support students’ epistemic agency while still following the overarching arc of the storyline. For example, he shifted the students’ roles during a scientist circle to promote greater student interaction, supported students in organizing the driving question board so it positioned students to drive the learning, outlined epistemic roles to position students as co-constructors of the consensus model and used students’ unanticipated data to push their understanding of the disciplinary ideas.

In “Enacting Curriculum that are Coherent from the Student Perspective: Exploring the Teacher-Storyline Relationship,” **Cherbow (2021) (Paper 3)** synthesized the analyses in Papers 1 and 2 to articulate a model of the relationship between the OpenSciEd storyline curricula materials and teacher, referred to as the "Teacher-Storyline relationship." In this relationship, the teacher draws on three resources: (1) story-mediated knowledge (e.g., equity, phenomena-based teaching), (2) teachers’ commitments (e.g., goals and beliefs), and (3) pedagogical design capacity (e.g., adapting materials based on student ideas). Consideration of these teachers' resources holds implications for the design of OpenSciEd instructional materials and professional learning.

In “Measuring Equitable Science Instruction at Scale,” **Krumm et al. (2020)** conducted a statistical analysis of data gathered from the OpenSciEd middle school field test to determine how teachers' instructional practices and students' classroom participation were explained by student identity and classroom composition. The study examined data from 259 teachers and exit tickets from more than 8,000 students. The analysis of teacher logs revealed that teachers' instructional practices were not significantly related to classroom-level demographics. Additionally, students' exit tickets revealed that students' racial identity was a significant predictor of whether students contribute to knowledge-building activities in the classroom. Furthermore, classroom demographics predicted whether some racial groups were more or less likely to contribute to classroom discussions. A key implication of these findings is that studies of equitable instruction should gather data directly from students and combine them with information about classroom-level demographics in order to capture ways that classroom composition may moderate students' individual experiences.

In "Considering Discussion Types to Support Collective Sensemaking During a Storyline Unit," **Lowell et al. (2022)** conducted an analysis of the turns taken in classroom discussions led by a highly skilled middle school teacher across three different types of classroom discussions found in the OpenSciEd materials (initial ideas, building understandings, and consensus). The study found that the teacher participant commonly used the practice of surfacing and clarifying ideas as a step in collective sensemaking across all three OpenSciEd discussion types, and this practice followed a distinctive Propose–Probe–Clarify–Restate (PPCR) sequence. This work, which may be a model to help students to surface and clarify ideas, is a productive resource for sensemaking, particularly in the discussion of the initial ideas. However, the other discussion types require a different combination of teacher moves to achieve unique epistemic goals. For example, evaluating students' ideas is a practice that can be highly productive in consensus discussions, but was not commonly observed.

In "Developing a Validity Argument for Practical Measures of Student Experience in Project-Based Science Classrooms," **Penuel et al. (2018)** articulate a preliminary validity argument for a student survey instrument designed to inform the improvement of project-based science teaching and learning. The instrument, the student electronic exit ticket (SEET), is intended to diagnose student experiences of the curriculum as enacted. In responding to the survey, students report on different aspects of their experience with the exit tickets, such as its perceived coherence, perceived relevance, and their affective response to the lesson. The paper presents developing evidence drawn from informal discussions with teachers, logs of use, a teaching survey, and observations of instruction to support validity claims about usability, value to teachers, frequency of use, and associations with three-dimensional science learning. A version of the SEET was used for the OpenSciEd field test studies and reported in other studies synthesized here (e.g., Krumm, et al., 2020; OpenSciEd 2019, 2020, 2021).

## Teacher Supports

In addition to the OpenSciEd summary reports described below, there were three publications having an empirical focus on teacher supports (tools and experiences to support teacher professional learning: one conference proceedings paper (Lowell & McNeill, 2022), one conference paper (Deverel-Rico et al., 2022), and one doctoral dissertation (Lowell, 2022). Each of these publications supports its claims using analyses of data gathered as part of teacher professional learning experiences, such as workshops or the use of a learning tool.

In “Learning to Teach with Storyline Curricula,” **Deverel-Rico et al. (2022)** investigated the experiences of 36 teachers through PD and enactment of storyline curricula as part of an OpenSciEd field study. Many teachers reported shifts in teaching that align with the goals of storyline curricula, such as supporting coherence from the student perspective, positioning students as knowledge builders, and building knowledge collectively. Teachers reported varied experiences with curricula structures such as the Anchoring Phenomena and Navigation routines, with some reporting that professional learning enabled them to better practice the routines, and a few reporting continued challenges with structures such as the Driving Question Board. Some teachers noted that the storyline units supported students to develop and revise models, as well as supported academically productive discussions among students. Teachers reported being challenged to teach all standards within the timeframe of a school year. Based on the findings, the authors proposed a hypothetical learning progression for teachers to learn to teach with storylines, which include (1) linking new and current practices, (2) organizing and identifying new and persistent challenges in practice, and (3) refining and extending practice.

In “Changes in Teachers’ Beliefs and Confidence: A Longitudinal Study of Science Teachers Engaging in Storyline Curriculum-Based Professional Development,” **Lowell (2022) (Paper 1)** analyzed survey responses from 322 teacher participants in teacher professional learning workshops implemented as part of the OpenSciEd field test. The analysis identifies changes in teachers’ beliefs and confidence before and after participating in four professional learning experiences over two years, occurring six months apart. The study found that teachers’ traditional beliefs about science instruction significantly improved after one professional development workshop and then leveled off, while teachers’ confidence in implementing OpenSciEd increased over the first few rounds of PD and then leveled off.

In “The Student Hat: A New Tool in Practice-Based Professional Development,” **Lowell (2022) (Paper 2)** describes a conceptual framework about the “student hat” as a professional learning approach. This paper contrasts other practice-based professional development activities with the student hat (e.g., analyzing video, analyzing student work, rehearsing teaching, doing science as an adult learner, and doing science in science hat). Lowell asserts that doing science in the student hat is a unique approach because it attends to the ideas, experiences, and interests of students, as well as their cognitive and affective responses. There is an illustrative example of a PD session with the dialogue of teachers working in the student hat to provide more context and operationalize what this learning approach could look like.

In “The Student Hat in Professional Development: Building Epistemic Empathy to Support Teacher Learning” and “Using the Student Hat to Push on Multiple Goals in Teacher Professional Learning,” **Lowell (2022) (Paper 3) and Lowell & McNeill (2020)** investigated how teachers describe their experience using the professional learning approach of wearing the "student hat" (engaging in curricular activities as students). After facilitating professional learning with more than 30 teachers piloting OpenSciEd curricula, 12 teachers were interviewed about their experiences. The study found that the student hat approach provided teachers with a safety net to deepen their content understanding, supported teachers' understanding of the instructional approach, and enabled them to empathize with student experiences during an OpenSciEd unit. These findings suggest that the student hat professional learning approach is particularly compelling for storyline curricula, which emphasize student-driven instruction.

### OpenSciEd Summary Reports

OpenSciEd released three summary reports of analyses of field test data for participating educators from the 2018-2019, 2019-2020, and 2020-2021 school years. These reports focus on outcomes from classroom enactment of the instructional materials as well as on teacher outcomes from participating in professional learning activities. They were prepared principally for district leaders in districts where OpenSciEd materials were field tested.

In the *2018-2019 Research Report to Participating Districts,* **OpenSciEd (2019)** reported on a field test study conducted during the 2018-2019 school year. The report summarizes analyses of more than 200 teachers' enactment of three OpenSciEd units. Using a variety of instruments, the study found that most students found OpenSciEd lessons interesting and relevant. Also, OpenSciEd materials were versatile, supported students' engagement in rich discussions of science ideas, and addressed three-dimensional science standards. In addition, OpenSciEd professional development activities influenced teachers' beliefs in ways that were consistent with the vision of the Framework, and teachers with varying levels of experience could teach OpenSciEd units.

In the *OpenSciEd Middle School Summary Report: Fall 2020 Data Collection,* **OpenSciEd (2020)** reported on a field test study conducted during the 2019-2020 school year where 139 teachers piloted six OpenSciEd units, although the implementation was disrupted due to the COVID-19 pandemic and shift to virtual instruction. Teachers faced a number of challenges due to virtual instruction, but still felt supported to adapt units for multilingual and special education students.

In the *OpenSciEd Report for Participating School Districts, Overview of Findings: Round 6,* **OpenSciEd (2021)** reported on a field test study conducted during the 2020-2021 school year. The report summarizes analyses of 147 teachers' enactment of three OpenSciEd units. Most teachers were facilitating virtual or hybrid instruction, which affected the pace at which they moved through each unit, with most not completing their unit. Teachers felt the embedded supports were less helpful than previous units, with the Cells and Earth Systems unit being accessible to a broader range of students than the Natural Selection Unit. Over half of the students found the content relevant. There were some patterns of disparity in student contributions between demographic groups in each unit.

## Synthesis

We have organized the synthesis of the empirical research on OpenSciEd based on the two primary synthesis questions (classroom enactment and teacher support). For each question, we articulate a handful of preliminary claims that have support from the available empirical evidence and identify some limitations of the current research. These limitations reflect the preliminary nature of OpenSciEd and the research studies that have occurred during field testing or shortly following its public release. As such, we view the limitations primarily as ongoing research opportunities, rather than as shortcomings of the materials or research studies.

## Question 1: To what extent are teachers able to enact OpenSciEd units with integrity to its distinctive principles?

***Preliminary Claim 1: OpenSciEd materials equitably support student participation and engagement.***

A fundamental underlying goal of OpenSciEd is to promote participation and engagement in practice-based science for all students. Equitable participation and engagement are prerequisites for promoting student agency, building consensus, and making anchoring phenomena meaningful and relevant; they also support the larger goal of broadening participation in STEM.

Based on data from the SEET, OpenSciEd materials were able to support the engagement and participation of students from a range of racial and cultural groups. Students from different race, gender, and linguistic backgrounds report they contribute to class discussions at high levels and say their ideas influence the class and help others (OpenSciEd, 2019). Classroom cultures were perceived to be similarly (and highly) supportive across different groups. More than 60% of students said they contributed ideas to class discussions across multiple units, and most of those students said they believed that their ideas influenced the classroom discussion (OpenSciEd, 2021).

These results are consistent with the intention of the units to elicit connections between classroom instruction and their everyday experiences. For example, in summarizing accounts of field test enactments, Reiser notes "Across our study classrooms, students brought up experiences such as hearing leaves moving outside a bedroom window, hearing a vacuum cleaner from a different floor in the house, a student's mother hearing her phone conversations from downstairs, and experiences hearing under bridges, underwater, inside cars, or with other objects in the path of the sound. This broadens questioning and sensemaking from the anchor and connects what students investigate to their own experiences." (Reiser et al., p. 815)

These results are also consistent with teachers' self-reports of classroom enactment. Though teacher self-reports do not directly support claims about the nature of student engagement and participation, they do illustrate that teachers perceive OpenSciEd materials to be equitable. For instance, 84% of teachers said that they were accessible to struggling readers, 76% of teachers said they were accessible to students with Individual Education Plans, and 68% of teachers said they were accessible to multilingual learners (OpenSciEd, 2019). Furthermore, teachers reported that the units supported the learning of students from a range of backgrounds (OpenSciEd, 2021), and they observed that students were able to grasp key disciplinary ideas and engage in scientific practices during the lessons (OpenSciEd, 2020). Finally, Krumm et al (2020) did not find any relationship between teachers' reported enactment of instruction and classroom composition.

### *Preliminary Claim 2: Students find OpenSciEd units to be relevant and coherent.*

Related to Preliminary Claim 1, the emphasis of OpenSciEd lessons on anchoring phenomena and on eliciting connections between these phenomena and students' everyday experiences aims to emphasize the relevance of the phenomena and help students recognize the connections between individual lessons and the broader goal of explaining the anchoring phenomenon, contributing to the perceived coherence of the units.

Based on analyses of the SEET administered during field tests, more than 90% of students reported instruction to be relevant to them in some way; this pattern was observed across students' racial backgrounds (Edelson et al., 2021; OpenSciEd, 2019). Students continued to report lessons to be relevant even when the units were enacted remotely during the COVID-19 pandemic (OpenSciEd, 2020). Analyses of the SEET also revealed that 87% of students reported understanding how that day's lesson "ties to the bigger picture" of what was being studied, indicating a high level of coherence as perceived by students (OpenSciEd, 2021).

Findings on the student-perceived coherence of units are supported by an analysis of teachers' self-reported enactment of coherence-building classroom practices (Krumm et al., 2020): (1) At the beginning of class, students discussed what we figured out during the previous lesson; (2) Students discussed a connection between the focus of today's lesson and the anchoring phenomenon, and (3) Students discussed what they figured out at the end of the lesson. The analysis found that these practices were enacted with high frequency (90.5%, 80.7%, and 82.3% of the time, respectively) relative to student sensemaking practices.

### *Preliminary Claim 3: Teachers are able to support rich and participatory science discussions during the enactment of OpenSciEd Units.*

OpenSciEd emphasizes classroom discussion as a way to promote students' equitable participation and engagement in science practices. An important question is whether teachers can facilitate rich discussions as part of OpenSciEd lessons, or whether they fall back on familiar patterns of interaction with students, such as Initiate-Response-Evaluate (IRE). While the evidence in support of this claim is currently limited to a handful of detailed analyses of enactment in specific classrooms, these studies provide helpful accounts of the ways that teachers are able to support rich science discussions.

Lowell et al. (2022) studied classroom enactment episodes of Mr. Morse, a highly experienced middle school teacher who also contributed to the development of the OpenSciEd professional development resources. An important finding of this study was that, across all three types of discussions (initial ideas, building understandings, and consensus), Mr. Morse focused primarily on surfacing and clarifying ideas, but his evaluation of students' ideas was absent from the discussions. These patterns "illustrate Mr. Morse's commitment to publicly acknowledge and accept students' ideas while also pushing them to further deepen and clarify those ideas" (p. 16), promoting equitable participation among students in the discussion. This study illustrates the extent to which an experienced teacher with high familiarity with the OpenSciEd instructional principles was able to elicit students' scientific ideas during the lessons.

Cherbow (2022) studied classroom enactment episodes of Mr. Kelly, an experienced middle school teacher with a particularly strong professional background in STEM. The study describes Mr. Kelly's instances of "principled improvisation" during his enactment of OpenSciEd discussion activities. These instances respond to situations where "students' coherence-seeking can deviate from premeditated coherence of the storyline during enactment" (p. 103). The analysis revealed that Mr. Kelly's improvisations across the discussions supported students' epistemic agency in enactment. For example, in one discussion, Mr. Kelly's principled improvisations attended specifically to "1) equitable participation in the sharing of questions and 2) finding consistency among the ideas embedded in questions" (p. 113). These findings are noteworthy because they illustrate a particular teachers' capacity to adapt their instruction in response to students' ideas that emerge from scientific discussions in the classroom. For OpenSciEd units to be enacted in a way that centers student agency, teachers must possess the capacity to respond to students' ideas that may not align with anticipated student sensemaking trajectories.

### *Adjacent Claim: The SEET is useful for gathering student perspectives from classroom enactment.*

While this claim does not respond directly to the synthesis question about classroom enactment, we believe that it is worth noting as an adjacent claim. In the previous section, we summarize the validity evidence for the SEET as described by Penuel et al. (2018). The SEET has been instrumental in supporting claims about students' experiences with the unit during the field test studies, specifically their perceived coherence and relevance of the units and the nature of their classroom participation. Moreover, Krumm et al (2020) remark that "efforts to understand students' opportunities to learn and their experience of instruction using an equity lens should, when possible, gather data directly from students" (p. 2467).

### *Key Enactment Challenges*

The current studies on OpenSciEd enactment point to a handful of primary challenges to classroom enactment, such as:

***Project fatigue.*** While teachers generally reported students are engaged by the phenomena and actively participate in activities, some teachers also reported that students' interest in the anchoring phenomenon declines over time (OpenSciEd, 2020, 2021).

***Unit length and pacing***. In interviews conducted with teachers who participated in OpenSciEd professional development, 20% reported struggling with the length and pacing of units during the field test (Deverel-Rico et al, 2022). Teachers expressed concerns about adhering to time constraints and the feasibility of teaching a full set of six units in a single year. These concerns are consistent with anecdotal accounts described by Edelson et al (2021) about teachers' ability to complete the units on a timeline consistent with the pacing guides.

***Pseudoagency***. Reiser et al., (2021) describe pseudoagency as situations where "students see teachers' attempts to open scientific sensemaking as disingenuous, where teachers ask for students' ideas, but then fail to fully honor them when standards require proceeding in other directions." (p. 808). For example, in the analyses of Mr. Kelly's planning and reflection cycles, Mr. Kelly discusses his decision not to provide students with a physical workbook spanning multiple lessons, in order to avoid "the unwarranted perception among students that they are not the primary drivers of knowledge-building." (Cherbow, 2021, p. 50). The analysis of Mr. Morse's enactment (Lowell et al., 2022) revealed that in many discussion sequences students interacted only with Mr. Morse to clarify their ideas, rather than with each other, raising questions about whether students might perceive their knowledge-building processes as circumscribed by the curriculum materials.

***Gaps in student sensemaking practices.*** While teachers were generally successful at enacting coherence-building practices, they were less likely to enact sensemaking practices, such as revising previous claims based on evidence or identifying gaps in their explanatory models (Krumm et al, 2020). Based on an analysis of the SEET across three OpenSciEd units, nearly half of the students did not have ideas about questions they should investigate next (OpenSciEd, 2021). Finally, in the analysis of Mr. Morse, while he was successful at surfacing and clarifying ideas across discussion types, there were many fewer instances of him building and evaluating ideas, which are important for building and refining consensus models.

## Question 2: To what extent do OpenSciEd teacher tools and professional learning experiences support teachers to enact OpenSciEd with integrity?

***Preliminary Claim 4: Professional learning experiences change teachers' views about the NGSS and prepare them to implement the materials.***

Analyses of teacher survey responses before and after OpenSciEd PD workshops indicate that the workshops influenced teachers' beliefs away from traditional views and toward views consistent with practice-based science. Teacher belief survey items asked teachers to state the degree to which they agree or disagree with statements such as *Hands-on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned* and *At the beginning of instruction on a science idea, students should be provided with definitions for new scientific vocabulary that will be used*. Analyses of responses from 322 teacher participants who engaged in PD workshops found that teachers' beliefs shifted significantly from the beginning to the end of PD (Lowell, 2022; OpenSciEd, 2019) and that teachers' beliefs changed most dramatically after the first workshop they participated in.

Lowell's (2022) analysis also revealed that the PD workshops increased teachers' implementation confidence. The pre-post survey asked teachers about their level of confidence in being able to implement key routines in OpenSciEd units, such as helping students ask questions, use science practices, and revise explanatory models. As with beliefs, implementation confidence increased over the course of initial PD experiences and leveled off over time. In the analysis of teacher interviews by Deverel-Rico et al. (2022), many teachers also reported increases in confidence with implementing routines, such as the Anchoring Phenomena and Navigation routines. These increases occurred over the course of multiple rounds of unit enactment and PD workshops, so the shifts cannot be attributed entirely to the professional learning experiences.

Finally, teachers reported that PD workshops prepared teachers to use and adapt the materials for their classrooms. Ninety-one percent of teachers reported feeling well prepared to adapt units for emerging multilingual students, and 85% reported feeling well prepared to adapt units for special education students. (OpenSciEd, 2020).

### *Preliminary Claim 5: "Student hat" activities and tools for planning and reflection support teachers' curricular sensemaking.*

To date, published studies focus on the affordances of two specific OpenSciEd supporting activities and tools: the "student hat" professional learning activities and a discussion planning tool. These studies document ways that teachers' experiences contribute to their sensemaking about OpenSciEd curriculum and students' perspectives.

The student hat (Lowell, 2022; Lowell & McNeill, 2020) refers to engaging teachers in curriculum activities in a way that embodies how they believe their students would engage in the activity. The underlying rationale for the student hat is to support teachers' understanding of student-perceived coherence of the unit, better enabling teachers to address and adapt to ideas that students bring to the investigation. In this way, the student hat has the potential to be uniquely beneficial for supporting teachers to enact storyline units because of their emphasis on students' perspectives, ideas, and agency. Studies of the student hat analyzed video recordings of teachers engaged in student hat activities during OpenSciEd professional development workshops and interviews with teachers. These analyses revealed that the student hat activities supported teachers' learning about science content ideas, their students, and the OpenSciEd instructional approach. In particular, teachers reported that student hat activities helped them empathize with their students, strengthened their understanding of content ideas and key features of the storyline approach, and supported teachers' planning and reflection around classroom enactment.

OpenSciEd teacher supports include a discussion planning tool that is designed to support teachers' planning, enactment of, and reflection on classroom discussions that occur across OpenSciEd lessons in a unit. Class discussions to elicit students' initial ideas, build understanding, and develop consensus are centrally featured in OpenSciEd's curricular approach, so tools to support teachers in facilitating these discussions are strongly aligned to OpenSciEd teacher professional learning goals. Cherbow (2021) and Cherbow and McNeill (2022) report on a case study of the aforementioned Mr. Kelly, who was deeply engaged in the use of the discussion planning tool (in collaboration with Dr. Cherbow) across all three discussion types (initial ideas, consensus, building understanding). The analyses highlight three themes in Mr. Kelly's sensemaking over the course of the planning and reflection cycles. First, Mr. Kelly navigated "tension between the coherence that was planned for in the storyline materials and his enactment of these materials in a manner that is coherent from the student perspective" (Cherbow & McNeill, 2022, p. 20). Mr. Kelly found new ways to address the lack of overlap between students' ideas and the premeditated coherence of the storyline. Second, Mr. Kelly addressed "tensions between his efforts to equitably involve all students in knowledge-building and his facilitation of students' incremental disciplinary understanding across the curriculum." (p. 25). Discussion planning supported Mr. Kelly in noticing and addressing tensions between promoting equitable participation and other goals such as promoting conceptual depth, adhering to time constraints, and enabling students' epistemic ownership of their scientific ideas. Third, Mr. Kelly "regularly confronted ambiguity concerning the variable forms of epistemic agency available to students in different discussion types" (p. 29). Through planning and reflection, he made increasingly nuanced distinctions between the epistemic functions and knowledge-building goals of initial ideas, consensus, and building understanding discussions.

### *Key Teacher Supports Challenges*

The current OpenSciEd research studies point to several challenges to supporting teachers to enact OpenSciEd. One concern is the implementation of student hat professional learning activities. Teachers articulated in interviews that they found engaging in student hat activities challenging in numerous ways (Lowell, 2022). The most common challenges reported were (1) their struggles to separate their own knowledge from what they thought students might know, (2) their perceptions of the student hat as not representative of real classroom enactment, and (3) their views that the activity limits their capacity to think about appropriate teacher moves. The analysis also noted that some teachers would unintentionally break from the student hat role during the activities.

Another challenge concerns teachers' capacity to engage deeply in discussion planning and reflection cycles as intended by the OpenSciEd discussion and planning tool. Mr. Kelly's experience included more than 15 years of middle school teaching, a strong disciplinary background in STEM, and prior design and enactment of practice-based science units. He was also supported in the planning and reflection cycles by one-on-one meetings with a researcher. Cherbow and McNeill (2022) characterize Mr. Kelly's planning, enactment, and reflection cycles as a partnership with students with the broader goal of "developing and managing the trajectory of their knowledge-building in the curriculum" (p. 36) and acknowledge that "novice teachers and teachers with limited experience with reform curricula will likely be less capable to initially engage this partnership" (p. 36).

Finally, a broad challenge around supporting teachers to enact OpenSciEd concerns the extent to which teachers will have access to and participate in professional learning activities. Edelson et al. (2021) raise the questions, "what percentage of adopting schools and districts will facilitate professional learning to teachers, and what quantity and quality of professional learning will they provide?" (p. 800). The status of OpenSciEd instructional and professional learning materials as open and freely available raises broad concerns about whether adopting districts will choose to abridge, or even forgo, professional development experiences for teachers and what impact these decisions will have on teachers' enactment and students' experiences with the units. We discuss this issue in more detail below.

# Discussion

To date, OpenSciEd research studies have aimed primarily to characterize students' and teachers' experiences with the units during enactment, teachers' instructional practices, and changes in teachers' knowledge and beliefs from professional learning experiences and sensemaking activities. Empirical findings provide preliminary evidence that unit enactment promotes equitable engagement and participation, students perceive the units as coherent and relevant, and teachers can facilitate rich science discussions across lessons. These three characteristics are cornerstones of OpenSciEd's design approach and instructional model. Findings that show student participation and relevance to be equitable across students of different races are especially promising. The findings also provide preliminary evidence that professional experiences have their intended impacts on teachers' knowledge, beliefs, and confidence related to practice-based science curriculum and instruction.

An important issue to raise concerning OpenSciEd enactment is that teacher-to-teacher variation appears to be measurably greater than lesson-to-lesson variation. For instance, the field test analysis from Krumm et al. (2020) found that teachers' enactment of practices differed from one another to a greater extent than they varied for individual teachers from lesson to lesson, even though all teachers in the field test participated in a full OpenSciEd professional learning experience led by members of the OpenSciEd development consortium. This finding is noteworthy because, eventually, teacher variation is expected to be even wider across teachers who do not participate in professional learning (or have an abridged experience). In instructional contexts where teachers download the instructional materials without engaging in professional learning activities, teachers' capacity to enact OpenSciEd with integrity to its distinctive principles will likely be greatly diminished. This issue gives rise to important future research opportunities (discussed below).

## Study Limitations

We identify four main types of limitations to the empirical studies synthesized above. These limitations include the small number of available studies, COVID-19 pandemic-related disruptions, other limits to study generalizability, and limitations in the types of data collected.

***Small number of available studies.*** With the recent completion of the field test studies and public release of the full course of middle school materials, all the empirical research publications so far have been co-authored by researchers who were part of the OpenSciEd middle school development consortium (and had access to field test data and participants). Over time, new studies will emerge as school districts increasingly adopt OpenSciEd, materials at other grade bands are developed and released, and investigators are able to procure funding for new research studies.

***COVID-19 pandemic-related disruptions.*** Field test classroom enactment was highly disrupted by the COVID-19 pandemic. School districts' shifts to remote instruction precluded the enactment of the materials as they were designed. Teachers' enactment would likely have been more successful under typical instructional conditions than was reported in studies conducted during periods of remote instruction.

***Other limits to generalizability.*** Initial OpenSciEd research studies appropriately examined teachers under some favorable conditions (remote instruction notwithstanding). As previously mentioned, all teachers in the field test participated in the full course of high-quality professional learning sessions, which will not be true of all teachers and districts who adopt and implement OpenSciEd completely under their own support. Furthermore, the case studies examined experienced teachers who had previous experience with practice-based science curriculum materials. While their selection as study subjects was appropriate for the research questions being investigated, their experiences will not necessarily reflect typical teachers' experiences during enactment or professional learning.

***Limitations in types of data collected in enactment studies.*** The published findings on classroom enactment draw primarily from analyses of the SEET, teacher surveys, teacher interviews, and case study analyses of individual teachers. Classroom observations conducted at a broader scale were not part of the field test research design, and the field test collected a limited amount of data on students' three-dimensional learning. These data will be needed to support additional claims about examples such as teachers' instructional moves and student learning outcomes.

## Opportunities for Future Research

This research synthesis points to several salient opportunities to further OpenSciEd research. We organize these opportunities according to the four themes identified in our previous Research Agenda: student agency and participation, promoting the Framework vision, materials customization and adaptation, and sustainable adoption and implementation.

***Student agency and participation.*** The current research studies identify key tensions faced by curriculum designers and teachers around promoting student agency. New research studies should investigate ways to address these tensions. One tension is the challenges teachers and designers face in balancing the need to surface and investigate students' questions against the requirement to address performance standards. A second tension is between teachers' role as the orchestrator of discussion and the benefits of students autonomously interacting with and engaging in discussions with each other. A third tension is between OpenSciEd's goal of building consensus and the affordances of other approaches that instead seek heterogeneity (Pierson et al., 2022). These tensions have implications for promoting equity in the classroom and represent potentially rich topics for research studies on the design of instructional materials, student learning, teaching, and teacher professional learning.

*Promoting the Framework vision.* While the evidence for students' engagement in practice-based science is promising, a salient gap in the current studies is the lack of available evidence of NGSS-based student outcomes. Studies characterizing students' three-dimensional learning based on learning artifacts (such as embedded assessment tasks or modeling artifacts) can leverage existing features and resources in OpenSciEd and provide further evidence that units promote equitable learning outcomes. Rigorous impact studies of OpenSciEd will depend on rigorously designed NGSS-aligned assessments supported by strong validity evidence. The development of such high-quality assessments remains a high priority for the science education research community.

*Materials customization and adaptation.* As an open educational resource, a key affordance of OpenSciEd is its capacity to be customized and adapted. While some of the current studies identify ways that teachers make small-scale adaptations in response to their students' ideas, these initial studies did not aim to examine the kinds of broader design customizations that can meet the needs of specific student populations, districts, or communities. For example, customizing OpenSciEd for multilingual learners or students with physical disabilities is a key equity consideration. Customizations districts make to teachers' professional learning materials in order to satisfy local constraints will also be an important issue to explore. A key question about customized materials is the extent to which they will maintain integrity to OpenSciEd's underlying commitments, or if they will be "watered down" versions of the certified, publicly-released materials that have empirical backing.

*Sustainable adoption and implementation.* As indicated above, all the available empirical studies addressed classroom enactment or teacher supports. No studies investigated questions about district adoption or state-level policies. As such, these questions represent a wide-open area for future OpenSciEd research. Though there are many directions for research studies in this space, the currently published work indicates that the role of teacher professional learning should inform how districts adopt OpenSciEd as an issue for immediate study. As a freely available resource, districts that adopt OpenSciEd would ideally direct resources typically allocated for curriculum materials toward teacher professional learning. Yet, many teachers will likely use the instructional materials without having any professional learning experiences. Lack of access to professional learning is also an equity issue, as districts with the fewest resources (who seek OpenSciEd as a lower-cost alternative) may also experience the greatest challenges in providing professional learning for teachers. Researchers should examine ways to encourage districts to provide professional learning for their teachers and study the enactment experiences of teachers who use OpenSciEd but lack support for their professional learning. These studies will help characterize and promote sustainable district adoption and implementation models for OpenSciEd.

## A Preliminary ESSA Tier 4 Argument

The Every Student Succeeds Act (ESSA) requires states to develop plans for improving outcomes for students in all districts. ESSA guidelines identify four tiers of methodological rigor for evidence-based research in educational interventions. Tier 1 (Strong Evidence) requires an experimental (e.g., randomized) design. Tier 2 (Moderate Evidence) requires a quasi-experimental (e.g., matched) design. Tier 3 (Promising Evidence) requires a correlational study with statistical controls. Tier 4 (Demonstrates a Rationale) requires a "well-defined logic model based on rigorous research" and that "an effort to study the effects of the intervention is planned or currently underway" (Regional Educational Laboratory at American Institutes for Research, 2019, p. 2). These tiers are important because they help districts determine whether interventions have supporting evidence for improving outcomes for students. In addition, many federal and state funding opportunities encourage or require districts to implement interventions that meet the criteria for ESSA Tiers 1, 2, and 3.

This paper, combined with the previous paper (which articulates an OpenSciEd logic model), outlines a preliminary ESSA Tier 4 argument for OpenSciEd. The logic model elaborates the rationale for expecting impact based on learning sciences principles, while this synthesis establishes the scope of the current effort to study OpenSciEd's effects and provides a basis for additional evidence gathering. This Tier 4 argument will become more rigorous as more detailed reporting of the field test studies emerges. While a Tier 4 argument alone does not qualify OpenSciEd for district adoption based on ESSA criteria, it does provide a strong foundation to conduct additional OpenSciEd studies that meet the criteria for one or more of Tiers 1, 2, and 3.

An important note is that the evidence tiers do not constitute a strict sequence, as the tiers represent levels of rigor and not necessarily a progression. A research program could start at Tier 4 and move up incrementally, but it may be equally feasible to plan a Tier 1 study that answers at least one research question at Tier 1, but others at Tiers 2 and 3 simultaneously. Some requirements to conduct a Tier 1 study on OpenSciEd include a validated student outcome measure, the ability to recruit 50-100 teachers to participate in (for example) a delayed treatment design, and a plan to provide teacher professional development and other resources consistently at scale. An efficacy study would require the research team's "best effort" to deliver high-quality professional development, while an effectiveness study would require only ordinary efforts. Typically, an efficacy study would precede an effectiveness study.

## Conclusion

This synthesis aims to inform science education community members' efforts to study, implement, and support OpenSciEd. The findings can help researchers identify questions, propose research studies, and conduct analyses. We also hope the insights about classroom enactment and teacher supports can help practitioners and leaders to improve classroom practice, provide high-quality professional learning opportunities for teachers, and devise approaches to adopt and implement OpenSciEd sustainably and equitably. Finally, we believe the findings can inform conversations between state-level policymakers and districts that will help promote successful and widespread OpenSciEd adoption and implementation.

## References


Affolter, R., McNeill, K. L., & Brinza, G. (2022). "Some of you are smiling now:" Supporting trust, risk taking, and equity in your classroom. *Science Scope,* 40–48.

Campbell, T., & Lee, O. (2021). Instructional materials designed for a framework for K-12 science education and the Next Generation Science Standards: An introduction to the special issue. *Journal of Science Teacher Education*, *32*(7), 727–734.

Cherbow, K. (2021). *Exploring the teacher-storyline relationship: Curricular design and enactment for coherence from the student perspective* (K. L. McNeill (ed.)) [Doctor of Philosophy]. Boston College.

Cherbow, K., & McNeill, K. L. (2022). Planning for student-driven discussions: A revelatory case of curricular sensemaking for epistemic agency. *Journal of the Learning Sciences,* 1–50.

Deverel-Rico, C., Allen, A.-R., Penuel, W. R., & Pazera, C. (2022). *Learning to teach with storyline curricula*. 95th Annual International Conference of National Association for Research in Science Teaching, Vancouver, British Columbia.

Edelson, D. C., Reiser, B. J., McNeill, K. L., Mohan, A., Novak, M., Mohan, L., Affolter, R., McGill, T. A. W., Buck Bracey, Z. E., Deutch Noll, J., Kowalski, S. M., Novak, D., Lo, A. S., Landel, C., Krumm, A., Penuel, W. R., Van Horne, K., González-Howard, M., & Suárez, E. (2021). Developing research-based instructional materials to support large-scale transformation of science teaching and learning: The approach of the OpenSciEd middle school program. *Journal of Science Teacher Education, 32*(7), 780–804.

Krumm, A., Penuel, W. R., Pazera, C., & Landel, C. (2020). *Measuring equitable science instruction at scale*. In M. Gresalfi & I. S. Horn (Eds.), The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020 (pp. 2461–2468).

Lowell, B. R. (2022). *Supporting science teacher learning in curriculum-based professional development* (K. L. McNeill (ed.)) [Doctor of Philosophy]. Boston College.

Lowell, B. R., Cherbow, K., & McNeill, K. L. (2022). Considering discussion types to support collective sensemaking during a storyline unit. *Journal of Research in Science Teaching, 59*(2), 195–222.

Lowell, B. R., & McNeill, K. L. (2020). *Using the student hat to push on multiple goals in teacher professional learning*. In M. Gresalfi & I. S. Horn (Eds.), The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020 (pp. 2241–2244).

McElhaney, K., Baker, A., Kasad, Z., Roschelle, J., & Chillmon, C. (2022, March). A field-driven, equity-centered research agenda for OpenSciEd: Updated version [White paper]. Digital Promise. https://doi.org/10.51388/20.500.12265/153.

McElhaney, K., Baker, A., Chillmon, C., Kasad, Z., Liberman, B., & Roschelle, J. (2022, March). An initial logic model to guide OpenSciEd research: Updated version [White paper]. Digital Promise. https://doi.org/10.51388/20.500.12265/152.

McNeill, K. L., & Affolter, R. (2020). *Design of OpenSciEd professional learning*. In M. Gresalfi, I. S. Horn, N. Enyedy, H.-J. So, V. Hand, K. Kackson, S. E. McKenney, A. Leftstein, & T. M. Philip (Eds.), Proceedings of the International Conference of the Learning Sciences (Vol. 5, pp. 2558-2560). International Society of the Learning Sciences.

McNeill, K. L., Affolter, R., & Clinchot, M. (2021). Shifting from learning about to figuring out: PD resources to support classroom change. *Science Scope, 45*(2).

National Research Council (NRC). (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press.

OpenSciEd. (2019). *2018-2019 research report to participating districts*. [White paper]. OpenSciEd.

OpenSciEd. (2020). *OpenSciEd middle school summary report: Fall 2020 data collection*. [White paper]. OpenSciEd.

OpenSciEd. (2021). *OpenSciEd report for participating school districts, overview of findings: Round 6*. [White paper]. OpenSciEd.

OpenSciEd (2022). *OpenSciEd: Science materials for teachers - Open educational resources*. https://www.openscied.org/

Penuel, W. R., Allen, A.-R., Henson, K., Campanella, M., Patton, R., Rademaker, K., Reed, W., Watkins, D., Wingert, K., Reiser, B., & Zivic, A. (2022). Learning practical design knowledge through co-designing storyline science curriculum units. *Cognition and Instruction, 40*(1), 148–170.

Penuel, W. R., Van Horne, K., Jacobs, J. K., & Turner, M. (2018). *Developing a validity argument for practical measures of student experience in project-based science classrooms*. Paper presented at the annual meeting of the American Educational Research Association, New York, NY.

Pierson, A.E, Brady, C.E., Clark, D.B., & Sengupta, P. (2022). *Epistemic commitments: A lens for heterogeneity in science*. In C. Chinn, E. Tan, C. Chan, & Y. Kali (Eds.). Proceedings of the 16th International Conference of the Learning Sciences - ICLS 2022 (pp. 885-888). Hiroshima, Japan: International Society of the Learning Sciences.

Regional Educational Laboratory at American Institutes for Research. (2019). *ESSA tiers of evidence: What you need to know* [Handout]. Institute of Education Sciences. https://ies.ed.gov/ncee/edlabs/regions/midwest/pdf/blogs/RELMW-ESSA-Tiers-Video-Handout-508.pdf

Reiser, B. J., Novak, M., McGill, T. A. W., & Penuel, W. R. (2021). Storyline units: An instructional model to support coherence from the students' perspective. *Journal of Science Teacher Education, 32*(7), 805–829.

## Appendix: Summary of Research Papers on OpenSciEd

| Citation | Article Type | Focus | Data Sources / Methods | Participants | Demographics | Discipline, Unit, Grade Level |
|---|---|---|---|---|---|---|
| Affolter, R., et al. (2022) | *Journal* | *Design (teacher professional learning)* | *Descriptive* | *n/a* | *n/a* | *n/a* |
| Campbell, T., & Lee, O. (2021) | *Journal* | *Design (instructional materials)* | *Synthesis* | *n/a* | *n/a* | *n/a* |
| Cherbow, K. (2021) - Paper 1 | *Dissertation* | *Classroom enactment* | *Case study: Teacher interviews, discussion logs* | *One middle school teacher and their students* | *Students:*<br>*73% Free and Reduced Lunch*<br>*95% Non-White*<br>*30% Multilingual*<br>*24% disabilities* | *PS: Forces at a Distance (7th)* |
| Cherbow, K. (2021) - Paper 2 | *Dissertation* | *Classroom enactment* | *Case study: Teacher interview; discussion logs* | *One middle school teacher and their students* | *Students:*<br>*73% Free and Reduced Lunch*<br>*95% Non-White*<br>*30% Multilingual* | *PS: Forces at a Distance (7th)* |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | *24% disabilities* | |
| Cherbow, K. (2021) - Paper 3 | *Dissertation* | *Teacher supports* | *Conceptual* | *n/a* | *n/a* | *n/a* |
| Cherbow, K., & McNeill, K.L. (2022) | *Journal* | *Classroom enactment* | *Case study: Teacher interviews, discussion transcripts and artifacts* | *One middle school teacher and their students* | *Students:*<br>*73% Free and Reduced Lunch eligible*<br>*95% Non-White*<br>*30% Multilingual*<br>*24% disabilities* | *PS: Forces at a Distance (7th)* |
| Deverel-Rico, C., et al. (2022) | *Conference paper* | *Teacher Supports* | *Teacher interviews* | *36 middle school teachers* | *Not specified* | *Multiple units (unspecified)* |
| Edelson, D.C., et al. (2021) | *Journal* | *Design (instructional materials)* | *Descriptive* | *n/a* | *n/a* | *n/a* |
| Krumm, A., et al. (2020) | *Proceedings* | *Classroom enactment* | *Teacher logs, student exit tickets* | *259 teachers* | *Teachers:*<br>*90% Female*<br>*82% White*<br>*7.3% Native Hawaiian or Pacific Islander* | *Multiple units (unspecified)* |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | *3.5% Multiracial*<br>*3.1% Black* | |
| Lowell, B.R. (2022) - Paper 1 | *Dissertation* | *Teacher supports* | *Teacher surveys* | *322 teachers* | *Teachers:*<br>*72% Female*<br>*77% White*<br>*Average years of teaching*<br>*experience: 12.2* | *PS: Light & matter (6th)*<br>*PS: Contact forces (7th)*<br>*PS: Chemical reactions & matter (8th)* |
| Lowell, B.R. (2022) - Paper 2 | *Dissertation* | *Teacher supports* | *Conceptual* | *n/a* | *n/a* | *n/a* |
| Lowell, B.R. (2022) - Paper 3 | *Dissertation* | *Teacher supports* | *Case study: Teacher interviews* | *32 teachers* | *Teachers:*<br>*66% identified*<br>*as women*<br>*34% identified as men*<br>*75% from large city*<br>*25% from small city* | *PS: Light & matter (6th)*<br>*PS: Contact forces (7th)*<br>*PS: Chemical reactions & matter (8th)* |

| | | | | | | |
|---|---|---|---|---|---|---|
| Lowell, B.R., & McNeill, K. L. (2020) | *Proceedings* | *Teacher supports* | *Video recordings, teacher interviews* | *37 teachers* | *Not specified* | *PS: Light & matter (6th)* |
| Lowell, B.R., et al. (2022) | *Journal* | *Classroom enactment* | *Case Study: classroom recordings* | *One middle school teacher and their students* | *Students:*<br>*47% free or reduced lunch eligible*<br>*90% students of color*<br>*3% multilingual learners*<br>*4% having a disability* | *LS: Metabolic Reactions (7th)* |
| McNeill, K.L., et al. (2021). | *Journal* | *Design (teacher professional learning)* | *Workshop observations* | *70 teachers* | *Not specified* | *How do things inside our bodies work together to make us feel the way we do?* |
| OpenSciEd (2019) | *White Paper* | *Classroom enactment and teacher supports* | *Student exit tickets, teacher logs, teacher* | *More than 200 teachers*<br>*More than 13,000 students* | *Not specified* | *PS: Light & Matter (6th) PS: Chemical* |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | *surveys, teacher interviews* | | | *Reactions & Matter (7th)*<br>*PS: Contact Forces (8th)* |
| OpenSciEd (2020) | *White Paper* | *Classroom enactment and teacher supports* | *Teacher surveys, student exit tickets* | *101 teachers and their students* | *Not specified* | *6 Units (across grade levels)* |
| OpenSciEd (2021) | *White Paper* | *Classroom enactment and teacher supports* | *Teacher surveys, student exit tickets* | *122 teachers and their students* | *Not specified* | *LS: Cells & Systems (6th)*<br>*ES: Earth's Resources & Human Impact (7th)*<br>*LS: Natural Selection & Common Ancestry (8th)* |
| Penuel, W.R., et al. (2018) | *Conference paper* | *Measurement* | *Student exit tickets, teacher interviews, teacher logs* | *19 teachers*<br>*127 students* | *Not specified* | *n/a* |

| | | | | | | |
|---|---|---|---|---|---|---|
| Penuel, W.R., et al (2022) | *Journal* | *Design (instructional materials)* | *Reflective surveys, written reflection, design artifacts, documented discussions* | *19 teachers, 7 researchers and 1 district science coordinator* | *Teachers:*<br>*92% white*<br>*4% Asian*<br>*4% Black* | *High School Chemistry* |
| Reiser, B.J., et al. (2021) | *Journal* | *Design (instructional materials)* | *Descriptive* | *n/a* | *n/a* | *How Can We Sense So Many Different Sounds from a Distance? (middle school)* |