Received: 14 February 2020 | Revised: 7 June 2020 | Accepted: 7 August 2020
DOI: 10.1002/sce.21595

GENERAL SECTION

Science Education WILEY

Consequences of curricular adaptation strategies for implementation at scale

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Abstract

This study examines and compares how developers designed two primary science curricula to support teacher adaptation and enable use of innovative materials at scale. The two cases—*Literacy Science* (a science and literacy curriculum for grades 2–5) *and Science as Inquiry* (a curriculum focused on matter for grades 3–5)—were selected because the curricula shared many key features, yet the designers undertook the challenge of designing for adaptation in substantially different ways. Data sources for analysis included interviews with design team members, the curriculum materials, and a range of project documentation. A comparative case study approach was chosen to enable an examination of key contrasting features within the context of each curriculum. Both curricula provide teachers with supports to enact an inquiry-based curriculum in ways that honor science epistemologies. However, one designer team designed explicitly for adaptation by providing *worked examples* that described a range of possible classroom and learner contingencies, along with alternative solutions. By contrast, the other design 9team sought to *build teachers' pedagogical capacity* by providing access to content and explanations from the cognitive and natural sciences. The paper examines how these design stances informed materials developed to support teachers' content knowledge, as well as students' scientific inquiry and classroom discourse. These approaches represent different points on a continuum of design for adaptation, each with its own consequences for enactment and the design of written materials. The cases provide models for designers seeking to support teachers at scale.

KEYWORDS

curricula, design, scale, science, teacher adaptation

1 | INTRODUCTION

Curriculum development has long been an important strategy for innovating in science education (Deboer, 1991), especially in the past half-century of design and experimentation to transform science education to more authentically reflect science as practiced (Munby, Cunningham, & Lock, 2000; Schwab, 1962). Standards and tests provide only limited guidance to teachers and teacher educators about how to achieve the desired science outcomes; instead a common assumption is that classroom materials, their nature, choice, and implementation are essential mediating tools for the teacher (see, e.g., Berk, 2014; Colson & Colson, 2016; Krajcik, 2014; Puttick & Drayton, 2017). Unfortunately, there is insufficient research on how to design effective curricular materials intended to support the range of teacher use and adaptations likely to be seen during large scale curriculum implementation.

This study addresses the question of how designers can develop curriculum materials that are both supportive of education reform efforts and responsive to the needs of teachers in a variety of implementation settings. Given the wide range of implementation contexts that teachers are likely to encounter in their work, the importance of designing for adaptation cannot be overstated. The literature provides some support for designers on this score (see McKenney & Reeves, 2019), for example by focusing on *how* and *why* teachers enact adaptations in their classrooms (DeBarger, Choppin, Beauvineau, & Moorthy, 2013; Drake & Sherin, 2006; Squire, Makinster, Barnett, Luehmann, & Barab, 2003), by offering ways to think about the alignment between innovative curricula and local contexts (McKenney, 2013), by offering design routines to support activity and assessment design (DeBarger, Penuel, Harris, & Schank, 2010), and by describing ways in which innovations can be made robust to support implementation in multiple contexts (Clarke & Dede, 2009). However, existing research does not offer specific strategies that designers can use to support adaptation at scale, nor does it examine how designers position their own thinking and work with respect to this need. The current analysis addresses this gap by asking the question, *How do designers envision teacher adaptation and use of materials, and how does that vision shape their design of science materials for use at scale?*

In the course of addressing this question, we explicitly probe the relationship between designer beliefs (about the teachers and students they are designing for), the intended enactment of the curriculum, and the use of different design-for-adaptation strategies to support use of the materials at scale. We use case studies of two innovative science curricula to describe different ways of approaching the challenge of designing for adaptation, while highlighting some of the questions and considerations designers may need to ask themselves when choosing a strategy for adaptation.

2 | THEORETICAL FRAMEWORK

In an era when standards, mandates, and definitions of “best practice” in science education are in active development, curriculum development cannot be understood as the creation of a product that is then delivered and deployed in "the classroom" as is. Rather, designers and teachers have always had to reckon with the dynamic nature of science (NOS), requiring the introduction of new material, or the reinterpretation of science content in light of new disciplinary understandings. They are at the same time coming to terms, on behalf of the learner, with important developments in the understanding of scientific epistemology, and the nature of learning and learning environments. Our analysis has been framed by our understanding of the designer and teacher as complementary and collaborating participants in the work of science education.

2.1 | Shared dilemma of teacher and designer

The standards for science education developed since the early 1990s (e.g. AAAS, 1993; National Research Council, 1996, 2000, 2012) have established "best practices" in science education which reflect the current understanding of the NOS and science practice. While teachers are called upon to incorporate these best practices, designers face a corresponding challenge to develop materials that support both teacher and student learning. Science is understood to be a sociocultural process, and science learning is viewed as a socially embedded process of meaning-making or knowledge construction by the learner (National Academies of Sciences, Engineering, and Medicine, 2018). In this view, students are seen as agents of their learning, gaining skill in scientific practices ranging from observation and data collection to data analysis, representation, argumentation and reasoning, and communication of their knowledge to their learning community.

The need to support teachers in the adoption and enactment of constructivist and sociocultural models of teaching and learning, in line with current understandings of the epistemologies of science (Bransford, Brown, & Cocking, 2000; National Research Council, 2012), has introduced fresh complexities. In particular, the emphasis on students' agency in learning science concepts in the context of science as a practice places large demands on teachers, as they learn to conduct a classroom that may be very different from their own experience of learning or of teaching (Arias, Bismack, Davis, & Palincsar, 2016; Schneider, Krajcik, & Blumenfeld, 2005; Schwab, 1959). Consequently, teacher learning—both of the science that the students are to learn and the pedagogy that facilitates active learning—is of primary concern if the best current understanding of science education is to become broadly implemented (Borko & Putnam, 1996). In the wake of the appearance of the NGSS, a broad literature has sprung up to help teachers with the challenge. Since teacher professional development seems most effective when it is in the context of curriculum to be taught (Darling-Hammond, Hyler, & Gardner, 2017), curriculum materials are seen to be crucial mediators for teachers' becoming "standards aligned" (Berk, 2014; Colson & Colson, 2016; Krajcik, 2014; Puttick & Drayton, 2017). This study involves changes in teachers' understanding of their work, and practical experience in trying new materials and new methods, evaluating the results, and refining practice as a result of experience. It is therefore not a one-time event, but a process that takes time and intentionality.

2.2 | How teachers use curriculum materials

The teacher's expertise and judgment enable discretionary use of curriculum materials in the classroom. As Brown (2011) suggests, teachers interact with curriculum artifacts in a number of ways: they *select* materials, they *interpret* these materials, they *reconcile* their perceptions of the intended goals with their own goals and capacities and constraints of the setting, and they *accommodate* the talents, interests, experiences, and limitations of their students. The research suggests, therefore, that "developers' designs thus turn out to be ingredients in—not determinants of—the actual curriculum" (Ball & Cohen, 1996, p. 6). The actual curriculum implementation is mediated by the teacher (Ball & Cohen, 1996).

As they respond to classroom conditions (including their students' skills and interests), and align new materials with classroom norms and obligations, teachers must adapt the curriculum (Anderson et al., 2018; Arias et al., 2016;

McNeil, Gonzalez-Howard, Katsh-Singer, & Loper, 2017; Squire et al., 2003). This adaptation, which rests on a process of interpretation and selection, may take many forms, and can productively be understood as a design process (Laurillard, 2012). When teachers adapt new materials with unfamiliar pedagogy, conceptual content, or evaluation methods, they can make changes which may render the result, the enacted curriculum, very different from the curriculum as intended by the designers (Anderson et al., 2018; McNeill, 2009; Schneider et al., 2005). The long-standing cultural presumption of teachers' control of classroom process and discourse (Duschl, Schweingruber, & Shouse, 2007; Herbel-Eisenmann, 2007; Puttick, Drayton, & Karp, 2015) may be more likely to surface in practice when a teacher is working with a curriculum for the first time, and especially if the curriculum's ideal enactment requires changes in a teacher's practice: changes will naturally be influenced by the teacher's background and educational philosophy (Arias, et al., 2016; Cohen, 1990; McNeill, 2009). Thus arises the paradox that in the earliest stages of implementing a new curriculum, a teacher may enact the curriculum with much apparent fidelity, but not with full understanding; as familiarity and ownership increase, the teacher's agency will grow as well (Hall & Hord, 1987), and their preferences, philosophy, and *habitus* (Bourdieu, 1980; Mauss, 1934) as practitioners will reshape the curriculum. This paradox is well known to most curriculum designers (Kanter, 2010; Schneider et al., 2005; Snyder, Bolin, & Zumwalt, 1992).

Given the important mediating role played by the teacher, two important questions arise for designers creating materials for large-scale use: how are teachers likely to adapt curriculum materials, and what factors impact those adaptation choices? A recent review of teacher implementation literature by Davis et al. (2016) suggests that teachers sometimes make changes to reduce the “cognitive demand” of curriculum tasks, and reshape materials to accommodate the new material into their current practice rather than involving a deep change in practice (Cohen, 1990). McNeill et al. (2017) examined teachers' implementation of an argumentation curriculum and found three primary factors that impacted teachers' curricular decision making: (1) teachers' understanding of argumentation as an epistemic practice (a limited understanding makes it harder to enact curriculum ideas), (2) teachers as reflective curriculum users (some teachers' choices resulted from reflections on the curriculum's purpose, while others just tried to follow closely along), and (3) the extent to which prior teaching experiences were compatible with the curriculum approach.

2.3 | How should designers respond?

2.3.1 | Designers' models of the teacher

In designing innovative science curricula for use at scale, designers must take account of important contextual factors, such as policy mandates for science education, current notions of best practices in science pedagogy, the availability and affordances of new technological tools, and key characteristics of the students (Barber, 2015; Edelson, 2001; Squire et al., 2003). In addition, designers need to establish for themselves key characteristics of the teachers for whom they are designing. In relation to these models of the teacher, the designer will make a judgment about what aspects of the curriculum-in-design will be novel or challenging for teachers.

The designers' model must also take into account the situational realities of teachers and the environments in which they work. Factors such as the amount of planning time teachers have available before implementing a new curriculum (Nicholas & Ng, 2012), and other factors in school and district culture (Davis et al., 2016), including concurrent reform activities (Falk & Drayton, 2004) have been shown to influence curriculum uptake. Design teams are likely to make assumptions about these factors, which inform a “situational model” for designers. This model, in turn, can have an impact on design work, for example, by suggesting that certainly levels of activity preparation or complexity are unrealistic, or that a particular new technology may be unreliably present, such that alternatives must be considered (Drayton, Falk, Stroud, Hobbs, & Hammerman, 2009).

2.3.2 | Designers' constraints

"The first and most obvious problem is how to construct curricula that can be taught by ordinary teachers to ordinary students and that at the same time reflect clearly the basic or underlying principles of various fields of inquiry" (Bruner, 1960, p. 18). In a constantly moving subject such as science, a new science textbook revision may present a reformulation of a subject domain that reflects trends in the scientific field, and the emphasis in teacher supports will then focus heavily on teachers' catching up with the scientific consensus (as happened in the 20th century in biology, when genetics leapt forward after the explication of DNA and the genetic code, or with the belated introduction of evolution as a core organizing principle). Even when the materials focus on long-established content, designers recognize that some teachers may not be prepared for it, and therefore provide background information sufficient to support them. On this basis, teacher supports are typically designed, often including "educative" elements to support teachers' learning-in-use, in addition to practical or logistical guidance for successful classroom implementation. Davis and Krajcik (2005) define several potential learning targets for teachers using educative materials: content knowledge (i.e., knowledge about the subject they are teaching), pedagogical content knowledge (PCK: i.e., "knowledge of how to teach the content" (Shulman, 1986), and PCK for disciplinary practices (i.e., knowledge of how to engage students in authentic disciplinary practices; Bond-Robinson, 2015; Grayson, n.d.). Indeed, research suggests that the level of teacher support provided in a curriculum can positively impact implementation (Pareja-Roblin, Schunn, & McKenney, 2018; Stein & Kaufman, 2010).

Sometimes direct evidence about what support is needed is available to guide designers' work. For example, Davis et al. (2014) based their development of educative curriculum features on a close analysis of existing curriculum materials, classroom enactment, and student outcomes. Whether or not this type of data is available, designers must collect more specific sources of input, such as data from pilot tests of their materials, to reinforce or correct their professional judgment about what kinds of support to provide for teachers (Drayton & Puttick, 2016; Wiser, Smith, & Doubler, 2012).

2.3.3 | Designing for adaptation

In designing curricular materials, designers work in (implicit) collaboration with the teacher (Davis et al., 2014; Remillard, 2005, 2012; Russell, 1997), which means that the designers' task involves both recognizing reform goals and honoring teachers' agency. Throughout the history of reform-oriented curriculum development, the pendulum has swung between the extremes of *designer control* in the form of "teacher proof" curriculum with a high value placed on fidelity of implementation and *teacher control* with an emphasis on teacher-developed curriculum materials (Snyder et al., 1992; also see p. 131 of Davis et al. 2016). A middle ground can be seen in the idea of *mutual adaptation*, which acknowledges that a natural variation in enactment is inevitable when materials are used in different settings, with different resources, and at different levels of acceptance for the innovation. This approach encourages designs that are tolerant of local adaptations (McKenney & Reeves, 2019) while avoiding "lethal mutations" (Brown & Campione, 1996) that would undermine the innovation. With this approach, designers concern themselves with the *integrity* of implementation, and the congruence with the goals and principles underlying the curriculum (Penuel, Phillips, & Harris, 2014). If curricula are to be used widely and under diverse conditions (Penuel & Fishman, 2012) which require teachers to engage in the (re)design of the materials for their students and situation, e.g. in an under-resourced school (McKenney, 2013; Roehrig, Kruse, & Kern, 2007), designers must design with adaptation in mind. For example, Kirshner and Polman (2013) describe two educational interventions enacted in different school contexts. In both cases, the dialogic nature of the intervention enabled local adaptations that were compatible with the schools' values. Similarly, Clarke and Dede (2009) describe an approach to creating tolerant designs that can retain efficacy even when, "major aspects of an innovation's design may not be enacted as intended by its developers (p. 355)". In both of these cases, the designers made choices about where teachers would need adaptation/integration support.

3 | FOCUS OF THE STUDY

We assert that designing for adaptation is a pivotal decision that designers make in response to the challenges of designing curriculum for use at scale. While there is a rich existing literature on curriculum design (e.g., Thijs & van den Akker, 2009; Walker, 1990), educative curricula (e.g. Davis & Krajcik, 2005), and studies of teacher use of curricula (e.g., McNeill et al., 2017), none of this study explicitly explores this issue with empirical evidence from designers. Therefore, our research question is: *How do designers envision teacher adaptation and use of materials, and how does that vision shape their design of science materials for use at scale?* Our contribution to the literature is to examine how designers understand the needs of teachers and how that understanding shapes the types of adaptations they envision to support use at scale.

Our operationalization of scale is informed by Coburn's (2003) four dimensions: depth, sustainability, spread, and shift in ownership. Depth is about change in teachers' understanding about the nature of learning, of science, and of pedagogy, such that classroom practice, and the norms of social interaction, are altered. Sustainability is whether conditions in the innovating classrooms or schools are such that the innovation becomes a durable element in the system. Spread of an innovation may be evaluated in terms of numbers of users. But spread may also be considered as *internal* spread to other classrooms taught by the same teacher, by other teachers in the same school, by teachers in other grade levels, or by other schools in the district. Finally, shift in ownership refers to whether authority for the reform is held by districts, schools, or teachers to sustain, spread, and deepen the reform.

4 | METHODS

4.1 | Comparative case study

This comparative case study (Yin, 2009) is situated within a larger project examining the design of science curriculum for use at scale, using a corpus of six projects (Bernstein, Drayton, McKenney, & Schunn, 2016; Bopardikar, Bernstein, Drayton, & McKenney, 2020). The project worked with curriculum design teams at two different institutions that design for, and conduct research on, STEM Education. Both of these institutions are aware of the challenges of designing for use at scale, and both have a successful track record with curriculum products that have gone to scale. Two cases (one from each institution) were selected because they were designed for wide use in terms of both significant numbers of users and diverse classroom settings, they shared important features (i.e., stances towards science and science learning, and their model of the teacher), and yet undertook the challenge of designing for adaptation in substantially different ways. This contrast makes possible a comparison of contrasting adaptation strategies to understand the implications for design.

4.1.1 | Literacy science (LS)

LS is an elementary school science/literacy curriculum, designed for grades 2–5. The curriculum is, in part, a response to a major U.S. policy started in 2001, which mandated state testing almost exclusively in reading and math. Classroom instructional time was reallocated to accommodate this focus on reading/math, often at the expense of time for science in the elementary grades. LS embodied a strategy in response, creating a science curriculum that could be implemented during literacy blocks. Each curriculum unit balances science and literacy activities, down to the detail of labeling some sessions as "science," some as "literacy" and some as both. LS provides students with access to every essential concept to be learned in a unit through a range of different learning modalities—called the Do-it, Talk-it, Read-it, Write-it approach. Each modality provides opportunities for students to apply, deepen, and extend their knowledge of that concept. The intended outcomes in science focus on science content knowledge, science practices, and the NOS, the term for the epistemologies of science current at the time. In addition, the curriculum design made use of research on learning progressions in making choices about content and sequence.

The LS materials include an extensive teacher guide, student notebooks, a summative assessment book, and several slender student books associated with each unit. Student investigation notebooks contain detailed directions about how to carry out different investigations (e.g., details about how many experimental trials students should carry out). Storybooks are used to contextualize inquiry activities, serving sometimes as a connection to what "real scientists" do, and other times as an overview of the inquiry process students are about to carry out. Some of these also include profiles of scientists or other workers in relevant fields, who serve in a sense as guides or motivators, as well as providing a human face on the sometimes abstract science content. Glossaries provide an introduction to unit science content by defining a few key terms.

4.1.2 | Science as inquiry (SI)

The SI project developed curriculum on the basis of prior research on a learning progression for matter and atomic molecular theory for grades 3–5. The SI materials are markedly different from the LS—the teacher materials per unit are less extensive, and the student materials are even more spare. An SI designer told us that they provided "materials for the children, and a curriculum for the teacher." The activities were to be introduced, contextualized, and overseen by the teachers, so that curricular control of student tasks was left very much to the teacher's discretion, within the constraints of the learning sequences and the guidance given about what made for productive scientific conversation in the elementary classroom.

The teacher materials are spare, with perhaps two pages of science background per unit, and a chart relating each unit's activities to the science standards and the learning progression underlying the curriculum. Each unit consists of an activity narrative with discussion guide, supplemented by: (1) essays aimed at the teachers from scientists on the science content and from cognitive psychologists on students' ideas; (2) some contextualized video clips on classroom discourse; and (3) videos for the teacher of scientists talking aloud while performing the student activities. "Concept cartoons" designed to elicit students' thinking are provided for assessment. Other opportunities for formative assessment of students' evolving understandings are noted throughout the units.

4.2 | Data sources

To learn about the designers' vision for supporting teachers at scale, we analyzed a subset of the broader project data, including project documentation, published curriculum materials, and six interviews with key project staff on each project (including the Principal Investigator and designers from different phases of each project). A wide range of document types were obtained, including grant proposals, annual and final reports to funders, evaluation reports, research reports, journal publications, curriculum materials (e.g., student and teacher books/guides), conference presentations, project memos, and project websites. The interviews addressed: designers' understandings of the likely strengths and weaknesses of their ideal teacher audience; how designers consider their core intentions given various settings, resources, and constraints; how designers attend to those considerations when envisioning enactment of the curriculum; and how attention to those considerations are actually manifested in the curriculum (see Bopardikar et al., 2020, for additional details).

4.3 | Procedures

Documents were used to develop a project profile including information about structural characteristics of the curriculum, a chronology of the design process, and the extent to which the project had achieved scale. Thereafter, two rounds of structured interviews were conducted. First, an initial interview with the project PI and senior staff was held to confirm the results of the document analysis. Following this, a second round of individual interviews was conducted with project designers, researchers/evaluators, and project leaders.

While the construction of each case study was informed by all of the documents described above, the current analysis draws primarily from two data sources—interviews with the curriculum design team, and the print materials produced by each curriculum team. Data analysis began with the design team interviews. The interviews were iteratively read and analyzed by the first two authors, who met frequently to discuss themes related to teacher support and adaptation emerging from the data (Miles, Huberman, & Saldana, 2014). Some of these early themes included "model of teacher" (e.g., teacher comfort/discomfort with different elements of the curriculum, teacher learning), "model of student" (e.g., student thinking), "designer values" (e.g., about teachers, about curriculum materials), "implementation" (e.g., constraints, model of implementation setting), and "materials" (e.g., key design elements). Inductive coding then looked for emergent themes in designers' assumptions about, and responses to, implementation settings and resources.

Curriculum materials were analyzed for the extent to which they included, and the ways in which they provided, support for teacher learning (i.e., teacher content knowledge, PCK for science content, and PCK for inquiry; Davis & Krajcik, 2005), support for teacher adaptation (i.e., procedural supports and accommodation supports; Pareja-Roblin et al., 2018), and support for student inquiry and classroom discourse (i.e., student worksheets, informational text). Two units from the Literary Science curriculum, and the 3rd grade unit from the Inquiry Science curriculum, were selected for this analysis.

Following these initial rounds of qualitative coding, the research team examined both data sources, in addition to the other data collected on each case, to triangulate the conclusions drawn during the first phase of analysis about how each design team approached the task of designing for adaptation (Miles et al., 2014). This triangulation allowed the researchers to corroborate statements made during the design interviews with the actual materials produced, and to consider the explanations provided by designers for *why* and *how* their design decisions were implemented. Figure 1 provides a visual overview of the approach used for each case.

5 | RESULTS

Our research examines how designers envisioned and planned for teacher use and adaptation of curriculum materials at scale. To address this question our analysis highlights both shared design principles, and the ways in which the differing designs reflected each team's adaptation strategy. Figure 2 describes the relationship between key principles that designers seek to support in enactment (also called envisioned enactment), general strategies for supporting teacher adaptation of the materials (i.e., via worked examples or capacity building), and more specific characteristics of the teacher and student written materials that are designed to meet those goals. We begin with a description of the shared key principles that are a foundation to both curricula and inform understanding of the unique features. We then move to the unique key principles to support in enactment, followed by the two different strategies used to support teacher adaptations that then result in specific written materials. These analyses both provide evidence for the use of these general adaptation strategies in curriculum design as well as serve as worked examples to other curriculum designers for how to apply these strategies in curriculum designs.

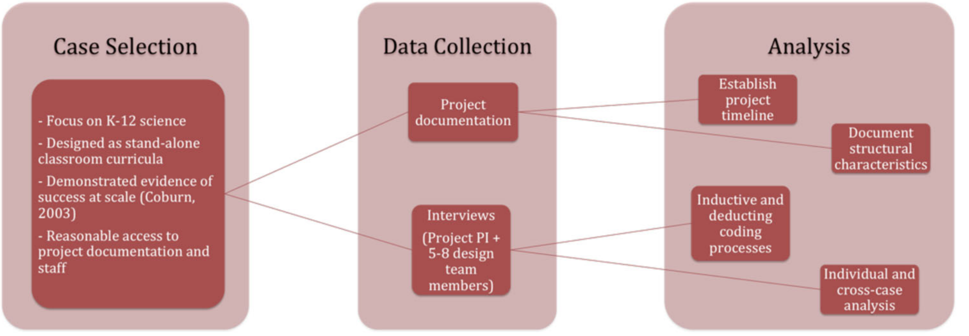

FIGURE 1 Methods overview [Color figure can be viewed at wileyonlinelibrary.com]

5.1 | Shared key principles

5.1.1 | Science is a sociocultural process

Both curricula have similar visions of what is most important in science and science learning—the foundational elements for productive enactments of science teaching. For example, the designers of both curricula view science as a sociocultural process. Thus, in both curricula, the assumption is that science involves both the investigation of phenomena in the natural world and the public discussion of such investigations. Similarly, both curricula espouse a sociocultural view of how learning happens. The teacher and the students are both important factors in the learning experience, and these are made explicit in various ways (and to varying degrees) in the context of the *kind of process* the students are engaged in, in which the principal focus is not primarily to learn what the experts have found, but to experience sense-making inquiry in increasingly productive forms. The teacher's role as envisioned assumes an informed understanding of the students' experiences as naïve learners, for whom the content and the processes of

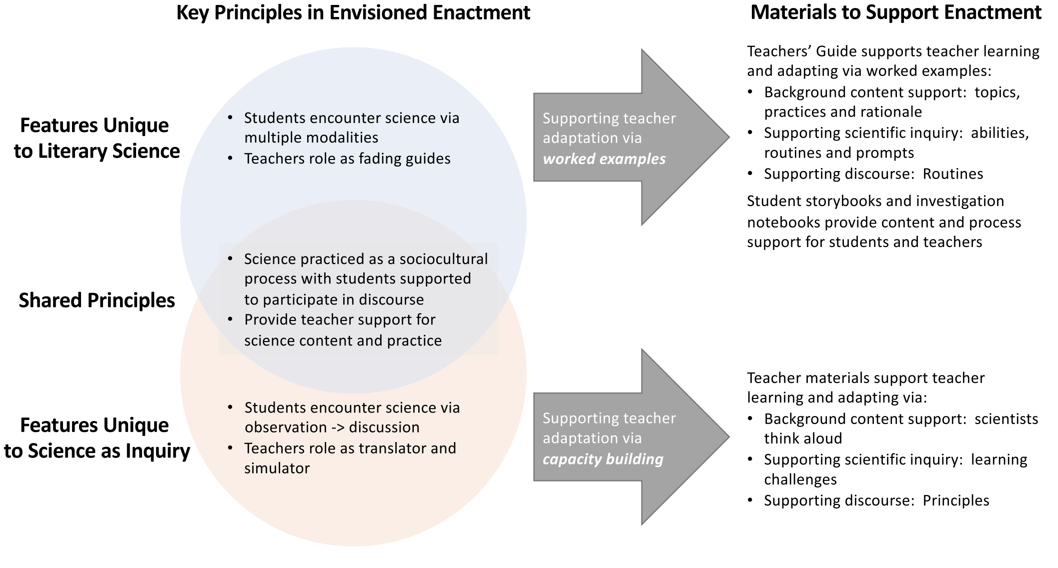

FIGURE 2 From visions of enactment to written materials via two different adaptation strategies [Color figure can be viewed at wileyonlinelibrary.com]

science are novel, and for which they need both explicit guidance and exemplification by a more experienced learner/investigator—the teacher.

5.1.2 | Provide teacher support for science content and practice

Both projects also had similar assumptions about what the teachers would most commonly have present. First, the models of teachers were not principally deficit models. For example, both curricula assumed that teachers' strengths will include classroom management and attentiveness to the students. Thus, the designers can build upon this expertise to support the use of specific classroom methods, inherent in the curricular design, such as inquiry pedagogy and supporting students' science argumentation and discourse. At the same time, the designers in both projects made some assumptions about gaps in elementary teachers as teachers of science. Based on extensive research on elementary science teaching (e.g., Banilower et al., 2018), designers assumed that their "target teacher" may not have taught science before, may not know much science, and likely will not themselves have learned science in a classroom whose pedagogy approximates the practices the curricula expect of them. Thus, teachers may be ill-prepared to understand either the learner's experience or the curricular intent without a fair amount of support. As one designer from the SI project told us,

> *it was pretty clear that if this was going to be used by any but a very select group of 3rd through 5th grade teachers, that one had to assume that the teachers were coming into this with [limited] science training.*

Therefore both teams of designers felt teacher support was imperative to successful implementation. As one LS designer said, the project was committed to, "supporting teachers in strengthening their own professional knowledge and skill set and bolstering their confidence by providing lots of on ramps for them." Similarly, an SI designer observed that reflecting on the limits of some teachers' prior knowledge "helped us to think about how much support we needed to provide for teachers." This perhaps is especially important in the SI curriculum because the activities themselves are simple, and without an understanding of the depths and sophistication of conceptual growth that these activities could foster, they could be done in a way that missed out on the potential. Designers' beliefs about teacher experience and efficacy in science led both projects to provide support around science content, NOS, and science practices.

This also dictated a careful consideration of the amount of preparation time that innovative materials may require of teachers, both with respect to logistical set-up and science learning that might be required for teachers to feel comfortable with implementing the curriculum. A LS designer said,

> *We had a whole section that I was super proud of… it's kind of coaching for teachers who maybe haven't done firsthand science before…. in terms of diverse classrooms where people have more or less time to prepare or more or less help, we actually tried to organize things so that they would be more likely to use it… we were definitely thinking about settings where teachers weren't used to heavy set up.*

These considerations, which included the extent of school cultural support for the new approach, weighed heavily on the SI designers as well:

> *this work is full of tensions… can teachers provide enough classroom time to go through this? If you want to give teachers the information and support that you think they need, does the document become too big for them to read? Are they going to spend that much time learning what they need to learn before they can teach this? So somebody would say, teachers aren't going to read all that. You've got to shorten it up. Well they need the information, yeah, but they're not going to spend the*

> *time on it. You're going to lose them. So rather than lose them, give them half a meal…. I think that there are plenty of settings where it just simply wouldn't work, where the teacher wouldn't feel supported by the school administration for putting that kind of time and energy into something that the administration didn't understand and support.*

5.2 | Key differences in envisioned enactment

5.2.1 | How students encounter science content

LS: Multiple modalities enable a constructivist approach to science content

While both projects shared a similar sociocultural approach to the teaching of science, each made use of different pedagogical principles. The LS team designed extensive student materials to provide students with both firsthand and secondhand opportunities to "gather evidence that would support their deep understanding" of the science content. These paired experiences form the basis of the "do-it, talk-it, read-it, write-it" approach to supporting student investigations through *multiple modalities*. The student materials, particularly storybooks and structured investigation notebooks facilitate engagement through multiple modalities and give students a chance to synthesize their understanding from different sources using a constructivist approach. Cycles of "Do" and "Read" enable students to gather evidence from multiple sources, while cycles of "Talk" and "Write" activities provide an opportunity for students to make sense of evidence, and revise their thinking based on new evidence. The designers believed that this approach of supporting student learning via multiple modalities would prove synergistic, providing an opportunity to deeply consider evidence and form a richer understanding than would have been possible from an investigation focused on a single modality. This way of approaching content was meant to provide an opportunity, "for students not only to understand what it is that we know about something, a concept or a topic, but how we find out about it as well."

The LS inquiry activities themselves were guided both by the materials (i.e., study storybooks and investigation notebooks), and by the teacher, supported by the extensive apparatus of content, literacy, and pedagogical supports. The designers wanted to situate the students' learning in a sociocultural context that included both the teacher and students, and other voices (mediated by the curriculum materials):

> *[we were] trying to move away from the idea that the way that you learn about science is by figuring it all out yourself through inquiry…. And we were trying to think about, is there something special, perhaps even magical, about actually trying to find a middle ground in which these things are sort of feeding each other and fueling each other, and you're positioning text in an assistive way, so that the students' actual engagements with physical objects, engagements in firsthand investigations were richer and better, and more likely to both engage students in wrestling with ideas to support their deep understanding but also to help them understand some, to gain insights into the nature of science and scientific inquiry.*

SI: Observation⟶discussion

In contrast, the SI curriculum is delivered by the teacher rather than through student materials. A structured sequence of investigative challenges lead the students, in their sense-making, to build from observations to generalizations or "theory" about the phenomena they examine. Students encounter the content through observation of phenomena; in each lesson, these observations are directed by a question for inquiry. The observations are developed through discussion, in small groups and as a whole-class, which iterate: observations are taken, initial findings are stated, differences are compared, and then with guidance from the teacher students are confronted again with the originating question. A culminating discussion and classroom consensus-representation completes the lesson. The next lesson moves from this place, in the same cycle—with the phenomena (usually materials) and inquiry questions carefully chosen in accordance with the learning progression underlying the curriculum.

> *this was not going to be a curriculum about telling. The teacher was not going to be telling students about this, and they weren't going to be reading about it either, not that reading and telling don't have their place. But the primary mode of students' deep understanding of ideas would come through their own gathering of evidence, and learning to evaluate evidence, discuss evidence, and discuss ideas such as the accuracy of the instruments they were using…So they started with a great question.*

In a section called "How the curriculum works," discussion is clearly foregrounded as the mechanism by which students learn both the content, and the practices related to the science that they're doing: "teachers are encouraged to find an additional 15 min. for students to complete their notebook writing or have an unhurried discussion where they practice articulating their ideas and explaining their reasoning."

5.2.2 | The teacher's role in enactment

LS: Fading guides

Designers of the LS curriculum envisioned teachers as guides, available to model and demonstrate science (and literacy) practices via a "gradual release" of responsibility framework which moved students towards independent practice (Pearson & Gallagher, 1983). As described in the teacher guide, the goal of the gradual release model was to, "[encourage] students to develop increasing independence as inquirers… early on teachers will actively guide students as they think about evidence while making observations and inferences. Later, students will practice and refine these skills with less direction from the teacher …" (as well as less support from other curricular elements). As one designer described it, the curriculum supported gradual release of both science and literacy practices, "So you always had explicit instruction early with teacher modeling, then shared half teacher modeling/half [students] doing it themselves, then [student] doing it by themselves for each one of the practices."

Along the way, LS teachers were to support students by prompting metacognitive reflection about how students' practices were similar to those of scientists, and by supporting collaborative work as students engaged in reasoning, argumentation, and sense-making.

SI: Translator/stimulator

In contrast, SI assumes that the students' knowledge will be built through productive discourse about phenomena. Through iterations of science talk, knowledge representation, and observation, students formulate, debate, and revise claims, until a classroom consensus has been reached that is consistent with the data thus far. Therefore, the teacher serves as a "translator" or implementer of the curriculum:

> *I think the burden is on the teacher to have, to be the translator, to know the students well enough, and to know the material well enough to make the translation, to not just stand there with a sheet of paper and read what we've written, but to understand her classroom, and the individuals in her classroom….So we provided materials for the children, and a curriculum for the teacher.*

The SI designers described the teacher's role and challenge as, "creat[ing] the kinds of sustained classroom discussions" which "draws on [and productively combines] many other thinking and reasoning abilities—such as engaging in thought experiments, making analogies, comparing and contrasting situations, and even engaging in simple deductive inferences in making predictions about what children expect will happen, given their existing beliefs."

It was the teacher's role to stimulate discourse and change the classroom's representation of ideas to reflect the class's reasoning. In addition, the teacher was expected to actively participate in discourse by modeling active listening, asking clarifying or extending questions, and encouraging others to bring in their own material in response to classmates' contributions. During the "exploration" of the phenomena, the teacher was to set the observation tasks and develop the methods of data recording in conversation with the students. In closing "meaning making" sessions, teachers would lead a whole-class conversation in which students revisit their conjectured answers, and explain their reasoning. Issues or contradictions were to be noted and discussed, and then the whole would be summarized, reviewing the investigation from initial question to final consensus.

5.3 | Approaches to supporting integrity of adaptation

5.3.1 | LS: Adaptation from worked examples

The LS designers explicitly sought to support teachers to adapt in a manner consistent with designers' intentions: "Good curriculum provides teachers with a default plan that's been tested, but a lot of support in how to modify it for unique settings, unique groups of students, unique resources," lest teachers go "off road." The designers supported adaptations in two primary but related ways. First, designers provided implementation support in the form of annotated scenarios—*worked examples*—and described many possible contingencies, so that a wide range of solutions have been identified and provided with alternatives (e.g., versions of the activities that would suit different types of learners). As one designer said, the intent was to provide, "step-by-step instructions for teachers that would facilitate" the type of engagement the designers envisioned. Another designer described the provision of, "options and customizability for different situations." For example, the right-hand page of the teacher's guide often includes notes about how to support to English Language learners using the curriculum, or instructional suggestions for students who need additional practice in a given area.

Second, to make these examples easier to adapt, the designers provided a *clear rationale for their design choices* (including which pieces of the design were important to maintaining the integrity of the approach). As one designer reflected, "We tried to provide support materials that explained to teachers why we were having kids engage in these ways, why we designed such weird texts… we wanted to engage them with our vision." Another designer described the goal as helping teachers make decisions in an "informed way":

> *We share with them the rationale behind many things—the instructional sequence, how the books were sequenced and developed, what the accessibility model is. The more that teachers could understand the rationale, the more comfortable then they are to understand what they can change and if they are changing it what's happening.*

For example, an "Instructional Rationale" statement was sometimes included to explain how the use of particular instructional methods or student materials reinforced the lessons' learning goals.

5.3.2 | SI: Capacity building from resources

By contrast, the SI strategy for supporting teacher adaptation may be characterized as *capacity building*. Through the teacher guide and accompanying professional development materials (available on a website), SI teachers were provided with resources that support a kind of apprenticeship to the cognitive and natural sciences. The intent was that as teachers work with the materials, their own understanding would deepen and allow them to act in concert with the curriculum's pedagogical philosophy, listening to student thinking and encouraging productive discourse about the science. Guidance from the cognitive scientist and physicist were provided through regular explanatory/exploratory essays in the teacher materials. Supports for content knowledge and implementation are cast in the context of insights about thinking and talking science—as seen by a cognitive scientist or a physicist.

In addition, however, the designers were aware that classroom realities include the policy climate increasingly shaped by the new science standards. Teachers tend to encounter standards as a series of objectives to be accomplished, or items to check off, and to be very anxious that their students be prepared to address assessments based on these standards. SI took care to help teachers on this point as well, in a capacity-building way that reinforced the pedagogical intent of the curriculum. They related the content of the curriculum to the relevant standards, but the descriptions of the concepts covered were narrative in tone, brief, and contextualized, which supported the teachers' taking ownership to apply the principles as needed in the classroom.

The collaborative, discourse-rich pedagogy that the curriculum sought to support was related in an integral way with the presentation of the background science content. It is through the prepared teacher's enactment that students experience science as a blend of concept and practices.

5.4 | Materials to support envisioned enactment

Based on the envisioned enactment (key principles to support) and the general adaptation strategies, specific materials were created to support strong classroom enactment. Here we review important differences in three types of materials that were created under each strategy for supporting enactment related to background knowledge, scientific inquiry, and discourse.

5.4.1 | Background content support for teachers

Literacy science

The LS curriculum positions teachers as models of science inquiry practices for their students. The teacher guide provided direct support for this role in two ways. First, the teacher materials provided explicit science background content for teachers (e.g., an explanation of the inquiry cycle which describes how students get more sophisticated in seeking out/using evidence; definitions of key science vocabulary terms). This information is available at multiple points in the teacher materials, including the front matter and embedded within the activity descriptions as targeted "Science Notes." Serving a similar function, the teacher materials also connect individual activities to student learning goals and science (and literacy) standards. The conceptual progression envisioned for students' learning throughout the unit is presented in the front matter, and followed up on each activity page with a list of content knowledge, science practice/inquiry skills, and vocabulary that will be introduced to students in each session.

Second, the teacher guide helps to reinforce scientific practice by both explaining those practices to teachers, and encouraging teachers to help students reflect on how they have "acted like scientists." This approach necessitates that teachers become comfortable with scientific practice and NOS. As one designer explained, "there's a certain way of talking, there's a certain way of acting in science and we are going to be explicit about teaching [it]…," and explicit about supporting the teachers to understand.

This background support was closely connected to guidance on how to teach this content. For example the teacher guide provides explicit guidance on how to introduce the language of science down to the types of vocabulary students and teachers can use to inform NOS and content conversations. Finally, the teacher materials provide guidance on how to reinforce the connection between student activities and the professional practice of science. For example, prompts in the teacher guide encourage teachers and students to "Discuss how they will learn to think like scientists…," often drawing on the student materials (i.e., storybooks) to facilitate conversation. As one designer reflected, including the supportive teacher material was important to reinforce the "culture of science":

> *So we had lots of texts that just described scientists' work, but also their dispositions towards the work, and how they became interested in the work, and how they look, you know, the lens that they use to look at the natural world… And we had teachers, we had the step by step to help teachers engage, and we had, talk to the teachers about why this was important. And I think the nature of science is something that often goes by the wayside, which I think is the sort of cultural dimensions of science. And yet, especially at the elementary level, this is something that doesn't get a lot of uptake. It's really all about the facts of science. So we did a lot of talk to the teachers in the text about how to engage kids with this, why it's so important that they not just learn a repository of facts, but that they also learn something about the culture of science.*

Science as inquiry

The SI materials were designed to maximize students' engagement with phenomena and materials, thereby articulating and illustrating the foundations of scientific practice—the ways of seeing, of organizing observations on the basis of questions, the evaluation of evidence and of conjectures in dialogue, the development of shared "sense" made by the group collaboration. Thus, the "nature of science" is implicit all through the curriculum design, but it is conveyed to the students as an orientation for understanding and exploring in nature.

However, rather than positioning teachers as models of scientists, the emphasis is on helping the teachers understand the scientists' approach to phenomena. As part of the capacity building strategy, SI designers embedded multiple ways of supporting teachers' content knowledge. For example, a table of key concepts to which students will be exposed throughout the three-year curriculum progression, a curriculum overview places the curriculum in the context of the new U.S. science standards (NGSS) generally. Most importantly, the project created "think-aloud" videos with scientists, created for the teachers' use (not the students'). One of the values of these "think aloud" videos was that they showed the scientists engaging at a very simple level with the phenomenon before them, and yet thinking and reasoning aloud in ways that showed how good questions, logical thinking, and testing by comparison and reflection, could bring a lot of meaning and a lot of consequence for future learning out of such simple materials. The materials and activities are simple, but the consequences can be complex and far-reaching, not only because the phenomena are examined in light of the learning progression, or conceptual progression, but also because the designers have chosen foundational ideas for much later science.

Importantly, the "think aloud" videos were not intended to teach the "right method," but to engage the scientists in the student tasks in a way that demonstrates how a person experienced with a particular kind of investigation might see, reason, and question the focal phenomenon. Yet:

> *The curriculum was focused on developing ideas and concepts, and [teachers are] not used to thinking about it that way… The epistemology is difficult. You know, the epistemology of science that depends on, not just an authority telling you something, but constructing a model. An epistemology that's not about right and wrong answers…*

Consonant with this approach, even the "scientist essays" for the teacher are not didactic about method or NOS, but speak in the voice of the practicing scientist, conveying the consequences of the knowledge and skills being addressed:

> *If I report that the density of a new material is 1470.3, an experimentalist in Germany or a theorist in Japan who wants to compare her results with mine needs to know whether that value is in kilograms per cubic meter, grams per cubic centimeter, pounds per cubic foot, or something else…otherwise the measurement provides no useful information.*

5.4.2 | Supporting scientific inquiry

Literacy science

In the LS curriculum, inquiry skills (e.g., making observations, recording data, comparing, and contrasting explanations) are carefully scaffolded for students through teacher modeling, sentence frames, scope of tasks, and/or working with a partner. As students move through the curriculum, all of these scaffolds are gradually released as students individually, or supported by each other, begin to incorporate these skills into their own practice.

The teacher's guide provides guidance for teachers around facilitating inquiry by (1) being explicit about the "Inquiry Abilities" students are practicing during each activity session, so that teachers can be prepared to support students in those particular aspects of inquiry; and (2) describing when and how to reinforce different inquiry practices, such the use of evidence during investigations or how to talk about investigations and data in a meaningful way. Specific features of the teacher guide include *instructional strategies and routines* (e.g., think-pair-share routines to structure student conversation about observations, findings, ideas), and *scripted prompts* (e.g., use of scientific language and "language of argumentation" sentence starters) to guide classroom conversation.

In explaining their approach to student inquiry and teacher support, one designer suggested that the deliberate scaffolding for both student and teacher was part of an overall strategy to focus attention of particular parts of the inquiry cycle, so that throughout the course of the multi-year curriculum, students could practice different inquiry skills. As one designer explained, "for each unit we are going to pick an aspect more than trying to like integrate all the parts of inquiry together in one experience for kids." By structuring the inquiry process for students and teachers, LS curriculum designers could provide direct support for a more targeted set of skills and practices.

5.4.3 | Science as inquiry

The SI designers described their curricular aims in terms that are analogous to their description of the scientific process. While recognizing that individual facts and concepts are part of the picture, their curricular aims focused more on building up a coherent fabric of understanding, a model of how part of the world works. Therefore, the pedagogy appropriate to their curriculum requires the teacher to help the students move, as it were, from a "low" descriptive level to the higher more conceptual level weaving back-and-forth from individual phenomena and observations to a growing understanding/model of the field of knowledge that they were engaging with.

A key element of the SI approach is that the teachers are to elicit and work with student thinking. The designers did not take for granted teachers' sophistication with respect to this part of their work. In a sense, the curriculum requires that teachers be aware of what sociocultural theory calls "microgenesis," the process through which a learner's understanding of something develops through a succession of partially formed working theories. The teacher support materials include *short essays from a cognitive scientist* to help teachers understand how to think about the content of the unit and how students may think about it. The scientist essays provided support for this as well, but from a different point of view, in which the scientific meaning (its place in an explanatory understanding of matter) of the unit topic is represented in a rigorous but qualitative manner. The "think aloud" videos also serve as support material for the teacher. One benefit of these videos is that they enable the teacher to see striking similarities between a scientist and a child exploring the same phenomenon, as well as the differences that greater experience and deeper knowledge may bring. But note again that this support in SI for pedagogy is indirect and capacity building: it is up to the teacher to translate these knowledge of the target understanding and student thinking into teaching actions.

5.4.4 | Supporting discourse

LS: Routines

In the LS curriculum, discourse served two important functions. First, it supported students' developing understanding of the science they were encountering. As one designer described it, using "discourse in a deep way, not just talking about what you did but using structures to debrief things that were done, to analyze data, to talk about ideas…" Second, discourse helps to set up the social/cultural experience of a scientific community. The idea of setting up, "the social and cultural experiences of the young scientist" within the classroom was important to LS designers.

To support this level of discourse in the curriculum, LS introduced *instructional and discourse routines*, for example Discourse Circles and paired sharing routines.

> *I think the discourse routines are very concrete…it's what curriculum development is all about. It's trying to engineer social interactions. You're trying to somehow remotely, through the magic of communication, create an event in the classroom… discourse routines are a way to take what is actually a really complicated social, linguistic practice, and give it a skeleton that will help support it happening in a certain way.*

The discourse routines add a layer of structure, for both teachers and students. The teacher also receives guidance from the teacher's guide with reference to what content the discussion should cover. There are prompts in the teacher guide with guidance like, "here is a point to emphasize in the discussion summary…" which serve among other things to maintain consistency of approach.

SI: Principles

SI took a distinctive approach to the role of language and discourse, and their "capacity building" approach to teacher support had to articulate and clarify the principles by which productive discourse would be supported.

> *We wanted the language to emerge from their experiences. So there was never vocabulary, we didn't introduce vocabulary. We, when students began working with a question and a phenomena, and then it made sense, it would have made sense to introduce a term that would make it easier to talk about something that was going on, we would, a word would be introduced…. Concept came before the vocabulary. Concept developed.*

While the emphasis in much of the project description was on the progression of concepts related to the nature and properties of matter on a considerable body of research about such progressions, the theory of action rested on another body of research about what the project calls "productive talk," building on research by Lauren Resnick, Sarah Michaels, and others (Resnick, Michaels, & O'Connor, 2010; Roth, 2005), in which productive science talk in the classroom is characterized by a culture of accountability to knowledge, accountability to standards of reasoning, and accountability to the learning community. A classroom discussion, in this view, must be "purposeful." In a section called "how the curriculum works," discussion is clearly foregrounded as the mechanism by which students learn both the content, and the practices related to the science that they're doing. The goal is reflection and consolidation of their experience, or, in Deweyan language, a reconstruction of their knowledge, fostered by the encounter with phenomena in the society of the classroom.

To support this central mechanism of the curriculum, the teachers' materials provide guidance about the kinds of discussion appropriate at each stage of an investigation. The first phase of each lesson is question-based. This serves several purposes. In the first place, it allows the students to begin orienting their thinking about the phenomenon they will be investigating, marshaling knowledge and ideas they may already have. This in turn gives the teacher a glimpse of the students' thinking and understanding, at this point, and also some idea of the language that the students will make use of in recording and discussing observations and conjectures. The teacher is advised to “use only the most open-ended prompts,” and “until you know what words the children are comfortable using, use non-technical ones and introduce the scientific terms later.” As the students bring their question to bear on actual phenomena, a second modality is introduced, as they jot observations, questions, and ideas in their notebooks: “Let them know that their notebook entries can include many different kinds of science information, including drawings, writing, charts, and graphs.”

When the students meet to make sense of their findings, the teacher is reminded of the purpose(s) of the discussion, a term drawn from Resnick et al.'s (2010) theory of “productive talk.” As with other guidance for the classroom discourse, this is for students as well as the teacher, so that both learner and teacher get in the habit of framing a discussion in purposeful terms. For example, from the initial Grade 3 activity Investigating materials:

> *The purpose of the discussion is for students to use data to*
>
> - *connect the investigation question and their data*
> - *reason about why there is variation in the groupings*
> - *make statements (claims) about the materials that objects from the classroom (things in my world) are made of, and to describe the supporting evidence.*

6 | GENERAL DISCUSSION

This study set out to answer the question, *How do designers envision teacher adaptation and use of materials, and how does that vision shape their design of science materials for use at scale?* The two design teams profiled in this paper expected that teachers could (and would) successfully guide students through the process of scientific inquiry, but that they would need support to do so in a way that honored curricular goals, students' needs, and local classroom conditions. Our analysis highlights two different ways designers can provide that support. The *LS* design team's vision of teacher enactment is reflected in the range of materials created. By providing extensive student materials plus worked examples in the teacher guide, the designers were supporting a carefully planned and sequenced enactment that took into account the teacher's need for content and facilitation support. With this support, teachers would be prepared to model science inquiry practices. In contrast, the *SI* design team created materials to support a different vision of enactment—one in which the teacher served not as a model, but as a more experienced learner seeking to understand, and by extension engage students in, different ways to approach and explore scientific phenomena. This vision resulted in a design that provided less structure for teachers and students, yet prepared teachers to make their own principled adaptations by increasing their capacity for scientific investigation.

We assume that successful implementation of new curriculum is a matter of collaboration (usually indirect) between the designers and the teachers. This point of view recognizes that enacting innovative curriculum provides an opportunity for learning and uptake of new pedagogy (Clarke & Dede, 2009; Davis et al., 2014; Duschl & Osbourne, 2002), and in science education this is predicated not only on developments in the learning sciences, but also on developments within the philosophy and sociology of science itself (NAS, 2018; Collins, 2015; Solomon & Gago 1994). The designer thus is (ideally) the teacher's ally in making practical sense of advances in science education, the learning sciences, and the sociology of science. Designers at the same time bear in mind that, if their work is to be as widely usable as possible, they must create materials that teachers can adapt in response to their interpretation of their students' needs and the conditions within which the materials will serve. Thus, innovative materials must also be adaptable without loss of integrity, that is, implementation remains congruent with the goals and principles underlying the curriculum (Penuel et al., 2014). Our cases explore two ways this multiplex challenge was met.

6.1 | Reflections on two approaches

Summarized at the start of the results section (in Figure 2), the findings showed two different strategies for supporting adaptation in curriculum materials. Each curriculum team saw the teacher's challenge and took a different approach to providing educative support while still promoting teacher agency and acknowledging the need for local adaptation. Their choices about how to support teachers express their view of teachers as collaborative adapters of their materials.

While both curricula support the expansion of a teacher's content knowledge and pedagogical repertoire, the LS curriculum does so by focusing on *how* teachers can enact scientific inquiry and evidence-based discourse in the classroom. This emphasis on *how* is seen most explicitly in the provision of step-by-step instructions and their centrality in the teachers' guide, the use of repeated instructional routines, the specificity of the student materials, and the ways in which variations required by different classroom conditions are explicitly supported. The crucial importance of this kind of guidance has been emphasized in the literature for decades, notably in Doyle and Ponder's (1978) classic essay on *The Practicality Ethic in Teacher Decision-Making*. Among other factors driving teacher perception of curriculum innovation, Doyle and Ponder explained that this dimension (which they refer to as “instrumentality”) is significant for both clarifying the intentions, and because translating new, abstract ideas into behavioral implications is something that is highly challenging and rarely required of teachers in their daily practice (note, e.g., the extensive work that has been undertaken in recent years to translate NGSS 3D learning principles into practical patterns and routines so that teachers do not have to do this themselves). Additionally, the LS teacher guide provides content supports to help teachers whose science background may be weak, which has long been shown to be a common challenge among primary school teachers, most of whom have completed limited coursework in science (Appleton, 2003; Kruger & Summers, 1988; Stoddart, Connell, Stofflett, & Peck, 1993). At the same time, the teacher guide also makes clear how each element in the units fits into what went before and what will come after, as envisioned by the current standards. This is consistent with recommendations from curriculum development in general (McKenney, 2008) as well as from literature on educative materials (Davis & Krajcik, 2005) and teacher professional development (Thompson, Wiliam, & Wylie, 2008). The LS vision of science as a *multimodal* engagement with natural phenomena at first-hand and at second-hand is realized and supported by the variety of student materials, and the designer's vision for classroom enactment is richly supported in addition by the variety of teacher materials. In the teacher and student materials, the designers support purposeful variation that is in keeping with the core principles of the curriculum.

By contrast, to support productive teacher adaptations, the SI curriculum materials focus more on *what* it looks like to be inquiring scientifically, and *what* evidence-based discourse looks like, but does not provide the same type of explicit support about how to enact the curriculum. In implementing this adaptation strategy, the SI designers undertook to engage their teachers in what we have characterized as something akin to an apprenticeship experience. This experience is targeted towards the twin areas of science instruction teacher's expertise: (1) the practice of a science, and (2) the understanding of student cognition and learning of that science. Capacity-building materials support teachers in understanding the curricular and instructional goals. This is done through videos, the use of which has become a significant part of teacher professional development on nearly every continent (Gaudin & Chaliès, 2015) as well as through scientist and child essays. When executed, this approach makes very different demands on the teacher. For example, the videos and child essays help shift the teacher's attention to students' thinking, a crucial aspect of effective teaching (Darling-Hammond et al., 2017), while also clarifying the nature of discourse-rich inquiry. At the same time, the videos and scientist essays emphasize the teacher's tasks as instructional and investigative leader. Many of these align with the roles that effective science teachers fulfill when supporting collaborative inquiry: motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor, collaborator and learner (Crawford, 2000). The teacher materials further support this focus by providing notes from scientists and cognitive psychologists, videos, and other supports to help the teacher support students' communications to increasingly reflect the actual discourse of practicing scientists: exploratory, dialectic, and constrained by phenomena (Grinnell, 2009). Attention is given to helping the teachers see the phenomena and practices through a scientist's eyes (which is the kind of boundary-crossing practice that can have positive influence on teacher content knowledge, attitudes, and pedagogical practices [Houseal, Abd-El-Khalick, & Destefano, 2014]), and on seeing the classroom as a locus of collaborative inquiry. Notes and video clips of other teachers are centered around supporting productive classroom discourse—question-driven, dialogic accounting for the phenomena under investigation, accumulating knowledge and at the same time enriching students' theoretical framing for what they have seen and discussed. Supports for doing so are essential, given the inherent tensions and challenges in facilitating meaning-making discussions (Scott, Mortimer, & Aguiar, 2006). The foundational vision for enactment is that teachers who makes that shift in stance or vision will make the adaptations or accommodations needed for their students. In contrast to the LS curriculum, it would appear that the SI curriculum primarily views the process of applying new ideas to classroom activities as the main vehicle for developing expertise (McKenney, 2017).

In both cases, the curriculum materials make clear the expected roles for students and teachers. In different ways, both of these curricula are educative (e.g., as developed in Russell, 1997). Whereas the SI design explicitly identifies in the curriculum what the teacher must bring to the inquiry environment, the LS may be said to distribute the curriculum across the teacher and the student materials in a way that may be more familiar to elementary teachers. The consequences of choices made by the LS and the SI teams provide an interesting contrast, as both are based on well-researched principles, yet the pathways taken to reach similar goals are quite different. This constitutes an important advancement in our understanding of curriculum design for adaptation in science, as we are aware of no previous research that has so closely examined designers' vision for use and commensurate consequences for curriculum materials.

Further, we conclude that some designers take a knowledge-building strategy, explaining the new framework and its practical implications carefully and often in extenso. Some provide background and support for the teacher, but advocate that new adopters take care to use the curriculum as designed, with minimal alteration, with the expectation that only when teachers understand through enactment how the materials are designed, will they be able to improvise in a way that will support curricular intent (Davis & Krajcik, 2005; Davis et al., 2014). And still others focus on developing teachers' professional capacity to support students' engagement in scientific inquiry (Davis & Krajcik, 2005). The choice of a way to enable teachers to use the curriculum to realize the intended enactment, while responding to the exigencies of their particular classroom, constitutes a central strategic decision on the part of the designer, and has far-reaching implications for materials design, and the sociotechnical system within which curricular change is embedded. The two curricula examined in this paper can be seen to represent two different strategies along this rough continuum.

6.2 | Limitations of the study

Our comparative study is limited, of course, by comprising only two curricula. Furthermore, it could be argued that even though we have had very rich materials from which to draw, our conclusions are tentative in the absence of contemporary member checking, which would be possible, for example, in a study developed by a more ethnographic or participant-observer approach. Finally, a key question that is not yet answered is how the two strategies for adaptation have in fact been realized: What kinds of adaptive challenges has each curriculum encountered in use, and what strengths and weaknesses have been shown in each of the two strategies for teacher support and learning? We expect that such research, well beyond the scope of the current data set, could provide useful insights for curriculum as design and as enactment.

6.3 | Significance

The present study adds to the literature by providing empirical evidence for different ways in which curriculum designers have explicitly addressed adaptation challenges. This is important because it can help designers to articulate, and thereby critique, their stance toward supporting adaptation. Further, these analyses offer worked examples to other curriculum designers for applying these strategies.

Design for scale is of particular interest in light of the long-running debate in the literature on curriculum implementation, which often views "fidelity of implementation" as the most straightforward way to ensure that the intended innovation reaches students in ways envisioned by the designer. While prior work addresses characteristics of curriculum that are most likely to be adopted, that is, address felicity conditions such as those suggested by McKenney (2013): tolerance, compatibility, clarity, and value-added (*ceteris paribus*—assuming, e.g., that there are not countervailing policy demands shaping the teachers' autonomy, or that the curriculum is being distributed effectively so as to make use at scale a practical possibility), this study sheds light on how to create materials that facilitate adaptation after adoption.

Without somehow enforcing or ensuring fidelity, the complexities of classroom and school culture have often had the effect of diluting challenging innovations (Cohen, 1990; Falk & Drayton, 2004). There is a natural "*tendency* of varieties to depart *indefinitely* from the original type," (to borrow A. R. Wallace's famous phrase). Other framings of the relationship between the designer and the teacher have been considered—for example, mutual adaptation, in which the designer adjusts the design in response to insights arising from teachers' experiences in diverse classroom conditions. This, however, suggests a relationship of designer with teacher that is necessarily rare given the typical very high ratio of teachers to designers, and rarely sustainable where it does occur. In any case, the tension between envisioned enactment and actual implementation remains. In truth, the designer must consider the teacher as central but at-a-distance collaborator in the final stages of the designenactment in the classroom—and provide materials that honor/empower the teacher as someone who can and will make choices about how the curriculum implementation will play out. Our research suggests that designers make intentional choices about their strategy for supporting adaptations, and emphasize alignment between envisioned enactment, adaptation strategies, and written curriculum materials in their subsequent design work. This effort ensures a consistency of approach that can support teachers in developing curricular adaptations that avoid adaptations that are in conflict with core commitments of the original curricular materials, and the possibility that the departure from the original design may be so great that what is enacted in the classroom is sometimes not a variation on the designed curriculum, but in effect a replacement or even nullification of it.

A commitment (on the part of the designer) to pedagogical change adds some specific challenges to this, since it requires teachers to alter their practice, and often also to understand the curriculum content, and classroom management and participant structures in new ways. Moreover, such materials also may incorporate insights from learning sciences, psychology, science, and philosophy which frame and understand learning itself in ways different from what the teacher has done before. Therefore, *teacher* learning is, perhaps surprisingly, at the heart of curricular change which is intended to facilitate *student* learning.

Many designers, understanding this situation, and recognizing the limited time and support that teachers have for their own learning, commit themselves to make their curriculum educative, so that in using it, the teacher imbibes (explicitly or implicitly or both) the novel insights guiding the design, in such a way that the teacher translates or re-represents the new views on learning, teaching, and content in their daily classroom enactments.

One final note on the collaborative relationship between designer and teacher: we have hypothesized that the key tension of control of innovative curriculum enactment has been addressed pivotally in these two curricula in decisions about the support of adaptation for implementation at scale (*sensu* Coburn, 2003), and from a retrospective study of materials and of designer accounts have provided evidence that the hypothesis can yield some insights about curricular design, and about the meaning and realization of educativeness in reform curriculum. We suggest that a different, more nuanced framing of "use at scale" helps to bypass the dilemma of designer control versus teacher control over enacted curriculum, such that innovations can in fact reach the classroom, and make a real contribution towards educational and especially pedagogical change. Under a model such as Coburn's (2003), the teacher's agency and understanding both attest or demonstrate the classroom-worthiness of the material, and consequently encourage broader use, and adoption/ownership in internal spread.

ACKNOWLEDGMENTS

The authors wish to thank Jacqueline Barber, Anushree Bopardikar, Natalie Pareja Roblin, and Sara Walkup for their contributions to, and guidance in, this project. This material is based upon work supported by National Science Foundation, through grants #1252416, 1251562, 1252373 to TERC, the University of Pittsburgh, and the Lawrence Hall of Science at the University of California-Berkeley. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

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REFERENCES

AAAS. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Anderson, C. W., X. de los Santos, E., Bodby, S., Covitt, B. A., Edwards, B. A., Hancock, J. B., II, Lin, Q., Thomas, C. M., Penuel, W. R., & Welch, M. M. (2018). Designing educational systems to support enactment of the Next Generation Science Standards. *Journal of Research in Science Teaching*, *55*, 1026–1052.

Appleton, K. (2003). How do beginning primary school teachers cope with science? Toward an understanding of science teaching practice. *Research in Science Education*, *33*(1), 1–25.

Arias, A. M., Bismack, A. S., Davis, E. A., & Palincsar, A. S. (2016). Interacting with a suite of educative features: Elementary science teachers' use of educative curriculum materials. *Journal of Research in Science Teaching*, *33*, 422–449.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book What is—or might be—the role of curriculum materials in teacher learning and instructional reform? *Educational Researcher*, *25*(9), 6–14.

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). Report of the 2018 NSSME+, Chapel Hill, NC: Horizon Research, Inc.

Barber, J. (2015). How to design for breakthrough: A story of collaborative design across disciplines. Educational Designer. Retrieved from http://www.educationaldesigner.org/ed/volume2/issue8/article29/

Berk, A. (2014). Translating NGSS into classroom instruction: 5E planning tool and teaching tips. Retrieved from https://www.teachingchannel.org/blog/ausl/2014/03/16/translating-ngss-intoclassroom-instruction-5e-planning-tool-and-teaching-tips/

Bernstein, D., Drayton, B., McKenney, S., & Schunn, C. (2016). Designing science durriculum for implementation at scale: Considerations for diverse and resource-limited settings. *Proceedings of the ICLS 2016*, Singapore. pp 886–889. https://doi.org/10.22318/icls2016.128

Bond-Robinson, J. (2015). Identifying pedagogical content knowledge (PCK) in the chemistry laboratory. *Chemistry Education Research and Practice*, *6*, 83–103.

Bopardikar, A., Bernstein, D., Drayton, B., & McKenney, S. (2020). Work-based curriculum to broaden learners' participation in science: Insights for designers. *Research in Science Education*, *50*, 1251–1279.
Borko, H., & Putnam, R. T. (1996). Learning to teach. In (Eds.) Berliner, D. C. & Calfee, R. C., *Handbook of educational psychology* (pp. 673–708). New York: Macmillan.
Bourdieu, P. (1980). The logic of practice. Cambridge: Polity Press.
Bransford, J. D., Brown, A. L. & Cocking, R. R., (Eds.). (2000). How people learn: Brain, mind, experience, and school, Washington, DC: National Academy Press.
Brown, M. W. (2011). The teacher—Tool relationship. In (Eds.) Remillard, J. T., Eisenmann, B. A. H. & Lloyd, G. M., *Mathematics teachers at work: Connecting curriculum materials and classroom instruction* (pp. 37–56). London: Routledge.
Brown, A. L., & Campione, J. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles and systems. In (Eds.) Schauble, L. & Glaser, R., *Innovations in learning: New environments for education* (pp. 289–325). Erlbaum.
Bruner, J. (1960). The process of education, Cambridge, MA: Harvard University Press.
Clarke, J., & Dede, C. (2009). Design for scalability: A case study of the river city curriculum. *Journal of Science Education and Technology*, *18*(4), 353–365. http://www.jstor.org/stable/20627713
Coburn, C. (2003). Rethinking scale: Moving beyond numbers to deep and lasting change. *Educational Researcher*, *32*(6), 3–12.
Cohen, D. K. (1990). A revolution in one classroom: The case of Mrs. Oublier. *Educational Evaluation and Policy Analysis*, *12*, 311–329.
Collins, H. (2015). Can we teach people what science is really like? *Science Education*, *99*, 1049–1054.
Colson, M., & Colson, R. (2016). Planning NGSS-based instruction. *Where do you start? The science teacher*, *83*, 51–53.
Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, *37*(9), 916–937.
Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). *Effective teacher professional development*. Palo Alto, CA: Learning Policy Institute.
Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher*, *34*(3), 3–14.
Davis, E., Palincsar, A. S., Arias, A. M., Bismack, A. S., Marulis, L., & Iwashyna, S. (2014). Designing educative curriculum materials: A theoretically and empirically driven process. *Harvard Educational Review*, *84*(1), 24–52.
Davis, E. A., Janssen, F. J. J. M., & Van Driel, J. H. (2016). Teachers and science curriculum materials: Where we are and where we need to go. *Studies in Science Education*, *52*(2), 127–160. https://doi.org/10.1080/03057267.2016.1161701
DeBarger, A., Penuel, W. R., Harris, C. J., & Schank, P. (2010). Teaching routines to enhance collaboration using classroom network technology. In (Eds.) Pozzi, F. & Persico, D., *Techniques for fostering collaboration in online learning communities: Theoretical and practical perspectives* (pp. 224–244). Hershey, PA: IGI Global.
DeBarger, A. H., Choppin, J., Beauvineau, Y., & Moorthy, S. (2013). Designing for productive adaptations of curriculum interventions. *National Society for the Study of Education*, *112*(2), 298–319.
Deboer, G. E. (1991). *A history of ideas in science education: Implications for practice*. New York: Teachers College Press.
Doyle, W., & Ponder, G. (1978). The practicality ethic in teacher decision-making. *Interchange*, *8*(3), 1–12.
Drake, C., & Sherin, M. G. (2006). Practicing change: Curriculum adaptation and teacher narrative in the context of mathematics education reform. *Curriculum Inquiry*, *36*(2), 153–187.
Drayton, B., Falk, J. K., Stroud, R., Hobbs, K., & Hammerman, J. (2009). After installation: Ubiquitous computing and high school science in three experienced, high-technology schools. *Journal of Technology, Learning, and Assessment*, *9*, 3. http://escholarship.bc.edu/jtla/vol9/3/
Drayton, B., & Puttick, G. (2016). Digital design of "smart images": A design story. *Educational Designer*, *3*, 9. http://educationaldesigner.org/ed/volume3/issue9/article32/index.htm
Duschl, R. A., & Osbourne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*, 39–72.
Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.
Edelson, D. (2001). Learning-for-use: A framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching*, *38*(3), 355–385.
Falk, J., & Drayton, B. (2004). State testing and inquiry-based science: Are they complementary or competing reforms? *Journal of Educational Change*, *5*, 345–387.
Gaudin, C., & Chaliès, S. (2015). Video viewing in teacher education and professional development: A literature review. *Educational Research Review*, *16*, 41–67.
Grayson, D. J. (n.d.). *Disciplinary knowledge from a pedagogical point of view*. Retreived from https://web.phys.ksu.edu/icpe/Publications/teach2/Grayson.pdf

Grinnell, F. (2009). *Everyday practice of science: Where intuition and passion meet objectivity and logic*. Oxford: Oxford University Press.

Hall, G. E., & Hord, S. (1987). Change in schools: Facilitating the process, Albany: State University of New York Press.

Herbel-Eisenmann, B. (2007). From intended curriculum to written curriculum: Examining the "voice" of a mathematics textbook. *Journal for Research in Mathematics Education*, *38*, 344–369.

Houseal, A. K., Abd-El-Khalick, F., & Destefano, L. (2014). Impact of a student–teacher–scientist partnership on students' and teachers' content knowledge, attitudes toward science, and pedagogical practices. *Journal of Research in Science Teaching*, *51*(1), 84–115.

Kanter, D. E. (2010). Doing the project and learning the content: Designing project-based science curricula for meaningful understanding. *Science Education*, *94*, 525–551. https://doi.org/10.1002/sce.20381

Kirshner, B., & Polman, J. L. (2013). Adaptation by design: A context-sensitive, dialogic approach to interventions. *National Society for the Study of Education Yearbook*, *112*(2), 215–236.

Krajcik, J. (2014). *How to select and design materials that align to the Next Generation Science Standards*. Retreived from http://nstacommunities.org/blog/2014/04/25/equip/

Kruger, C., & Summers, M. (1988). Primary school teachers' understanding of science concepts. *Journal of Education for Teaching*, *14*(3), 259–265.

Laurillard, D. (2012). Teaching as a design science: Building pedagogical patterns for learning, New York: Taylor & Francis/Routledge.

Mauss, M. (1934). Les techniques du corps. *Journal de Psychologie*, XXXII, ne, 3-4, 15 mars–15 avril.

McKenney, S. (2008). Shaping computer-based support for curriculum developers. *Computers & Education*, *50*(1), 248–261.

McKenney, S. (2013). Designing and researching technology-enhanced learning for the zone of proximal implementation. *Research in Learning Technology*, 1–9. https://doi.org/10.3402/rlt.v21i0.17374

McKenney, S. (2017). Een infrastructuur voor de professionele groei van docenten [Infrastructuring teacher professional growth], *Inaugural lecture*. Enschede: University of Twente.

McKenney, S. E., & Reeves, T. C. (2019). *Conducting educational design research* (2nd Ed.). London: Routledge.

McNeil, K. L., Gonzalez-Howard, M., Katsh-Singer, R., & Loper, S. (2017). Moving beyond pseudoargumentation: Teachers' enactments of an educative science curriculum focused on arugmentation. *Science Education*, *101*, 426–457.

McNeill, K. L. (2009). Teachers' use of curriculum to support students in writing scientific arguments to explain phenomena. *Science Education*, *93*(2), 233–268.

Miles, M. B., Huberman, A. M., & Saldana, J. (2014). Qualitative data analysis: A methods sourcebook (3rd Ed.). Washington, DC: Sage.

Munby, H., Cunningham, M., & Lock, C. (2000). School science culture: A case study of barriers to developing professional knowledge. *Science Education*, *84*, 192–211.

National Academies of Sciences, Engineering, and Medicine. (2018). *How people learn II: Learners, contexts, and cultures*. Washington, DC: The National Academies Press. https://doi.org/10.17226/24783

National Research Council. (1996). National science education standards, Washington DC: The National Academies Press.

National Research Council. (2000). Inquiry and the national science education standards, Washington, DC: The National Academies Press.

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

Nicholas, H., & Ng, W. (2012). Factors influencing the uptake of a mechatronics curriculum initiative in five Australian secondary schools. *International Journal of Technology and Design Education*, *22*(1), 65–90.

Pareja-Roblin, N., Schunn, C., & McKenney, S. (2018). What are critical features of science curriculum materials that impact student and teacher outcomes? *Science Education*, *102*(2), 260–282.

Pearson, P. D., & Gallagher, M. C. (1983). The instruction of reading comprehension. *Contemporary Educational Psychology*, *8*(3), 317–344.

Penuel, W. R., & Fishman, B. J. (2012). Large-scale science education intervention research we can use. *Journal of Research in Science Teaching*, *49*(3), 281–304.

Penuel, W. R., Phillips, R. S., & Harris, C. J. (2014). Analysing teachers' curriculum implementation from integrity and actor-oriented perspectives. *Journal of Curriculum Studies*, *46*(6), 751–777.

Puttick, G., Drayton, B., & Karp, J. (2015). Digital curriculum in the classroom: Authority, control, and teacher role. *International Journal on Emerging Technologies in Learning*, *10*(6), 11–20.

Puttick, G., & Drayton, B. (2017). Biocomplexity: Aligning an "NGSS-ready" curriculum with NGSS performance expectations. *American Biology Teacher*, *79*(5), 344–349.

Remillard, J. T. (2012). Modes of engagement: Understanding teachers' transactions with mathematics curriculum resources. In G. Gueudet, P. Birgit, & T. Luc (Eds.), *From Text to "Lived" resources: Mathematics curriculum materials and teacher development'* (pp. 105–122). New York: Springer.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research*, *75*, 211–246.
Resnick, L. B., Michaels, S., & O' Connor, C. (2010). How (well structured) talk builds the mind. In (Eds.) Sternberg, R. & Preiss, D., *From genes to context: New discoveries about learning from educational research and their applications*. New York: Springer.
Roehrig, G. H., Kruse, R. A., & Kern, A. (2007). Teacher and school characteristics and their influenceon curriculum implementation. *Journal of Research in ScienceTeaching*, *44*(7), 883–907.
Roth, W.-M. (2005). Talking science: Language and learning in science classrooms, Lanham, MD: Rowman & Littlefield Publishers, Inc.
Russell, S. J. (1997). The role of curriculum in teacher development. In (Eds.) Friel, S. N. & Bright, G. W., *Reflecting on our work: NSF teacher enhancement in K-6 mathematics* (pp. 247–254). Lanham, MD: University Press of America, Inc.
Schneider, R., Krajcik, J., & Blumenfeld, P. (2005). Enacting reform-based science materials: The range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching*, *42*(3), 283–312.
Schwab, J. (1962). The teaching of science as enquiry. In (Eds.) Schwab, J. J. & Brandwein, P. F., *The teaching of science* (pp. 1–103). Cambridge, MA: Harvard University Press.
Schwab, J. J. (1959). The "impossible" role of the teacher in progressive education. *The School Review*, *67*(2), 139–159.
Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education*, *90*(4), 605–631.
Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.
Snyder, J., Bolin, F., & Zumwalt, K. (1992). Curriculum implementation. In (Ed.) Jackson, P., *Handbook of research on curriculum* (pp. 402–435). New York: Macmillan.
Solomon, J., & Gago, J. M. (1994). Science in school and the future of science culture in Europe. Proceedings of a Eurscientia Conference, Lisbon.
Squire, K. D., Makinster, J. G., Barnett, M., Luehmann, A. L., & Barab, S. L. (2003). Designed curriculum and local culture. *Science Education*, *87*(4), 588–612.
Stein, M. K., & Kaufman, J. H. (2010). Selecting and supporting the use of mathematics curricula at scale. *American Educational Research Journal*, *47*(3), 663–693.
Stoddart, T., Connell, M., Stofflett, R., & Peck, D. (1993). Reconstructing elementary teacher candidates' understanding of mathematics and science content. *Teaching and Teacher education*, *9*(3), 229–241.
Thijs, A., & van den Akker, J. (Eds.). (2009). *Curriculum in development*. Enschede, The Netherlands: SLO Netherlands institute for Curriculum Development.
Thompson, M., Wiliam, D. & Wylie, E., (Ed.). (2008). Tight but loose: A conceptual framework for scaling up school reforms, *Tight but loose: Scaling up teacher professional development in diverse contexts* (pp. 1–45). Princeton, NJ: Educational Testing Service.
Walker, D. (1990). *Fundamentals of curriculum*. San Diego: Harcourt, Brace Jovanovich.
Wiser, M., Smith, C. L., & Doubler, S. (2012). Learning Progressions as tool for curriculum development: Lessons from the Inquiry Project. In Eds. Alonzo, A. & Gotwals, A., *Learning Progressions in Science* (pp. 359–403). Boston: Sense Publishing.
Yin, R. (2009). Case study research: Design and methods (4th Ed.). Washington, DC: Sage.

How to cite this article: Drayton B, Bernstein D, Schunn C, McKenney S. Consequences of curricular adaptation strategies for implementation at scale. *Science Education*. 2020;1–25. https://doi.org/10.1002/sce.21595