Refining Inquiry with Multi-Form Assessment: Formative and Summative Assessment Functions for Flexible Inquiry

Steven J. Zuiker
Arizona State University

J. Reid Whitaker
Rice University

Abstract

This paper describes the 5E+I/A inquiry model and reports a case study of one curricular enactment by a US fifth-grade classroom. A literature review establishes the model's conceptual adequacy with respect to longstanding research related to both the 5E inquiry model (Bybee, Taylor, Gardner, Van, Powell et al., 2006) and multiple, incremental innovations of it. As a collective line of research, the review highlights a common emphasis on formative assessment, at times coupled either with differentiated instruction strategies or with activities that target the generalization of learning. The 5E+I/A model contributes a multi-level assessment strategy that balances formative and summative functions of multiple forms of assessment in order to support classroom participation while still attending to individual achievement. The case report documents the enactment of a weeklong 5E+I/A curricular design as a preliminary account of the model's empirical adequacy. A descriptive and analytical narrative illustrates variable ways that multi-level assessment makes student thinking visible and pedagogical decision-making more powerful. In light of both, it also documents productive adaptations to a flexible curricular design and considers future research to advance this collective line of inquiry.

Keywords: *inquiry; assessment; case study; K-12*

Introduction

The idea of inquiry is an enduring yet evolving reflection of the nature of science. As examples, early inquiry models have evolved over time (e.g., Barrow, 2006) and seemingly essential features of inquiry vary according to social and cultural conditions (e.g., Abd-El-Khalick, BouJaoude, Duschl, Lederman, Mamlok-Naaman et al., 2004). Such changes underscore that context matters (e.g., Gilbert, 2006).

Despite shifting approaches to inquiry, efforts to translate it into researchable models and curricula abound. Experimental evidence for refining and comparing models, nevertheless, falls short of generalizing them. We examine these challenges with respect to one longstanding, ongoing, and evolving line of research into inquiry-based science education. First, we consider a widely used inquiry model called the Biological Sciences Curriculum Study 5E inquiry model (5Es; Bybee, Taylor, Gardner, Van, Powell et al., 2006) and various derivative models in order to establish the conceptual adequacy of a new derivative called the 5E+I/A inquiry model. Second, we report a case study that illuminates some ways in which the 5E+I/A model adapts to support the variable, inevitably local conditions of an elementary school classroom.

The manuscript unfolds in four parts. A review of literature on the 5Es and various incremental innovations frames the intellectual merit of the 5E+I/A model. A description of the context of this case and our approach to methodic inquiry accounts for the generation and transformation of data. Findings describe and analyze one classroom enactment of the 5E+I/A model. Lastly, conclusions from the case report consider implications for future research.

Literature Review

Inquiry models in science education enlist research-based principles in order to engineer effective yet efficient learning environments (e.g., Bransford, Brown, & Cocking, 2000; Taber, 2000). As two examples from these syntheses, science education is more effective when it builds on prior experience and when it advances through an active, dynamic process. Whether or how common research-based principles might also inform a singular, research-based approach to inquiry remains an open question. In fact, the range of approaches to inquiry more often illustrate that these principles give rise to diversity and complementarity not uniformity (e.g., Bybee & DeBoer, 1994; Millar & Osborne, 1998).

Rather than a singular form, inquiry has been characterized in terms of multiple key aspects that progress by degree from simple to complex forms (e.g., Olson & Loucks-Horsley, 2000). One proposed aspect, for example, is working in autonomous small groups. Inquiry can be progressive with respect to grouping, at base, because it may not necessarily suit students with little prior inquiry experience. Given the variable conditions of the context of inquiry, framing inquiry in terms of multiple, progressive aspects underscores that acting autonomously and collaboratively is not a precondition. Rather, it rests on a set of practices established over time, together with classmates, under the guidance of a teacher. In this light, whether and how autonomous grouping occurs during inquiry is not uniform, let alone invariant; it is an adaptive and often progressive aspect.

A contrasting perspective on inquiry considers inquiry holistically. Isolating key aspects and characterizing them in terms of linear progressions such as autonomous grouping may be simplistic (Songer, Lee, & McDonald, 2003). That is, multiple authentic case exemplars, rather than multiple key aspects, may better characterize the essential complexity of inquiry because cases communicate the interrelatedness of autonomous grouping, for example, with other aspects of inquiry. Ultimately, both key aspects and holistic cases represent two among other competing viewpoints. Many presume that the unique conditions of a learning community inevitably mediate how an inquiry model operates and preclude standardized, uniform approaches. In turn, inquiry models and curricula may be more productive to the extent that they are flexible and adaptive to the local conditions and interpretations of inquiry in classrooms.

The remainder of this review examines one longstanding line of research in inquiry-based science education against this general backdrop. The goal of the review is twofold. It documents a well-delineated family of inquiry models in order to characterize a collective line of research and the individual contributions of each model. The review itself then serves as a specific backdrop against which to establish the intellectual merit and conceptual adequacy of the 5E+I/A inquiry model.

The 5Es Instructional Model

The 5Es is shorthand for a five-step inquiry process involving engagement, exploration, explanation, elaboration, and evaluation (Bybee, Taylor, Gardner, Van, Powell et al., 2006). In brief, illustrative introductory experiences enlist students' interests and prior experience to build connections to learning objectives (engagement step); inquiry activities investigate relevant phenomena (explore step); concepts are then explicated, including opportunities to demonstrate conceptual understanding (explanation step); complementary experiences then challenge and deepen understandings (elaboration step); lastly, formal, summative assessments evaluate students understanding (evaluation step). The 5Es provide opportunities to construct then refine ideas about the conceptual and material tools of science, both during and after direct experiences with relevant phenomena. In this way, each 5Es step builds one on another, framing a progression.

While this review primarily focuses on incremental innovations of the 5Es, it is instructive to highlight that the 5Es is itself a derivative of a more general learning model. The 5Es progression constitutes a learning cycle that Bybee, Taylor, Gardner, Van, Powell, and colleagues (2006) frame relative to an earlier three-step learning cycle involving exploration, invention, and discovery (Karplus & Their, 1967). The 5Es evolves and adds steps that leverage research-based principles from cognitive science concerning the roles of prior learning and metacognition. In this way, the 5Es is, itself, one aspect of broader and ongoing lines of research.

Empirical research establishes that the 5Es can support effective instruction and meaningful learning. A case study in which ten elementary school students enacted a 5Es curriculum reports positive results with respect to interest, motivation, and higher-order thinking (Boddy, Watson, & Aubusson, 2003). An experiment with random assignment generated statistically significant differences suggests a positive relationship between 5Es instruction and student achievement in a pre-service education course in Turkey (Yalçin & Bayrakçeken, 2010). In a more robust experimental study also involving randomized assignment, Wilson, Taylor, Kowalski, and Carlson (2010) compared multiple measures of learning in a voluntary sample of US high school students who completed either a 5Es or a well-explicated, conventional curriculum. Statistically significant differences in favor of the 5Es on both immediate and delayed post-testing of achievement, scientific reasoning, and scientific argumentation again support the model's efficacy. These three studies highlight the empirical base concerning instructional effectiveness and meaningful learning with the 5E model. It is bolstered by an unpublished meta-analysis report by the 5Es developers (Bybee, Taylor, Gardner, Van, Powell et al., 2006). Moreover, these positive findings have inspired incremental innovations of the 5Es.

Incremental Innovations of the 5Es Inquiry Model

While retaining much of the five-step progression featured in the 5Es, three derivative models represent both complementary intuitions and specific variations that productively extend theoretical and empirical research.

6E Model.[1] By adding an express step and modifying the 5E's elaborate step, Duran, Duran, Haney, and Scheuermann (2011) further emphasize and leverage assessment. The 6E's novel express step incorporates a preliminary assessment after the explain step. Leveraging insights from this assessment data, a modified elaborate step then differentiates the level of challenge and complexity students encounter. Taken together, the 6E model innovation represents a formative assessment strategy that precedes the final summative evaluation step. In a quasi-experimental comparison of the 6Es and 5Es, Fletcher (2011) reports no significant difference on achievement measures while also acknowledging only modest differences between conditions.

7E Model. The 7E model expands the 5Es to support productive transitions both into and out of inquiry (Eisenkraft, 2003). To better illuminate learners' prior knowledge at the outset of inquiry, the 7Es features an initial elicit step that enhances the engage step. To support the generalization of learning, it adds a final extend step that highlights a focal concept's reach into different circumstances and contexts. In a quasi-experimental

[1] Chessin and Moore (2004) characterize an alternative 6E model that adds cross-cutting "e-search" as a sixth step with the goal of integrating technology-enhanced activities but no empirical studies address this model.

comparison with conventional science instruction, Siribuannam and Tayraukham (2009) report statistically significant differences in favor of the 7Es on achievement and analytical thinking measures, but no articles citing Eisenkraft (2003) compare it to the 5Es.

4Ex2 Model. Enlisting three core steps from the 5Es, Marshall, Horton, and Smith (2009) organize a recurring 4-step sequence that emphasizes formative assessment, metacognition, and like the 7Es supports more general consequences of learning. With respect to design, the 4Es eliminates the elaborate and evaluate steps then adds an extension step to facilitate generalization of learning. It also incorporates two crosscutting features. The first, metacognitive reflection, emphasizes a self-aware process for reconsidering inquiry experiences. The second, formative assessment, organizes formal cycles of feedback that support teaching and learning. While no empirical studies citing the 4Ex2 model were identified, multiple resources complement this approach. A general template with a design checklist and prompts for developing 4Ex2 lessons is provided and, additionally, a web-based collaborative environment also exists (Dong, Marshall, & Wang, 2009).

Comparison of models. Each of the three inquiry models incrementally innovates the 5Es. The 6E and 7Emodels add or modify 5E steps while the 4Ex2 model also integrates crosscutting strategies, surfacing two themes. First, whereas the 5Es encapsulates assessment in the evaluation step, each derivative model expands assessment. The 6E model's express step and the 7E model's elicit step integrate formative assessment strategies as discrete steps. The 4Ex2 model's crosscutting formative assessment strategy, meanwhile, underscores the pervasive role of formative feedback. The second theme is a focus on generalizing learning. The extend steps in both the 7E and 4Ex2 models and a differentiated instructional strategy associated with the 6Es' elaboration step challenge students to think both about and beyond the immediate experiences associated with inquiry. They incorporate additional problem scenarios that situate relevant concepts in contrasting circumstances, highlighting ways in which concepts relate similarly and differently to particular conditions, supporting the generalization of learning (Marton, 2006). In these ways, the respective approaches of each model are distinct yet complimentary with respect to formative assessment and the generalization of learning.

Taken together, the 5Es and the permutations in form and sequence across the 6E, 7E, and 4Ex2 models constitute a resource for research and practice alike. While a core focus on engaging, exploring, and explaining remains, the range of possibilities beyond this primary steps reflects the complexity of classroom inquiry rather than a single, uniform approach (Songer, Lee, McDonald, 2003). Extending these points, the next section describes the 5E+I/A model in order to establish its own conceptual contribution.

The 5E+I/A Inquiry Model

The 5E+I/A model likewise concentrates on formative assessment and the generalization of learning but enlists a multi-level assessment strategy to accomplish both. Whereas the 5E and derivative models above all distinguish assessment *for* learning (i.e., formative assessment) from assessment *of* learning (i.e., summative assessment), the 5E+I/A model views all assessment *as* learning, reflecting a socio-cultural perspective on assessment. "Rather than an external and formalized activity, assessment is integral to the teaching process and embedded in the social and cultural life of the classroom" (Gipps, 1999, p. 378). The process of assessment, in other words, matters as much as its products in supporting productive teaching and learning, underscoring two central design principles. Multi-level assessment considers individual student performance as a unit of concern but concentrates on collective participation as the primary unit of analysis for understanding the conceptual resources developing during inquiry (e.g., Hickey & Zuiker, 2012). In turn, every assessment balances formative and summative functions to support collective participation. Combining these aspects, the 5E+I/A model coordinates assessment across all steps with respect to levels of instructional outcomes.

Designing multi-level assessment requires the coordination of curricular experiences, learning objectives and complementary assessment tools. The goal of coordinating assessments in this way is to support the formalization of disciplinary ideas and concepts. Multiple levels balance formative and summative functions differently by framing individual questions or entire assessment resources at different levels of formality along the inquiry sequence. While all assessments aim to support, refine and generalize learning, differentiated levels organize different forms of feedback. Embracing design principles articulated by Hickey and Zuiker (2012; see also 2003), multi-level assessment approximates a continuum of close, proximal, and distal outcomes (cf. Ruiz-Primo, Shavelson, Hamilton, & Klein, 2002) together with increasingly formal accountability and feedback structures. Open-ended prompts embedded in curricular resources frame learning objectives at a close level in terms of immediate, specific, and ongoing participation in order to informally foster scientific discourse about inquiry practices. At the opposite end, closed-ended, multiple-choice items at the distal level frame the same learning objectives generally, if not abstractly. The goal of moving beyond specific activities and concrete experiences in this way organizes participation around the formal articulation, and refinement, of invariant properties of underlying scientific concept. Coordinating such a continuum along multiple levels of representation and formality embeds conventional psychometric tools with performance-based tasks in order to generate multi-faceted data. These data, in turn, serve teaching and learning with respect to moment-to-moment actions during daily lessons, lesson-to-lesson activities during weekly units, and unit-to-unit inquiry instruction across semesters, all with respect to grade-level learning standards.

The 5E+I/A model leverages multi-level assessment in three ways: as discrete steps, as activities featured within a step, and as prompts embedded in an activity. Most prominently, a discrete step like the 6Es and 7Es supports the generalization of learning by re-framing concepts with respect multiple, broader contexts. Specifically, parallel sixth steps labeled acceleration and intervention organize differentiated instruction based on individual performance during the evaluation step. The intervention step structures a form of remedial inquiry while the acceleration step offers new problem-based learning scenarios. The case study that follows illustrates these parallel steps along with multi-level assessment activities and embedded items.

Taken together, multi-level assessment incorporates an additional I/A step and a crosscutting assessment strategy for supporting and understanding collective participation in inquiry. Its multiple forms of data and feedback may also illuminate challenges and opportunities related to specific local classroom conditions and therein inform productive local adaptations of the model. The merit of the 5E+I/A model obviously resides in both its conceptual and empirical adequacy. To this end, Whitaker (2012) provides an anecdotal account in which school-wide adoption of the model accompanied noteworthy learning gains on annual state tests relative to previous years. Meanwhile, the following case study provides methodic descriptions and analyses of the model.

Case Study

This case study seeks to advance understanding about the relationship between inquiry and assessment and, in particular, how it supports flexible and adaptive science education curricula. To this end, we enlist a socio-cultural theoretical framework to consider relational and contextual factors that inevitably shape, and are shaped, by enactments of the 5E+I/A model. An in-depth examination of the particulars of a case can make progress on the interplay between principled scientific practices, principled educational assessment, and their intersections under local conditions in which teachers, students, and other educational stakeholders interpret and enact them. Focusing the case at the nexus of inquiry, assessment, and local interpretation enables us to address claims about whether and how multi-level assessment informs pedagogical decision-making and, in turn, claims about whether and how the 5E+I/A inquiry model flexes to the local conditions illuminated through this interplay. To begin, we characterize the general case context.

Context of the Case

We briefly describe the context of our study in terms of relevant aspects of both the school and specific classroom as a first step in understanding our method and case report. The study takes place in urban elementary school classroom in the southwest United States. A large majority of its students face economic hardships as indicated by the fact that 90% receive a US federal lunch subsidy. Further, the minority status of its predominantly Hispanic population as well as learning disabilities and/or prior behavioral issues of any student designate 67% of the children as “at-risk” for academic failure. The negative trends implied by these statistics, however, stand in contrast to actual achievements of the school’s students, faculty, administration, and the community supporting them. That is, in spite of the above challenges, the school consistently meets federal goals related to performance and repeatedly earned the highest possible state rating in recent years. These outcomes reflect the idea that learning and knowing relate to what is valued and useful in the broader community of which any school is part (Bruner, 1996) and that proxy variables remain basic indicators of complex communities. By extension, these efforts may also be ideal for understanding how science education attempts to leverage rather than mitigate these same broader social and cultural conditions (Calabrese Barton, 1998).

Resolving how the 5E+I/A model creates meaningful opportunities to learn also depends on the specific context of the science classroom. The fifth-grade science class at this school emphasized inquiry-based instruction; moreover, the teacher used the 5E+I/A model to organize each of 22 weekly inquiry units for three separate science classes. (He also acknowledged organizing several weeks of focused preparation for the high-stakes testing that immediately preceded the study.) This level of repetition suggests students are familiar with the model’s steps and activities, if not also the underlying scientific practices. It also suggests that the study focuses not simply on the model but rather on its continuity and transformation. The ongoing practical experiences of classroom participants and attendant personal strategies of the teacher illuminate how they adapt the model against the backdrop of the school context.

Methods

To understand the 5E+IA model relationally and contextually, we prioritize ecological validity. We therefore adopt Stake’s (1995) approach to case study as a means of understanding an everyday enactment; in turn, we enlist naturalistic and ethnographic research methods that concentrate on particularity rather than generalizability. This section therefore accounts for the construction and transformation of data, which enables us to examine the flexibility and sustainability in terms of the relations among participants, activities and materials organized around the 5E+I/A model.

5E+I/A Inquiry Model Curriculum

The 5E+I/A inquiry model provides a framework for an online science education platform called STEMscopes. Weeklong units feature customizable activities and resources. The appendix describes all unit materials, each nested within the step that it is designed to support. The end-goal of the intended curricular design is to support and, through assessment, illuminate student-centered experiences during collaborative and self-directed learning. Each activity and resource stands alone in order to enable teachers to add, remove, or reorder materials as necessary. Such a design strategy also emphasizes that inquiry is a process supported by materials rather than a lock-step procedure. Importantly, the 5E+I/A's crosscutting and multi-level assessment also supports this customization strategy by generating data that inform teacher decision-making between and sometimes during lessons. That is, the combination of assessment items embedded in components of earlier steps and assessment components formally included in later steps generate ongoing feedback to support the 5E+I/A model without overly structuring the inquiry process.

The particular unit featured in this study focuses on the concept of density. Activities associated with the first three steps engage students with density in multiple ways: contrasting the density of various materials (e.g., cotton balls, balsa, and oak); measuring mass and volume then calculate density for both rectangular and irregularly shaped potato wedges; and again measuring and calculating to identify unknown liquids. The assessment strategy evolves across the unit: informal questions about the idea of density probe intuitive understanding and solicit everyday examples described in vernacular language; more conceptual questions directly frame activities and relate density to mass and volume; discrete items formally, and sometimes abstractly, consider density; meanwhile, the evaluate step incorporates a proxy to high-stakes state achievement measures together with open-ended items that continue to probe conceptual understanding grounded in curricular experiences.

Participants

Twenty fifth-grade students and their veteran science teacher of 20 years, Mr. Lee (all names are pseudonyms) enacted the density unit across five 120-minute lessons. As an example of purposive sampling, the case features a teacher, Mr. Lee, selected on the basis of consistent use of the STEMscopes curriculum. We identified high-use candidate teachers using basic STEMscopes website analytics data (i.e., logins, downloads) for registered teachers and selected Mr. Lee on the basis of convenience. Mr. Lee's 22 unit enactments with three classes during the 2011-2012 academic year ranked him in the top 1% in terms of basic use. This strategy targets exemplary conditions for understanding the sustainability and adaptability of the 5E+I/A model (Flyvbjerg, 2004) because the teacher and students are familiar with the model but, moreover, their ongoing practical experiences across recurring enactments enable them to shape and to be shaped by the model. Purposive sampling, in sum, takes advantage of Mr. Lee's consistent classroom engagement and persistent efforts to localize the model in order to develop a realistic and meaningful descriptive and analytical account.

Data Generation Strategy

In order to construct data about continuous classroom participation, I (Zuiker) assumed the role of participant observer, attending all lessons (600 total minutes), writing fieldnotes (11 single-spaced pages), and conducting unstructured, in-situ student interviews about curricular experiences (17 total minutes) and semi-structured debriefing teacher interviews after each lesson (29 total minutes). Additionally, two video and four audio recordings captured classroom interaction; a wide-angle camera documented the whole classroom while, during small group activities, a second video documented one student group and audio recorders documented the other four groups.

Data Analysis Strategy

We transformed data in order to understand how the 5E+I/A model operated under circumstances that might illuminate both its flexibility and sustainability under ecologically valid conditions. To this end, we first reduced the continuous audio-video data into content logs (Jordan & Henderson, 1995). Logs segmented the five lessons according to general classroom activity structures (e.g., teacher lecture, student group investigation) and particular episodes of social interaction unfolding therein (e.g., teacher questioning, student argumentation). The content logs then served a multistep analysis. As preliminary deductive analysis, we enlisted the a priori model-derived categories to identify segments in the content logs that featured 5E+I/A inquiry steps, assessment, or their integration (e.g., assessment items embedded in inquiry resources) as well as extra-model activities and episodes. At the same time, the analysis does not aim merely to seek out and relate segments to the model but rather to situate and understand the role of materials, activities, and participation in the enactment of the model. We therefore also identified discrepant segments that challenged us to consider whether the enactment reflected the design intentions underlying the 5E+I/A model or perhaps either adaptations of or departures from these intentions. Through a process of analytical induction, we re-examined the activities and episodes implicated in our deductive analysis. First, we directly but selectively returned to the audio-video data in order to transcribe and more closely interrogate peer discourse during small group activities and teacher-facilitated whole class discussions. Second, due to frequent discrepancies related to teacher-led activities, our preliminary deductive analysis also warranted an inventory of the teacher's indigenous pedagogical practices relative to those featured in the curricular design in order to describe emergent phenomenon apart from our initial a priori categories. Finally, we characterized patterns in participation within and across lessons, activities, and episodes and identified negative cases that challenged each pattern and tempered our subjectivities. In this way, we attempted to make sense of various parts and aspects of the enactment in order to report a holistic case study of the model. Building from this account, we next present a case report that combines descriptive and analytical accounts in order to characterize how the teacher, students, and curricular resources mutually shape the enactment.

Findings

Enlisting the methodic process described above, our findings consider learning and participation with respect to the inquiry model and multi-level assessment, concentrating on the role of integrated assessment plays in pedagogical decision-making and local adaptations to the 5E+I/A model. Our case report begins with a vignette that captures a sequence of activities that characterize opportunities to learn through inquiry. We then situate the vignette within the weeklong enactment of the 5E+I/A model and the interplay between inquiry and assessment operating therein.

Introductory vignette

With over 20 years experience, Mr. Lee is a veteran teacher and a longstanding member of an elementary school that predominantly serves students from a low-SES urban community. It is the final weeks of the school year and the 20 science students in his first period class have just completed two weeks of accountability-related testing. Science class nevertheless begins as it has nearly every other Monday, with a new weeklong inquiry unit. As an introduction to the idea of density, Mr. Lee explains that students will compare identically shaped blocks (of more and less dense woods). Peer groups will conjecture whether or not each will float in a container full of water before submerging and observing them. One student asks, "so we'll be giants for everything we'll be doing this week, right?" The question frames density relative to the student and, therein, reframes the activity in relative terms. Matter-of-fact reactions from students and Mr. Lee suggest that the question is familiar. If not already a heuristic invoked from previous units, it typifies the kinds of shared understandings achieved across 22 completed inquiry units that serve as a common foundation on which the class coordinates and thinks together about science.

As groups begin examining the blocks, students share their intuitions about what might happen when the blocks enter the water. They talk and listen to one another; some revise their initial conjectures in light of a peer's idea. However, it is not until the blocks enter the water and make relative density visible that groups achieve some degree of consensus. Based on student conversations during the activity, Mr. Lee later speculates that students generally understand how density operates while also admitting that the experience perhaps raises more specific questions than it answers. Ultimately, he emphasizes an affective facet of the experience, saying, "I feel like the engage gets them excited. You saw. The whole class just changed the minute they got to touch things and that's what I love about science." The observation seems to be supported by student engagement and enthusiasm during the first lesson, while also revealing Mr. Lee's emphasis on student-centered, hands-on activities as a driver of inquiry learning. In this sense, as "the whole class just changed" during the engage step activity, it creates opportunities to learn that might otherwise not be available in the classroom. Density is accessible, visible, even contestable during activities and in dialogue, and therefore open for inspection.

The process of inquiry in this vignette is a necessary account of how the 5E+I/A model operates but alone is insufficient. Multiple inquiry models already support the conceptual and empirical adequacy of similar learning opportunities. Our case builds on this vignette by considering the interplay between a core focus on inquiry and the supporting role of multi-level assessment. To this end, we next situate the vignette within the broader enactment from which it derives.

Documenting a 5E+I/A enactment

Our case provides an opportunity to understand the flexibility of the 5E+I/A model and the capacity of multi-level assessment to support productive adaptations. We assume that inquiry is not uniform or standardized nor are the classrooms in which it operates, training our focus on both continuity and transformation in order to characterize meaningful and sustainable engagement with science. We therefore begin by characterizing the enactment of the 5E+I/A model with respect to our intended design.

Mr. Lee and his fifth grade class enact all six steps of the 5E+I/A model across 5 lessons. Mr. Lee enlists

16 of the 26 STEMscopes curricular resources enumerated in the appendix for the density unit in order to enact the 5E+I/A model. Importantly, while the engage activities described in the introductory vignette are the first step of the unit, they are not the first activities in the classroom. They follow after several indigenous pedagogical activities that Mr. Lee incorporates as a consequence of previous enactments, documenting an immediate departure from the model that we detail in several ways. First, Table 1 below presents the enactment as a temporal ordering of the 5 lessons in order to highlight how the 5E+I/A model remained the same and how it changed due to Mr. Lee's activities.

[Insert Table 1 about here]

From left to right, the table documents the unfolding of each lesson and featured inquiry steps, STEMscopes resources, and indigenous pedagogical activities. Gray shading indicates variation from the intended design; italics indicate activities and resources beyond the model or curricular resources. Table 1 shows, firstly, that Mr. Lee consistently engineers an explanation-like episode to begin each of the first four lessons and, secondly, that he appropriates resources associated with one particular inquiry step in the service of another.

These departures document that Mr. Lee consistently had the final say in enacting the model. Obviously, these observations discount claims of rigorous implementation fidelity while also beginning to characterize a practice-centered approach. Whether diminished fidelity is a symptom of an unproductive mutation or a productive adaptation remains unclear from this general framing of the enactment. However, it clearly frames an opportunity to understand whether and how these changes reflect the model's flexibility for organizing productive inquiry and the role multi-level assessment plays therein. At best, the counted and sequenced representation in Table 1 suggests but does not illuminate either one.

The value of examining this timeline in terms of sequentiality-in-context (Stake, 1995) addresses two considerations. First, do these adaptations enlist the principles underlying the 5E+I/A model productively yet flexibly and, second, how do these adaptations relate to multi-level assessment? The remainder of this case report therefore considers the enactment as the evolution of the 22 preceding enactments and the formative and summative functions of multi-level assessment.

Contextualizing a 5E+I/A enactment

While it matters which steps and resources that Mr. Lee enlists and when, how and ultimately why matters more. In order to contextualize the enactment, we inductively analyzed content logs with respect to the model-derived categories, constructing several themes.

The first theme is Mr. Lee's emphasis on both student-centered and hands-on experiences. While he uses all STEMscopes resources associated with the engage and explore steps, he also repeatedly adapts them in order to maximize the time available for students complete these activities. In the introductory vignette, for example, Mr. Lee re-engineers the STEMscopes Teacher Demonstration (see appendix) as a peer group-directed activity. Meanwhile, as time runs short during the third lesson, Mr. Lee shifts his own role during explore step activities from facilitating parallel group efforts to leading all groups at a pace that enabled them to generate and analyze data. Both adaptations of activity structures illustrate Mr. Lee's emphasis on direct student engagement with scientific practice. Alone this theme affirms the literature reviewed above; it is noteworthy, however, in connection to a second, contrasting theme of our inductive analysis.

In addition to emphasizing small group, hands-on inquiry, Mr. Lee also developed and integrated a recurring exposition of bookish content to begin each of the first four lessons. For this unit, these expository activities included a brief lecture, a video about the general idea of density, and note-taking about nine key points. One key point, for example, was "density is the same for all the objects that are made from the same material." The initial focus on content apart from inquiry departs from, rather than adapts, the model. That is, the intended design of the engage and explore steps seeks to leverage students' prior experiences and to foster an active learning process as preconditions for these kinds of explanation (e.g., Bransford, Brown, & Cocking, 2000). Mr. Lee's notes aim to simultaneously explicate insight and facilitate inquiry, but run the risk of reframing student investigations of ideas new to themselves into a search for predetermined knowledge and facts. In debriefing conversations, Mr. Lee confirmed that these expository pedagogical practices occurred in at least the last ten units (48%). In this sense, they are not an arbitrary improvisation, but rather a specific and precisely repeated local transformation of the model. Taken together with the first theme, the customization of the model represented in Table 1 appears to simultaneously diminish and enhance inquiry.

In retrospect, such a contradiction can be considered from a different vantage point. A broader theoretical frame that considers the more encompassing phenomenon of schooling provides a plausible account of these practices. That is, with respect to yearlong cycles of enacting the 5E+I/A model however, these contradictory themes may, in fact, resolve competing social and cultural conditions. A learner's beliefs about her own learning matter (Ketelhut, 2007) and, in particular, students whose beliefs do not strongly resonate with socio-cultural approaches may learn less from inquiry (Linn & Songer, 1993) or even resist it altogether (Tobin, Tippins, & Hook, 1995). In this light, explicating the content embedded in inquiry may facilitate engagement for some learners. Such an interpretation is plausible, reflecting the mutual influence of teachers and students on curricular enactments. It remains a situated account of learning and teaching but one that relates learning not only to the means by which inquiry models can support and organize it but also to the means by which curricula must support teachers in re-organizing it with respect to the broader and more encompassing extra-curricular context of schooling.

While student beliefs about inquiry are often tacit, and therefore more difficult to characterize, they lend additional insight to this interpretation. In-situ interviews bring to light student perceptions about the model and its relationship to inquiry. During the explore step, for example, one small group considered what was similar across all the units. In the following transcript, the comments of four students in one group illustrate the variable perspectives typical of each group interview.

Zuiker: how is the explore activity you did for density similar to other explore activities you've done this year
Student 1: check measurements
Student 2: always use hypotheses
Zuiker: say more about that
Student 3: there's no right wrong answer (pause) you're always right (group laughs)
Zuiker: that's interesting do you guys wanna say a little more about that
Student 2: like if you say something like […] if we put alcohol and water in the same container then alcohol will sink but then if you do an experiment and alcohol floats then it doesn't mean you were wrong because it was just your thinking
Student 4: we wear our goggles when working with liquids

Student 1's comment on rigor and method and student 4's comment on safety address general scientific practices, reflecting relatively surface features of the explore step. Meanwhile, students 2 and 3's comments and elaboration indicate that the explore step is generally about thinking critically rather than initially being right or wrong, reflecting relatively deep features of the model. Together with other group interviews, these responses highlight two things. First, after 22 cycles of inquiry, groups do not share a common view, which is consistent with our earlier conjecture that students' differing beliefs about learning may inform Mr. Lee's indigenous pedagogical practices. Second, the complementarity across these responses is itself a resource when inquiry, and multi-level assessment, revolve around collective participation rather than individual performance as described by the idea of co-regulated learning (McCaslin & Hickey, 2001; Hickey & Zuiker, 2005). A group's shared task involves coordinating not only the goals and expectations of participation in science but also the multiple social worlds operating therein. The transcript begins to illustrate how inquiry operates at the confluence of these perspectives and further underscores the plausibility of characterizing Mr. Lee's indigenous pedagogical activities in terms of their practical force rather than seeming theoretical contradictions.

By contextualizing the enactment, we illuminate both apparent contradictions and plausible interpretations as to why they emerged over time in this classroom. Students' beliefs about science are not bounded by classrooms. Therefore, inquiry instruction must adapt to the inherent diversity of perspectives while also leveraging the resources entailed in these viewpoints. Conjectures as to why also depend on how such local interpretations and transformations come about. The remainder of this case examines how the 5E+I/A multi-level assessment strategy generates data that informs Mr. Lee's practical considerations about the intersections of inquiry, learning, and teaching.

Tracking multi-level assessment

The 5E+I/A multi-level assessment aims to amplify the interplay between teaching and learning. As they investigate density as a ratio quantity, students not only compare the weight and volume of materials but also reconcile its significance in terms of their prior experience and curricular objectives. The STEMscopes student guide (see appendix) supports data collection and data analysis and is accompanied by a student journal (see appendix). Embedded assessment prompts in both resources make thinking visible, organizing occasions to self-monitor and underscoring that individual performance is a unit of concern. More broadly, as an explicit framing of experience in terms of learning objectives, they solicit conjectures among group members about their collective actions and observations, providing opportunities for co-monitoring inquiry. For example, one question states, "do you think that a part or slice of a substance will have a different density than the whole piece? Explain your ideas about this." By characterizing the features of phenomena, students and groups make their thinking explicit, accessible to peers and visible to Mr. Lee. Embedded prompts create opportunities for informal discussion and occasions for Mr. Lee to engage groups casually yet consistently. As examples of a multi-level assessment tool operating a close level, prompts remain informal and focus concretely on the experience at hand, maximizing the formative potential of assessment..

The explain step follows after the explore step and introduces the first discrete assessment activity. Mr. Lee employs the progress monitoring assessment (PMA, see appendix) at the end of the third lesson groups complete data analysis. Rather than the immediate particulars of the explore activities, PMA items frame density with respect to a broader and more general range of contexts. One proximal-level item, for example, features an irregularly-shaped object made of nondescript material rather than the wood blocks featured in the preceding steps as a means of generalizing the concrete particulars through which inquiry unfolded.

As a discrete assessment activity, the performance monitoring assessment also enlists summative and formative functions differently. Students complete all PMA items individually. Mr. Lee does not collect their papers but rather discusses their responses semi-formally. He encourages peer discussion before selecting a student to answer aloud and then evaluating her response directly or asking another student to do so. Isolated, individual completion of the PMA increases its summative function, generating discrete data about individual understanding, and enlists the data explicitly during a conversation that semi-formalizes its formative functions

A second illustrative item illustrates the value of proximal-level framing as well. The item re-frames density in terms of gases. Whereas all previous activities only featured liquids and solids, a third state of matter subtly expands the concept of density as well as the potential for feedback. States of matter are irrelevant to the item's solution, but lead one student to ask how the density of a gas can be measured. Through similar whole class discussions of PMA items, Mr. Lee resolves a qualitative sense for class-wide understanding then ends the third lesson with an informal survey question: "How many feel like you know more today about density than you did last Friday?" Counting the raised hands, he adds, "Yeah, we're still a little shaky and that's okay 'cause not only are you doing something different in science, you're doing something different in math." The observation suggests that the PMA augments Mr. Lee's understanding of his students at the same time that it refines their understanding of density. He makes a similar point subsequently during our lesson debriefing conversation.

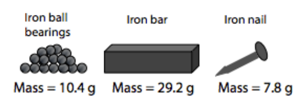
> [The PMA] is the big clue about how they're gonna do tomorrow. […] [Teachers] need to be able to figure out how they're doing. I don't wanna find out on test day how they're doing. I wanna know ahead of time and that's why I told them we're gonna have to do a little practice before the test tomorrow.

The PMA enables Mr. Lee to characterize student understanding and determine how to proceed. In this way, the comment describes a formative feedback loop in which "how they're doing" guides Mr. Lee's decision "to do a little practice."

The fourth lesson illustrates how the PMA data informs subsequent instruction. Mr. Lee repurposes the STEMscopes guided practice resource associated with the model's intervention-acceleration step (see appendix) in order to provide additional hands-on activities during lesson four. The featured activity organizes inquiry with irregularly-shaped pliable clay and provides a new experience through which to advance whole class discussion similar to the PMA review above. ,Students then individually complete, and Mr. Lee formally grades, the standards-based and open-ended assessments featured in the evaluate step (see appendix). These multi-level assessment items frame density more distally with respect to state science standards. That is, items either abstract or randomize contextual features, which might favor a particular curriculum, in order to maximize the summative functions and, in turn, provide weekly opportunities to wrestle with the generality and abstraction central to many forms of high-stakes accountability testing.

The results of the evaluation step reveal to Mr. Lee a lingering and critical misunderstanding. Seventy percent of the class incorrectly answered the item in Figure 1 below.

6. There are three objects shown. Which of these objects has the highest density?



- A The iron bar
- B The iron nail
- C The iron ball bearings
- D The density is the same for all of the objects

Figure 1. Standards-based assessment item involving relative density

One student indicated that the nail is denser and 13 that the bar is denser, suggesting a widespread misconception that density is a property of the form or mass of a substance rather than the ratio of them. Ironically, the underlying idea is also one of the key points that Mr. Lee repeatedly presents to students during his indigenous pedagogical activities.

Such a misconception is noteworthy for several reasons. In their work on misconceptions related to density, Smith and colleagues (Smith, Snir, & Grosslight, 1992; Smith, Maclin, Grosslight, & Davis, 1997) underscore the importance of learners' intuitive or commonsense notions, often qualitative in nature, because such notions constrain whether and how the learner understands density. "Students are seldom encouraged to reason qualitatively about conceptual relations starting from their own commonsense ideas, to construct qualitative models of phenomena, or to refine their own intuitions about the physical world" (p. 319). On the one hand, it is striking that the above misconception remained after a weeklong unit featuring hands-on experiences focused on qualitative reasoning and modeling. On the other hand, these results echo longstanding research that documents persistent misconceptions despite clear explanations aimed at dispelling them (Magnusson, Templin, & Boyle, 1997). That such a pattern of responses occurred in this case affirms prior research on misconception and likewise underscores that the 5E+I/A model is not a simple solution to such a complex problems. Moreover, it punctuates the value of the additional intervention-acceleration steps featured in the 5E+I/A model, which leverage the evaluate step to sort students for differentiated instruction that can addresses lingering misconception. Remediation in this instance is relatively simple because the misunderstanding is widespread and singular but the resources associated with the latter steps, in principal, equip teachers to manage more complex remediation strategies as well, involving multiple misconceptions distributed across overlapping student subsets. In this way, the 5E+I/A model's incremental innovation organizes a framework for both revealing and productively redressing misconceptions.

Conclusions

This study provides a conceptual account of the 5E+I/A model and an empirical account of the final enactment of a yearlong effort to faithfully appropriate and adapt the model in one science classroom. Together, these two accounts consider inquiry, multi-level assessment, and their relationships to pedagogical decision-making and, in turn, adaptations of the model that either accommodate or, at times, take advantage of local conditions.

The case report described the enactment of one weeklong 5E+I/A unit. It attended to the coupling of multiple opportunities to inquire with the recurring cycles of feedback organized by multiple levels of assessment. These opportunities supported participation in inquiry in order to develop collective understanding of the nature of science and individual performance on learning objectives. The case report also drew insights from the real world complexities of a classroom while also recognizing an inherently incomplete perspective on a limited number of aspects relevant to the 5E+I/A model. First, a widespread misconception made visible during the evaluation step of the original 5Es underscores the value of coupling it with the intervention-acceleration step of the 5E+I/A model. The combined steps revealed and then attempted to redress an errant yet persistent view. It is a noteworthy aspect of the case not only for what it affirms about the resolute challenges of prior experience but also for the value of integrating the additional intervention-acceleration step as an additional opportunity to learn. Second, multiple adaptations of curricular resources carried out by the teacher reflect insights generated by the assessments he used. In this way, the multi-level assessment strategy underlying the model informed pedagogical decision-making as well as efforts to adapt the 5E+I/A model to local conditions (Squire, McKinster, Barnett, Luemann, & Barab, 2004; Zuiker, 2012).

Sometimes long-term local efforts such as the 23 5E+I/A inquiry units enacted in this class arrive at a new point of stability (Bielazcyc, 2012), reflecting the fact that teachers learn from and through the curricular resources they appropriate (e.g., Shulman & Sherin, 2004; Simon & Tzur, 1999). This case begins to establish ways in which multi-form assessment (Hickey & Zuiker, 2012) can enable and empower teachers to leverage the diversity within classroom communities as a collective resource to intensify learning rather than as a variable to control it. The 5E+I/A model seeks to organize inquiry at the same time while simultaneously coordinating cycles of feedback that support learning and instruction. Rather than a controlling script, the case illustrates mutual adaptations as one 5E+I/A model unit unfolds. It establishes that feedback loops of assessment data in the 5E+I/A model can productively inform both informal, moment-to-moment adaptions as well as formal lesson-to-lesson ones. That 22 other units preceded this case also suggests that the teacher actively and critically refined enactments unit-to-unit, underscoring broader interplay among practical, circumstantial, social, and cultural conditions. Well-designed curricula inevitably fail as remote controls perhaps because they remain inherently incomplete; they are a resource for inquiry but also for productive improvisation, enabling teachers to create value through informed local interpretation.

The 5E+I/A model's assessment strategy complements the formative assessment agendas at work in a collective line of inquiry associated with the 5Es. Specifically, it links formative assessment to a more holistic strategy that balances formative and summative functions. It suggests that, while individual performance (i.e., evaluation step) must always remain a unit of concern, collective participation as illuminated with multi-level assessment must remain the unit of analysis in order to sustain and improve inquiry instruction locally.

The case serves to illuminate the practical force of sustained use in one setting but is not a conclusive argument about the 5E+I/A model. It is compelling and therefore justifies ongoing case studies across settings in order to understand the dynamic, mediated relationships between the 5E+I/A model and its enactment under contrasting local conditions (cf., Zuiker, 2012). Such case-based comparison and differentiation advance the development of principled yet flexibly adaptive models of inquiry in science education (e.g., Penuel, Fishman, Cheng, & Sabelli, 2011). It also justifies future quasi-experimental investigations into the relative impact of the 5E+I/A model's approach to assessment *as* learning. Understanding core principles and curricular flexibility is necessary in order to support sustainable inquiry models that enable general but flexible models capable of scaling down to local conditions rather than scaling up a standardized approach. In urban schools such as this one, if innovations are to be usable, there must be a fit with culture, capabilities, and policies in schools (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000). As the 5E+I/A model implies and this case narrative begins to document, goodness of fit relates to the goodness of flex.

References

Abd-El-Khalick, F., BouJaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., … Tuan, H. (2004). Inquiry in science education: International perspectives. *Science Education, 88*(3), 397–419. doi:10.1002/sce.10118

Barrow, L. H. (2006). A brief history of inquiry: From Dewey to standards. *Journal of Science Teacher Education, 17*(3), 265–278. doi:10.1007/s10972-006-9008-5

Barton, A. C. (1998). Teaching science with homeless children: Pedagogy, representation, and identity. *Journal of research in science teaching*, *35*(4), 379-394.

Bielaczyc, K. (2012). Informing design research: Learning from teachers' designs of social infrastructure. *Journal of the Learning Sciences.* doi:10.1080/10508406.2012.691925

Blumenfeld, P. C., Fishman, B. J., Krajcik, J. S., Marx, R. W., & Soloway, E. (2000). Creating useable innovations in systemic reform: Scaling up technology-embedded project-based science in urban schools. *Educational Psychologist, 35*(3), 149–164.

Boddy, N., Watson, K., & Aubusson, P. (2003). A trial of the 5Es: A referent model for constructivist teaching and learning. *Research in Science Education, 33*(1), 27-42.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.) (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Bybee, R.W., & DeBoer, G.E. (1994). Research on goals for the science curriculum. In D.L. Gabel (Ed.), *Handbook on Research in Science Teaching and Learning* (pp. 357–387). MacMillan, New York.

Bybee, R. W., Taylor, J. A., Gardner, A., Van, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model : Origins and effectiveness*. Science. Colorado Springs. Retrieved from http://website.bscsconnect.org/pdf/bscs5efullreport2006.pdf

Chessin, D.A., & Moore, V.J. (2004). The 6-E learning model. *Science & Children, 42*(3): 47–49.

Dong, L., Marshall, J., & Wang, J. (2009). A Web-based Collaboration Environment for K-12 Math and Science Teachers. In *39th ASEE/IEEE Frontiers in Education Conference* (p. W2C1-W2C6).

Duran, E., Duran, L., Haney, J., & Scheuermann, A. (2011). A learning cycle for all students. *The Science Teacher*, March, 56-60.

Eisenkraft, A. (2003). Expanding the 5E model. *The Science Teacher, 70*(6), 56-59.

Fletcher, S. (2011). The impact of the 6E model on a third grade science classroom. Unpublished Master's Thesis. Bowling Green State University.

Gilbert, J. K. (2006). On the nature of "context" in chemical education. *International Journal of Science Education, 28*(9), 957-976.

Hickey, D. T. & Zuiker, S. J. (2003). A new perspective for evaluating innovative science learning environments. *Science Education, 87* (2), 539-563. doi:10.1002/sce.10087

Hickey, D. T. & Zuiker, S. J. (2005). Engaged participation: A sociocultural model of motivation with implications for educational assessment. *Educational Assessment*, *10* (3), 277–305. doi: 10.1207/s15326977ea1003_7

Hickey, D. T., & Zuiker, S. J. (2012). Multi-level assessment for discourse, understanding, and achievement. *Journal of the Learning Sciences, 21*(4), 522-582. doi: 10.1080/10508406.2011.652320

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences, 4*, 39-103.

Karplus, R., & Their, H. D. (1967). *A new look at elementary school science*. Chicago, IL: Rand McNally.

Ketelhut, D. J. (2007). The impact of student self-efficacy on scientific inquiry skills: An exploratory investigation in River City, a multi-user virtual environment. *Journal of Science Education & Technology,16*(1), 99-111, doi: 10.1007/s10956-006-9038-y

Linn, M. C., & Songer, N. B. (1993). How do students make sense of science? *Merrill-Palmer Quarterly*, *39*(1), 47-73.

Magnusson, S. J., Templin, M., & Boyle, R. A. (1997). Dynamic science assessment: A new approach for investigating conceptual change. *Journal of the Learning Sciences, 6*(1), 91–142.

Marshall, J. C., Horton, B., & Smart, J. (2009). 4E × 2 Instructional model: Uniting three learning constructs to improve praxis in science and mathematics classrooms. *Journal of Science Teacher Education, 20*, 501-516. doi:10.1007/s10972-008-9114-7

Marton, F. (2006). Sameness and difference in transfer. *Journal of the Learning Sciences*, *15*(4), 499–535. doi:10.1207/s15327809jls1504_3

Millar, R. & Osborne, J. (1998). *Beyond 2000: Science education for the future*. London: King's College.

Olson, S., & Loucks-Horsley, S. (Eds.) (2000). *Inquiry and the national science education standards*. Washington, DC: National Academy Press.

Pellegrino, J., Baxter, G., & Glaser, R. (1999). Addressing the two disciplines problem: Linking theories of cognition and learning with assessment and instructional practice. In A. Iran-Nejad, & P. D. Pearson (Eds.), *Review of research in education* (pp.

309–355). Washington, DC: American Educational Research Association.

Penuel, W. R., Fishman, B. J., Cheng, B. H., & Sabelii, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher, 40*(3), 331-337.

Ruiz-Primo, M. A., Shavelson, R. J., Hamilton, L., & Klein, S. (2002). On the evaluation of systemic science education reform: Searching for instructional sensitivity. *Journal of Research in Science Teaching, 39*, 369–393.

Shulman, L. S., & Sherin, M. G. (2004). Fostering communities of teachers as learners: Disciplinary perspectives. *Journal of Curriculum Studies, 36*, 135–140.

Simon, M. A., & Tzur, R. (1999). Explicating the teacher's perspective from the researchers' perspectives: Generating accounts of mathematics teachers' practice. *Journal for Research in Mathematics Education, 30*(3), 252–264.

Siribuannam, R., & Tayraukham, S. (2009). Effects of 7E, KWL, and conventional instruction on analytical thinking, learning achievement, and attitudes toward chemistry learning. *Journal of Social Sciences, 5*(4), 279-282.

Smith, C., Maclin, D., Grosslight, L., & Davis, H. (1997). Teaching for Understanding : A Study of Students ' Preinstruction Theories of Matter and a Comparison of the Effectiveness of Two Approaches to Teaching About Matter and Density. *Cognition and Instruction*, *15*(3), 317-393.

Smith, C., Snir, J., & Grosslight, L. (1992). Using conceptual models to facilitate conceptual change: The case of weight-density differentiation. *Cognition and Instruction*, *9*(3), 221-283. doi:10.1207/s1532690xci0903_3

Songer, B. N., Lee, H-S, & McDonald, S. (2003). Research towards an expanded understanding of inquiry science beyond one idealized standard, *Science Education, 87*(4), 490 – 516.

Squire, K. (2006). From content to context: Videogames as designed experiences. *Educational Researcher, 35*(8),19 – 29.

Squire, K., MaKinster, J., Barnett, M., Luehmann, A., & Barab, S. (2003). Design curriculum and local culture: Acknowledging the primacy of classroom culture. *Science Education, 87*, 468-489.

Stake, R. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Taber, K.S. (2000). Chemistry lessons for universities? A review of constructivist ideas. *University Chemistry Education, 4* (2): 26–35.

Tobin, K., Tippins, D. J., & Hook, K. S. (1995). Students' beliefs about epistemology, science, and classroom learning: a question of fit. In S. M. Glynn & R. Duit (Eds.), *Learning science in the schools: Research reforming practice* (pp. 85-110). Mahwah, NJ: Erlbaum.

Torp, L. & Sage, S. (1998). *Problems as possibilities: Problem-based learning for K-12 education*. Alexandria, VA: Association for Supervision and Curriculum Development.

Wilson, C. D., Taylor, J. A., Kowalski, S. M., & Carlson, J. (2010). The relative effects and equity of inquiry-based and commonplace science teaching on students' knowledge, reasoning, and argumentation. *Journal of Research in Science Teaching, 47*(3), 276-301.

Yalçin, F. A., & Bayrakçeken, S. (2010). The effect of 5E learning model on pre-service teachers' achievement of acids-bases subject. *International Online Journal of Educational Sciences, 2(*2), 508-531.

Whitaker, J. R. (2012). Methods and strategies: Responding to the need for intervention. *Science & Children*, *50*(4), 75-79.

Zuiker, S. J. (2012). Educational virtual environments as a lens for supporting and understanding both precise repeatability and specific variation in classroom learning. *British Journal of Educational Technology, 43*(6), 981-992. doi:10.1111/j.1467-8535.2011.01266.x

Table 1.
STEMscopes components and 5E+I/A steps ordered according to the case enactment
(shading and italics indicate variation from design)

Lesson	Step	Component
Lesson 1	Explain	*Mr. Lee's Notes*
		Video
		Student Vocabularly Cards
	Engage	*KWL worksheet*
		Demonstration Presentation
		Starters!
Lesson 2	Explain	*Mr. Lee's Notes*
	Explore	Setup Video
		Student Guide
		Student Journal
Lesson 3	Explore	Setup Video
		Student Guide
	Explain	Progress Monitoring
Lesson 4	Explain	*Mr. Lee's Notes*
		Question Prompts
	Elaborate	Guided Practice
	Evaluate	Standards-Based Assessment
		Open-Ended Assessment
		Readings Science!
Lesson 5	Elaborate	Interactive Review Game
	Explain	Picture Vocabulary
		Interactive Vocab. Game
	Intervention	CLOSE-ing in on Science
		Concept Attainment Quiz
	Acceleration	Exploration E-Portfolio

Appendix

List and descriptions of STEMscopes curricular components

5E+I/A Inquiry Step	*Component*	Description
Engage		
	Demonstration Presentation	elicit prior knowledge and provoke curiosity
	Pre-Assessment	determine initial conceptual understanding
	Starters	activities to raise interest in topic
Explore		
	Set-up Video	Brief video explicating activity details
	Student Guide	hands-on investigation activity procedures
	Student Journal	reflective prompts at key stages of investigations
	Exploration E-Portfolio	template to summarize and share inquiry experience
Explain		
	Question Prompts	discussion questions about engage and explore steps
	Picture Vocabulary	definitions and pictures of key terms
	Student Vocabulary Cards	materials for reviewing key terms
	Interactive Vocabulary Game	class- or individual-level game review of key terms
	Progress-Monitoring Assessment	multiple-choice items targeting concept mastery
Elaborate		
	Next Step Inquiry	develop experimental designs about unit concept
	Extensions	additional elaboration activities and ideas
	Reading Science!	expository passage about unit concept
	Books on Topic	books aligned to unit objective
	Web Surfing Science	webquest activity about unit concept
Evaluate		
	Concept Builder	performance assessment and rubric
	Writing Science!	writing prompt and holistic rubric
	Standards Based Assessment	evaluates achievement on criterion-based tests
	Open-Ended Response Assessment	determines concept mastery via constructed responses
	Interactive Review Game	class- or individual-level game review of unit concept
Intervention		
	Guided Practice	guide and activities for small-group remediation lesson
	CLOZE-ing in on Science	fill-in-the-blank activity
	Concept Attainment Quiz	multi-format retesting to determine concept mastery
Acceleration		
	Problem-Based Learning Science!	application of unit concept to relevant problem scenario