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Developing Coherent Conceptual Storylines: Two Elementary Challenges

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Abstract The 'conceptual storyline' of a lesson refers to the flow and sequencing of learning activities such that science concepts align and progress in ways that are instructionally meaningful to student learning of the concepts. Research demonstrates that when teachers apply lesson design strategies to create a coherent science content storyline, student learning is positively impacted (Roth et al., 2011). Because the conceptual storyline is often implicit within a lesson, and teachers often have difficulty articulating this aspect of lesson design (Lo et al., 2014), our professional development program engages elementary teachers in analyzing and

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developing graphic representations of a lesson's conceptual storyline to make that element explicit. In this exploratory study, we present typologies that represent two primary challenges teachers faced in developing coherent conceptual storylines in their lesson design, and examine the extent to which professional development enhanced their capacity to develop a coherent conceptual storyline.

Keywords Conceptual storylines · Professional development · Elementary science teaching · Pedagogical design capacity

Introduction

Elementary science is widely recognized as providing an important foundation for student learning and interest in science and science-related careers. Yet, according to the 2012 National Survey of Mathematics and Science Education, only 39 % of US elementary teachers reported feeling very well prepared to teach science, in comparison with 81 % indicating they were very well prepared to teach language arts (Banilower et al., 2013). While activities recommended by colleagues may be adopted by elementary teachers as a way to compensate for their lack of confidence in their science knowledge (Appleton, 2006), this can manifest itself as 'activitymania' (Moscovici & Nelson, 1998) or the stringing together of a series of hands-on activities that have little conceptual connection to one another. This trend was evident in many US science classrooms in the TIMSS video analysis study, which indicated that in the majority of US science classrooms, 'ideas and activities are not woven together to tell or reveal a coherent story' (Roth et al., 2011, p. 120). That is, while students are actively engaged in activities, the sense-making component of those activities is often lacking.

Recent reforms, including the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), require major shifts in how science is taught in US classrooms. Specifically, the standards call for a focus on key disciplinary core ideas, the use of scientific practices to construct and use understandings of these ideas, and an emphasis on coherence and building ideas systematically across time and disciplines. That is, science instruction should be built around a coherent conceptual storyline. Within the NGSS, this is articulated across grade bands through the Disciplinary Core Idea Progressions (Appendix E); however, the idea of coherence is also important within grade levels and within units and lessons. In this paper, we focus on conceptual coherence specifically at the lesson level.

Purpose of the Study

This study explores the extent to which teachers' lessons exhibit conceptual coherence, and the challenges they face in designing lessons that have coherent conceptual storylines. Our purpose is to identify ways in which professional development (PD) can support teachers in enhancing conceptual coherence of their lessons as they adapt materials for use in their classrooms. Specifically, we seek answers to two research questions:

1. What challenges do elementary teachers face in constructing a coherent conceptual storyline in their existing science lesson planning practices?
2. To what extent does teachers' participation in professional development contribute to teachers' capacity in relation to developing coherent conceptual storylines?

Conceptual Storylines

Building a 'conceptual storyline' (Ramsey, 1993) involves connecting and sequencing learning activities so that they build from students' prior knowledge in a coherent manner. This has also been referred to as a 'science content storyline,' which Roth et al. (2011) described as the flow and sequencing of learning activities such that concepts align and progress in ways that are instructionally meaningful to student learning. Sequencing and connecting scientific concepts in a storyline is important because this conceptual structure can help provide meaning to students. A novice learner tends to see science concepts as fragmented pieces of information, while an expert is able to organize and integrate scientific ideas into a conceptual framework (National Research Council, 2005). Creating intentional storylines allows teachers and students to follow a progression toward the organization of science knowledge around main foundational disciplinary ideas. Since using a science content storyline lens is positively associated with student learning (Roth et al., 2011), creating PD initiatives that support teachers in developing and analyzing conceptual storylines of science lessons would be a possible approach to improve student learning.

In using the term 'storyline,' we are both conscious and cautious, as this term has been used in different ways and defined at a variety of grain sizes. For example, the topical arrangement of the NGSS features a storyline at each grade level that describes the content to be taught and how those ideas connect to one another (NGSS Lead States, 2013). In contrast, researchers have defined 'storylines' within the context of a lesson or unit. Developing the content storyline of a lesson involves (a) carefully selecting and sequencing science ideas and concepts around a learning goal, (b) developing a coherent sequence of activities that includes those science ideas, and (c) engaging students in those activities (Roth et al., 2009). Along these lines, when we use the term 'storyline' and its variants hereafter, we are referring to the conceptual understanding underpinning a *single lesson* or *instructional sequence* that may include multiple activities and experiences.

There is limited research related to conceptual storylines and teacher and student learning. Hanuscin, (2015) explored teachers' ability to distinguish between lessons with coherent versus incoherent storylines using an approximation of practice (Grossman et al., 2009) in which teachers were asked to evaluate and select one of the two lessons for use in the classroom. While the majority of teachers expressed a preference for the lesson that had a coherent conceptual storyline, teachers' preferences for one lesson versus another more often reflected reasons other than conceptual coherence, such as opportunities for student collaboration, hands-on activities, and the anticipated appeal and interest of the lesson to students. The researchers suggest that conceptual coherence may be an overlooked factor in teachers' decision-making process regarding lesson quality. Lo, Krist, Reiser, and Novak (2014) used a storyline approach to guide teachers in choosing productive anchoring phenomena around which to organize their lessons. They noted that teachers tended to describe their lessons in terms of students' activities and what they were doing in the lesson, and had difficulty articulating the storyline in terms of specific scientific concepts (i.e., ideas students would be developing in each activity). Roth et al. (2011) guided teachers in using the idea of science content storylines as a lens to analyze curriculum materials and their classroom implementation of those materials. Researchers identified four science content storyline strategies that were positively associated with student learning: (a) selecting activities aligned with the learning goal, (b) providing opportunities to use content representations aligned with the learning goal, (c) linking science content ideas and activities, and (d) linking content ideas to other content ideas.

The studies above support the claim that PD focused on the construction and analysis of conceptual storylines may help teachers plan and implement lessons with conceptual coherence and that this in turn can improve student learning. However, we have yet to understand two gaps in the literature: the ways in which teachers give priority to conceptual coherence when selecting and adapting materials for use in their existing lesson planning practices (as opposed to their use of specific practices they are taught in PD), and how an awareness and understanding of conceptual storylines may assist teachers in adapting their own existing curriculum materials (as opposed to K12 curriculum provided by professional developers).

Addressing the first gap could provide a foundation for improving PD interventions. Difficulties that teachers experience learning to implement new approaches may be different from those they experience in their preexisting planning approaches. Given instructional planning may be, to some extent, dictated by school districts (e.g., the use of a standardized lesson planning form), research in this area may also have implications for K12 policy and practice. Addressing the second gap is important because while some PD programs may be associated with district partnerships and commitments to adopt specific curriculum materials, those curriculum decisions are not permanent, and specific materials adopted can vary from district to district and state to state. That is, approaches to developing conceptual coherence that are tied to a particular curriculum implementation may not be sustainable when that curriculum changes. Research needs to examine ways in which PD can build teachers' capacity to construct coherent conceptual storylines, regardless of particular curricula and/or instructional planning constraints. Accordingly, we frame our study with the notion of 'pedagogical design capacity' (PDC).

Theoretical Framework

Brown described *pedagogical design capacity* as a teacher's 'skill in perceiving the affordances of the materials and making decisions about how to use them to craft instructional episodes that achieve his or her goals' (2009, p. 29). Teachers draw on *personal resources* (experiences, knowledge, beliefs, and dispositions) and curriculum or *material resources* (historical, social, and cultural values embedded in the curriculum materials that specify what is important to teach and how) as they design instruction (Beyer & Davis, 2012).

Brown argued that a teacher's ability to enact curriculum materials cannot be solely understood in terms of their individual capacity—that curriculum materials, like other tools, offer particular affordances that assist teachers in achieving goals they might not otherwise accomplish on their own. Nonetheless, curricula (e.g., lesson plans and other instructional materials) are written in a type of instructional 'shorthand' that relies heavily on interpretation (Brown, 2009). Within this framework, it is important to recognize that even when teachers are provided curriculum materials, they still make decisions *as designers* about what to implement and how. PDC in terms of conceptual storylines encompasses teachers' ability to perceive the conceptual storyline of curriculum materials, as well as the subject matter knowledge they possess that allows them to critique that storyline in terms of its appropriateness and coherence. In other words, PDC is important in helping teachers interpret the 'shorthand' of lesson plans.

Methodology

We used an instrumental case study approach for this study (Stake, 2006). According to Stake, this design is appropriate when researchers 'may get insight into the [research] question by studying a particular case' (2006, p. 3). Instrumental cases are useful for providing insight into a particular issue, redraw generalizations, or build theory. This design allowed us to focus specifically on teachers' existing capacity for constructing coherent conceptual storylines and the extent to which the PD supported building that capacity. The boundaries of our search for cases were limited to elementary teacher lesson planning activities for a single topic, conducted prior to and during participation in a PD program. These boundaries allowed for the identification and emergence of multiple instrumental cases where the data did not converge.

Professional Development Program

The PD program focuses both on developing elementary teachers' content knowledge of physics topics (magnetic forces and interactions), as well as pedagogical knowledge of the 5E learning cycle (Bybee, 1997). We chose to use the Learning Cycle, because it is an approach that advocates for the meaningful connecting and sequencing of learning activities so that they build from students' prior knowledge to form a coherent conceptual storyline (Ramsey, 1993). We note, however, that this framework provides structural coherence in guiding teachers' selection of learning activities, but by itself may not provide conceptual coherence. That is, the 5E model is very often articulated in terms of the activities of the teacher and students (cf. Abell & Volkmann, 2006), as opposed to the conceptual ideas being developed (for an exception see Bybee, 2015).

We instructed teachers using a physics curriculum for adult learners that was explicitly organized around the 5E learning cycle. Developed specifically for this PD program, it was designed utilizing conceptual storylines. That is, the conceptual storyline for each learning cycle was explicitly developed as a first step in the process (see 'Appendix') and served to guide selection of activities, representations, and assessments and to provide a basis for engaging teachers in analysis of practice (Grossman et al., 2009), as described below.

Building Awareness of the Conceptual Storyline of Science Lessons

We first introduced teachers to the idea of a conceptual storyline using a Conceptual Storyline Probe (CSP; see 'Appendix'). The CSP engages teachers in comparing and contrasting two very similar lessons. While both follow the structure of the 5E Learning Cycle, Lesson 1 has a focused and coherent conceptual storyline, while Lesson 2 jumps from concept to concept with each phase of the cycle. Because many teachers' responses indicate they struggled to detect the lack of coherence in the storyline of Lesson 2, we use a comparison of the television show *Saturday Night Live* (*SNL*) with the PBS series *Downtown Abbey*. Though SNL has a predictable structure of monologue, skits, musical guests, etc., these do not fit together to tell a coherent story. In contrast, the episodes of *Downtown Abbey* were developed to follow storyline sequence within and across episodes. Teachers then apply this same thinking to the conceptual focus of the two lessons. As a result, the CSP make salient the notion that simply having activities connect via a broad topic (e.g., 'magnets') does not provide coherence; rather, coherence is important in terms of a key concept or idea that is emphasized throughout a lesson (e.g., magnets interact with some materials, but not others).

Analysis of Practice Through a Conceptual Storyline Lens

Once teachers were familiar with the conceptual storyline as a construct, we engaged them in an analysis of practice (Grossman et al., 2009) by examining their own experiences, as learners of the program's physics curriculum—specifically, tracing the development of the conceptual storyline within and across each of the learning cycles in which they participated. Teachers discussed the ideas they developed in each activity, how those ideas connected across activities, and speculated how removing specific activities might impact overall understanding of the key concept of the lesson. We made our thinking as instructional designers explicit to teachers as we compared their interpretation of the storyline with our intended storyline.

Representing Conceptual Storylines

Because the conceptual storyline is not typically an explicit component of lesson plans and materials, and teachers have difficulty articulating their lessons in conceptual terms (Lo et al., 2014), we engaged teachers in visually mapping out the conceptual storyline of a learning cycle from the curriculum. We utilized a similar mapping process by adapting a graphic organizer developed by Bybee (2015) in our development of the curriculum (see 'Appendix').

Developing Conceptual Storylines

To design lessons for elementary students, teachers constructed a conceptual storyline using concepts and activities appropriate to their grade level and aligned with their curriculum standards. In collaborative groups, teachers worked together to create a 5E learning cycle for elementary students. While they often adapted activities from the physics curriculum we taught them, they also supplemented this with their own ideas and existing curriculum resources.

As outlined above, our approach differs from, and builds on, the professional development activities of Roth et al. (2011) and Lo et al. (2014) in several ways. First, we engaged teachers with curriculum materials for *adult learners*, as opposed to curricula designed for elementary students, and that curriculum was explicitly developed around a coherent conceptual storyline. That is, our curriculum provided a *model* of a conceptually coherent material as opposed to being ready to implement with elementary students. Second, we embedded explicit instruction about conceptual storylines within the framework of the 5E learning cycle model, providing a scaffold for sequencing multiple learning activities for a concept. Finally, we engaged teachers in explicitly articulating and graphically representing the conceptual storyline of the lessons in which they engaged and designed. They did this in terms of science concepts and ideas, rather than characterizing the storyline in terms of strategies.

Participants

Participants included a cohort of 33 elementary teachers enrolled in the professional development institute. All taught third grade and came from a cross section of urban, rural, and suburban school districts in a Midwestern state. The majority (85 %) was white and only two were male. The average number of years of teaching experience within the cohort group was 9.26 years with 10 having less than 5 years of experience, 14 having 5–10 years of experience, and 9 having 11 or more years of experience.

Data Sources and Analysis

We used multiple data sources to develop a robust understanding of teachers' instructional design strategies for science prior to and during participation in the PD. These included a lesson plan task (Van der Valk & Broekman, 1999), completed both prior to and after participating in the PD program. We asked teachers to submit a lesson (see Table 1) and to complete the Content Representation Tool (CoRe; Loughran, Mulhall, & Berry, 2006). A CoRe consists of a matrix that outlines important aspects of teaching and learning of specific science content such as what teachers intend students to learn, difficulties/limitations connected with the content, and specific strategies they plan to use and why. We also interviewed teachers about their lesson plans and responses to the CoRe, to further probe their pedagogical knowledge and reasoning. Additional data sources included artifacts from PD sessions, such as teacher responses to the CSP, their conceptual storyline representations, and written reflections on the PD activities.

All data were transformed into electronic format and entered into QSR NVivo 10 software for analysis. The researchers first independently examined teachers' initial lesson plans and grouped them together based on similarities in the level of coherence in the conceptual storylines. We then met to compare groupings, discuss salient features, and note patterns in terms of elements that detracted from coherence. We used this as a basis to identify major typologies for the difficulties teachers faced (LeCompte, 2000). We then cross-checked CoRe and interview data from teachers within each group to further examine personal and instructional resources teachers drew upon in creating and/or adapting their lessons and used this to validate our decisions about how we defined each group. As a next step in the analysis, we examined teachers' lesson plans and related data post-program to examine changes in teachers' capacity to construct a coherent conceptual storyline following their participation in the program. We used our previous groupings of teachers (based on their initial challenges) as a basis for identifying capacity-building patterns within and across groups.

Findings

Our analysis of the data resulted in identification of two main typologies characterizing teachers' challenges in constructing a coherent conceptual storyline. We present each of these typologies below as single instrumental cases constructed from the data of multiple participants who had similar difficulties related to the coherence of the conceptual storyline of their initial lessons. Each case represents an amalgam of data and therefore is discussed holistically; however, in instances where appropriate, we identify specific numbers or percentages of teachers who typify a particular aspect of the case where variation was evident in the data. In each case, we describe teachers' PDC in terms of both personal and material resources related to constructing coherent conceptual storylines.

Table 1 Lesson plan task instructions

Prepare and upload one *detailed* lesson plan on a concept related to *magnetism that* you would teach to your third graders. This could be a lesson you have already taught or one that you might teach, but it should reflect a *typical science lesson* in your current classroom. If your school or district requires a specific template or format, you may use that, or you may choose one of your own

Case Typology 1: 'More is Better'

Lessons provided by teachers fitting case typology 1 were collections of activities loosely related at the topic, rather than concept level (i.e., they all related to magnets) and reflected a belief that the more students could learn about in one lesson, the better. We found rather than focusing on a single concept in depth, many teachers submitted lessons that addressed multiple concepts simultaneously, but superficially. That is, the lesson did not progress toward building understanding of any particular concept through a coherent storyline. For example, in one lesson, a teacher facilitated an activity in which students used a magnet to guide a paperclip through a maze drawn on paper, which illustrates that magnets can attract objects through other materials. The teacher then provided explanations and asked questions that addressed the north and south poles of magnets and the strength of magnets. In another instance, a teacher used multiple activities and assessments including journaling, discussions, a hands-on activity, Internet research, vocabulary lessons, and enrichment activities—each of which focused on a different concept or combination of concepts related to how magnets interact with other objects, how poles interact, forces, and how magnets are used in our daily lives.

As we further examined the *personal resources* (beliefs, goals, and orientations) that teachers fitting this case drew on to construct their lessons, we noticed several things. First, teachers had difficulty articulating the 'big idea' or central concept of the lesson. When asked about the 'big idea' of the lesson, teachers' responses tended to be vague and not specific to concepts (see Table 2). Only three teachers whose lessons fit this case typology could articulate a 'big idea' in terms of conceptual understanding, and one of these three simply restated the state standard cited in her lesson plan. Interestingly, the teachers who cited standards in their lesson plans also exhibited difficulties in articulating conceptual goals for students.

Table 2 Variations in teachers' identification of the 'big idea' of their lessons

	Examples of responses
Vague and nonspecific	Concepts of magnets
	Magnet strength
Specific but not conceptually defined	Understanding how magnets work
	Understand how magnets interact with other objects
Skills focused versus concept focused	Use investigation skills to explore properties of magnets and how they work
	Make observations using magnets
Specific concept identified	Some items are attracted to a magnet, while others are not
	Forces are classified as contact or non-contact (magnetism)[a]
Phrased as a question	What is magnet and what are magnets used for?
	How are magnets used to improve or assist our daily life?

[a] In this case, the teachers' articulation of the big idea was a restatement of the state standard from her lesson plan

Second, we noticed that teachers' self-described goals aligned with an activity-driven orientation (Friedrichsen, van Driel, & Abell, 2010; Magnusson & Palinscar, 1995). Anderson and Smith (1987) describe this orientation, stating elementary teachers 'focus primarily on the activities to be carried out in the classroom: textbook reading, demonstrations, experiments, answering questions, and the like' (pp. 99–100). Most teachers believed it was important for students to know how what they learned applied to the real world, and stated hands-on activities, exploration, and collaboration as means to promote learning. Teachers' focus was on engaging students in these activities, rather than supporting students in developing an understanding of one concept. For example, one teacher stated that she wanted students to 'get their hands dirty, so to speak' to make the lessons real-world applicable. Another stated that without exploration and collaboration, students '…won't really think about how we use them in everything.' They viewed these kinds of experiences as necessary to the learning process and shaped their learning goals around skills they wanted students to utilize and practice, as opposed to the ideas they wanted students to develop.

As we examined the *curricular resources* teachers from this case group drew upon to create their lessons, we noted that only two used existing commercial curriculum materials; however, these materials lacked conceptual coherence in terms of applying science content storyline strategies (Roth et al., 2011). Several of the teachers used a district-mandated lesson planning form; yet, we noted that only one of these formats explicitly asked teachers to identify a conceptual goal for students—that is, the conceptual understanding students should develop through the lesson. Instead, learning goals were more often articulated as essential questions (without stating the intended answer to those questions) or in terms of the activities of students and what they would be doing in the lesson. Overall, their existing curricular materials provided few affordances and supports for ensuring conceptual coherence.

We also noted within this typology that teachers who created their own lessons relied primarily on resources from the Internet, such as YouTube, Teachers Pay Teachers, and Pinterest. For example, before the summer institute, one teacher submitted a lesson that addressed various properties of magnets, magnetic fields, and the functions of a compass. During her follow-up interview, she explained searching for resources:

> …there were some things on Pinterest with a teacher coming up with a lesson plan of making her own compass, and I guess one thing led to another…and that kind of led me into the Earth's magnetic field, so it just was kind of a trickle-down effect.

Many of the resources teachers relied on focused on a multitude of concepts related to magnetism, rather than a single idea. Because they did not have a specific 'big idea' or concept in mind, teachers used resources in their entirety, as opposed to mining them for particular information. Whereas one might expect that using state or national standards to guide lesson planning might help teachers narrow the focus of their lesson and be selective with resources, we found that roughly half (41 %) of teachers who fit this case typology *had* cited specific standards in their lesson. This suggests that teachers may not have been able to unpack these standards or that they simply cited them as a requirement of the lesson planning forms.

Case Typology 2: 'One and Done'

Teachers who fit this typology focused on one generic concept (e.g., 'magnets') when preparing their lessons. They tended to design one single activity for the lesson, usually relying on a single hands-on activity to support students' understanding of the concept. For example, a common lesson plan submitted by the teachers included a 'fishing' or 'sorting' game—in which students sort objects that are attracted by magnets or are not—as an activity to engage students with the topic of magnetism as well as to address students' misconceptions. We argue, however, this approach is insufficient to help students reach the lesson learning goal. A single activity does not by itself provide enough affordances and supports to develop a deep and robust understanding of a concept. For example, having students sort everyday materials to examine whether they were attracted to a magnet, does not by itself help students achieve the learning goal of identifying which metals were attracted by a magnet. Students would need additional scaffolds to identify and classify types of metals and mixtures of metals in different materials.

As we examined the *personal resources* (beliefs, goals, and orientations) that teachers fitting this case typology drew on to construct their lessons, we noticed several patterns. First, teachers relied on the engaging nature of hands-on activities as a first step to make students familiar with the concepts to be taught. A teacher explained, '…we always want them to have the hands-on so they can really get a better understanding of what that looks like and what that means, so after we started off our lesson with our anchor chart.' Teachers tended to justify their choices because they believe elementary students need concrete anchors and connections to real experiences. Therefore, students need to experience the objects, such as magnets as a scaffold. Likewise, teachers believed that the use of concrete and hands-on activities was helpful to later introduce scientific vocabulary and, sometimes, because they were engaging and attractive for students. Overall, these characteristics connect with an activity-driven orientation to teaching science (Friedrichsen et al., 2010; Magnusson & Palinscar, 1995).

Second, these teachers also mentioned that selecting this activity was adequate for addressing students' previous ideas on the topic, either misconceptions or everyday ideas. For example, since students were familiar with fridge magnets, some teachers included them in the sorting game so that students have opportunities to recognize that magnets attract other ferromagnetic objects, despite having a plastic cover. Similarly, teachers mentioned that including pennies in the sorting game would help students address the misconception that not all the metallic objects are attracted by a magnet.

For some teachers, the purpose of the exploratory activity was to engage students to later introduce scientific vocabulary. Other teachers connected the exploratory activity to address scientific ideas developed in previous lessons. A teacher explained, for example, that since her students previously explored properties of matter, she was able to connect this content with magnets.

> It was in the section about solids they were exploring the properties of solids. And there were lots of different ones like you know that different solids float or sink and this one happened to be that some of the properties of some solids is that they are magnetic

Third, a common characteristic in these lessons was the lack of specificity in the learning goal. In some cases, the learning goal did not address a big scientific idea, while in others, goals were stated in terms of the activities. For example, for the fishing/sorting activity, one teacher defined the lesson learning goal as 'experiment with a variety of solid objects to determine if they are magnetic.' Rather than indicating the concepts that students will come to understand in the lesson, this learning goal is defined in terms of the skills that the students will execute. Likewise, it paraphrases the activity.

Regarding *curricular resources*, teachers from this group tended to rely more on existing activities from commercial curricula or from teaching materials provided by the school district (compared to the teachers from the typology 'More is Better'). In some cases, teachers adapted them to design their lesson plans. For example, teachers reported using Web-based resources and the input from their colleagues to create new or adapt existing lesson plans—especially when teachers were not quite familiar with the content. For example, a teacher explained her decision to include the sorting game because 'I was not too familiar yet with third grade concepts so I decided just to do kind of like more of a simple introductory lesson.' That decision may be connected with her perceived lack of confidence in the content (magnetism).

Fourth, the lessons submitted had the purpose of making it adequate to the school or district requirements. One teacher justified the exploratory activity because it is connected to what 'our district wants the third graders to know, so for us we really didn't go more in depth in it just because that's kind of where our curriculum guide was laid out for us.' Some lesson plans were designed in order to be aligned with school/district requirements, such as the use of 'I can statements' or graphic organizers (anchor charts). Although these activities have the potential to engage students with scientific concepts, we argue they need to be better scaffolded and integrated in a learning sequence. Rather than relying on their own understanding to evaluate an activity from an external curriculum, teachers selected them because it was related to the topic. To some extent, this lack of depth and reflection in lesson design was also reflective of the limitations of the district-provided curriculum materials, which each teacher in this group cited as a main source of their lessons.

Impacts on Teacher Capacity

Our second research question was concerned with the extent to which participation in PD builds teachers' capacity in relation to developing coherent conceptual storylines. As our program was not differentiated based on teachers' specific difficulties, we were especially interested in understanding how the PD activities we designed addressed the challenges of the 'One and Done' and 'More is Better' approaches. In the sections that follow, we consider the ways in which different tools presented in the PD sessions served as scaffolds in enhancing teachers' PDC for constructing coherent conceptual storylines.

Conceptual Storyline Probe (CSP)

As we anticipated, the idea of a 'conceptual storyline' underlying a lesson was a new concept for the teachers in our PD. Even though two-thirds of the teachers (67 %) stated a preference for the lesson in the pair that had a coherent conceptual storyline, they did not justify their preference in relation to the way in which the concepts connected and built upon one another. The CSP served as a mediating tool to help teachers develop an understanding of what a conceptual storyline *is* by providing an example/non-example. In this manner, it provided a scaffold to help teachers recognize when a storyline is or is not coherent.

After participating in the CSP, teachers were asked to respond to the statement 'I used to think…but now I know…' to evidence their change in understanding of conceptual storylines. As shown in Table 3, the CSP was useful in challenging the underlying assumptions of both case groups of teachers with regard to addressing breadth conceptual depth of lessons. Yet, our evidence indicates that the CSP did not move teachers beyond a tacit understanding of conceptual storylines. That is, while they could distinguish between 'coherent' or 'not coherent', they were not able to articulate the conceptual storyline of the lessons in terms of specific concepts and ideas.

Analysis of Practice and Representing Storylines

Unique to our PD program was the manner in which we facilitated teachers in developing representations of the storyline of a lesson—that is, shifting the idea of a conceptual storyline from a tacit conception to an explicit conception. To do so, teachers needed to be able to identify the specific science concepts and ideas underlying each activity within a lesson sequence—something they were not able to

Table 3 Teacher reflections on what they learned following the conceptual storyline probe

I used to think…	Now I know…
…a lot of activities were great to achieve more learning	…in depth of one activity/topic is better
…lessons were decent because of the activities in them with or w/o regard to concepts being the same	…within one lesson there must be the same concept between each [activity]
…good activities made a lesson effective	…an effective lesson is about so much more than just activities! Everything from planning to evaluating needs to be cohesive and thought out
…I needed to make sure lessons kept 'moving forward'	…student understanding and the building of required foundational knowledge must govern the sequential planning of lesson

do well in their initial lesson plans submitted prior to the PD. To address this, we engaged teachers in mapping out a representation of the conceptual storyline of a lesson in which they had participated in as learners on large sheets of chart paper (see Posters 1–6 in the 'Appendix').

Initially, teachers (regardless of which typology they fit) articulated what the students would be doing in the lesson as they mapped out the lesson's storyline. To scaffold their ability to articulate the *concepts* underlying the activity, we drew the head of a student with a thought bubble next to each activity on the chart and asked teachers to write in what the student should be thinking and/or understanding at that point. For example, for an activity teachers described as 'Experiment with magnetic interactions with different objects,' the associated student thought bubble contained the idea that 'Not all metals are attracted by the magnet' (See Poster 1). As teachers focused more and more on students' ideas throughout the lesson, they began to include possible misconceptions students might hold at the start of the lesson and take these into account as the lesson progressed. That is, they articulated the conceptual storyline as it would develop *for students* (see Posters 2, 3, and 6). As they did this, several groups were prompted to recognize instances in which they, as the teacher, might need to supply explanations to students to help construct the storyline—such as identifying the metals that magnets attract as being iron, nickel, and cobalt (see Posters 1, 3, and 6). Interestingly, some groups focused on bigger metacognitive concepts, such as understandings about inquiry and how science works, that students should be developing as well—such as what makes a 'fair test' (see Poster 2). Yet other teachers incorporated their existing practice of writing 'I can…' statements of learning goals, articulating students' thinking at each point in the lesson as 'Now I know… and now I can…' (see Posters 4 and 5). While this technique helped teachers articulate the underlying conceptual storyline, they expressed some hesitance about planning lessons in this manner. This was understandable, given the vast difference between this experience and their existing lesson planning practices.

While the CSP helped teachers recognize conceptual coherence as a dimension of lessons, mapping out the storyline helped them shift their attention to the concepts underlying the activities of the students and to articulate the storyline and its development. In doing so, it supported teachers in establishing a link between the activities of the students and the conceptual understandings they would be building through those activities; one of the four science content storyline strategies found to impact students' learning (Roth et al., 2011). Representing the conceptual storyline helped teachers understand an already-designed lesson; however, teachers did not fully realize its utility in designing lessons themselves.

Developing 5E Lessons

An important aspect of our lesson planning approach was moving teachers beyond the traditional 'shorthand' format of a lesson plan (that often neglects articulating underlying ideas about content and pedagogy) by utilizing the 5E learning cycle (Bybee, 1997) and CoRe (Loughran et al., 2006). Developing 5E

Lessons using the CoRE required teachers to articulate their underlying rationales and decision-making with regard to their lesson design.

Following the PD, teachers whose initial lessons fit the 'More is Better' typology were able to recognize the underlying concepts of each activity and eliminate those activities that did not align with their conceptual learning goal. For example, one teacher initially submitted a lesson in which students answered questions about the north and south poles of a magnet and magnetic strength through a maze activity. The same teacher's post-program version of the lesson gave students the opportunity to build on their prior knowledge about magnetic interactions with other materials, but did not extend to address additional concepts of magnetic strength and polarity. For the teachers fitting the 'One and Done' typology, the 5E learning cycle's multi-phase approach challenged the idea that one lesson was equivalent to one activity. For example, one teacher has originally used a fishing activity (using a magnet to 'fish' for objects) for her lesson. She later used additional activities and non-fiction reading about magnetic interactions to align her lesson with the 5E learning cycle.

In summary, prior to the summer institute, teachers focused more on the hands-on nature of activities rather than the use of those activities toward building conceptual understanding. While this might be expected to serve as a barrier to their learning, we noted that teachers found consistency between the 5E learning cycle and their activity-driven orientation toward science teaching. Following the professional development, teachers in both case groups submitted lessons that demonstrated conceptual coherence by identifying a single concept and developing that throughout each phase of the 5E learning cycle using multiple activities. We also noted that teachers were better able to articulate their learning goals for students in conceptual terms and to identify a 'big idea' to which each activity in the lesson related.

Discussion and Implications

This concept of a 'storyline' and its usefulness in developing conceptually coherent lessons is an important aspect of improving the quality of science teaching, especially at the elementary level. Our work contributes to the literature by pinpointing and clarifying common difficulties that elementary teachers may face in designing lessons with a conceptually coherent storyline and suggesting approaches that can support teachers in overcoming these difficulties.

In this study, we explored teachers' existing lesson planning practices in terms of conceptual coherence. Based on our analysis, we constructed two case typologies. The first was characterized by lesson plans that included different activities that were not connected to each other, nor were they organized in a coherent conceptual sequence. The second case was characterized by teachers' reliance on a single activity, usually a hands-on, that by itself was inadequate to support depth of student understanding of the intended scientific concepts. It is important to note that both cases reflected an activity-driven orientation, yet that was manifested in two very different approaches to developing lessons. Because teachers' orientations may play out in distinct ways, generalizations about teachers based on their science teaching orientations may actually mask important differences in their pedagogical approaches and different professional development needs. For example, while teachers fitting both case typologies needed support in identifying and articulating the big idea of their lesson, the ‘More is Better’ case group needed to eliminate extraneous material and narrow the focus of their lessons, while the ‘One and Done’ case group needed to expand their pedagogical repertoire of activities for the same concept. While Appleton (2006) has indicated that ‘activities that work’, or recommendations from colleagues, can provide a scaffold for elementary teachers who lack pedagogical content knowledge for teaching specific topics, our findings highlight a potential pitfall in this practice, in that access to activities alone is not sufficient for teachers to design lessons with conceptual coherence. Moreover, conceptual coherence may not factor into teachers’ existing lesson planning practices.

In this study, we also sought evidence to understand the ways in which the strategies used in our PD program contributed to teachers’ pedagogical design capacity with regard to constructing coherent conceptual storylines. Brown described pedagogical design capacity as the ‘teacher’s capacity to perceive and mobilize existing resources in order to craft instructional episodes’ (2009, p. 29). This implies teachers must possess skills in perceiving the affordances of the materials and making decisions about how to achieve the goal. This was particularly true in our study, in which we found teachers primarily relied on district-provided materials and/or lesson formats while seeking out additional resources and activities.

At the outset of our study, teachers did not ‘perceive’ the conceptual storyline as an element of lesson design. Even when curricular materials had high levels of conceptual coherence, teachers themselves did not perceive this coherence and were not able to articulate the ‘big idea’ the conceptual storyline developed. Brown (2009) emphasized that curricula (e.g., lesson plans and other instructional materials) are written in a type of instructional ‘shorthand’ that relies heavily on interpretation. What is clear from our study is that teachers need support in interpreting this shorthand when it comes to conceptual coherence and the underlying conceptual storyline of lessons—particularly because many of their existing curriculum materials and district-provided lesson plan formats did not give explicit attention to conceptual dimensions of the lessons. Similar to the findings of Lo et al. (2014), teachers focused on activities in which the students would engage, and what the students would be *doing* in the lesson, there was almost no emphasis on the science ideas and concepts students would develop. Following the PD, we found teachers progressed in the extent to which they were able to recognize coherence or lack thereof, and articulate the conceptual storyline of a lesson in terms of the concepts and ideas underlying each of the activities in a lesson sequence.

Our study demonstrates how professional developers can use tools such as the CSP and CoRe as scaffolds for supporting teachers, particularly when conceptual coherence is not explicitly addressed in the instructional materials provided to teachers and the specific lesson planning protocols they are expected to follow. However, simply adding a box on the lesson plan, so to speak, may not be enough.

For example, while the district-provided lesson planning formats used by teachers often asked for standards to be cited, we found citing relevant state or national standards was not a good predictor of either the conceptual coherence of the lesson or teachers' ability to articulate the 'big idea' that students should learn. This suggests that while the use of standards may support teachers' lesson planning, teachers need to develop their abilities to unpack standards and capitalize on the affordances of those for designing lessons with conceptual coherence. As professional developers work with individual teachers, schools, and district partners, highlighting the importance of conceptual coherence and how local policies regarding lesson planning and lesson plan formats could be modified to support teachers in this regard will be important.

While our reliance on teachers' lesson plans, as opposed to observations of their lesson implementation, can be viewed as a limitation of our study, we argue that teachers, to the extent they are able to understand a lesson's conceptual storyline and recognize conceptual coherence as an element of lesson design, can be more successful in enacting curriculum materials (either created by themselves or adopted from standardized formats). As highlighted above, while some curriculum materials may exhibit conceptual coherence, the conceptual coherence and the underlying conceptual storyline may not be readily apparent to teachers or well understood. As Brown emphasizes, 'PDC describes the manner and degree to which teachers create *deliberate* (emphasis added), productive designs that help accomplish their instructional goals' (2009, p. 29). Thus, if teachers do not understand the conceptual storyline themselves or articulate well-formed goals for supporting students' conceptual understanding, even high-quality, conceptually coherent materials may not be implemented with coherence. Teachers' initial struggles to articulate their goals in terms of students' conceptual understanding are noteworthy and suggest that the impact of our program on teachers' awareness and ability to articulate their goals in relation to the conceptual storyline of their lessons are critical to their future lesson enactment. Since teachers bring to PD a set of personal resources (beliefs, tools, etc.) as well as curricular resources (lesson planning formats, curriculum materials, etc.) that influence their lesson planning approach, PD strategies should be connected to their personal contexts and challenges. Therefore, it is important that teachers have opportunities to make explicit how they create their lesson plans, what types of resources they use, and the constraints and requirements imposed on them by their schools or districts.

By analyzing their own experiences learning science content in our PD, teachers were better able to identify the way in which specific activities contributed to their conceptual understanding—that is, the link between specific ideas and activities. Outside of such a content learning experience, it is unclear whether teachers might have achieved the same outcomes. Thus, further research might examine the role of teacher content knowledge in analyzing and constructing conceptual storylines and how teachers are able to translate their knowledge about conceptual storylines to other content areas.

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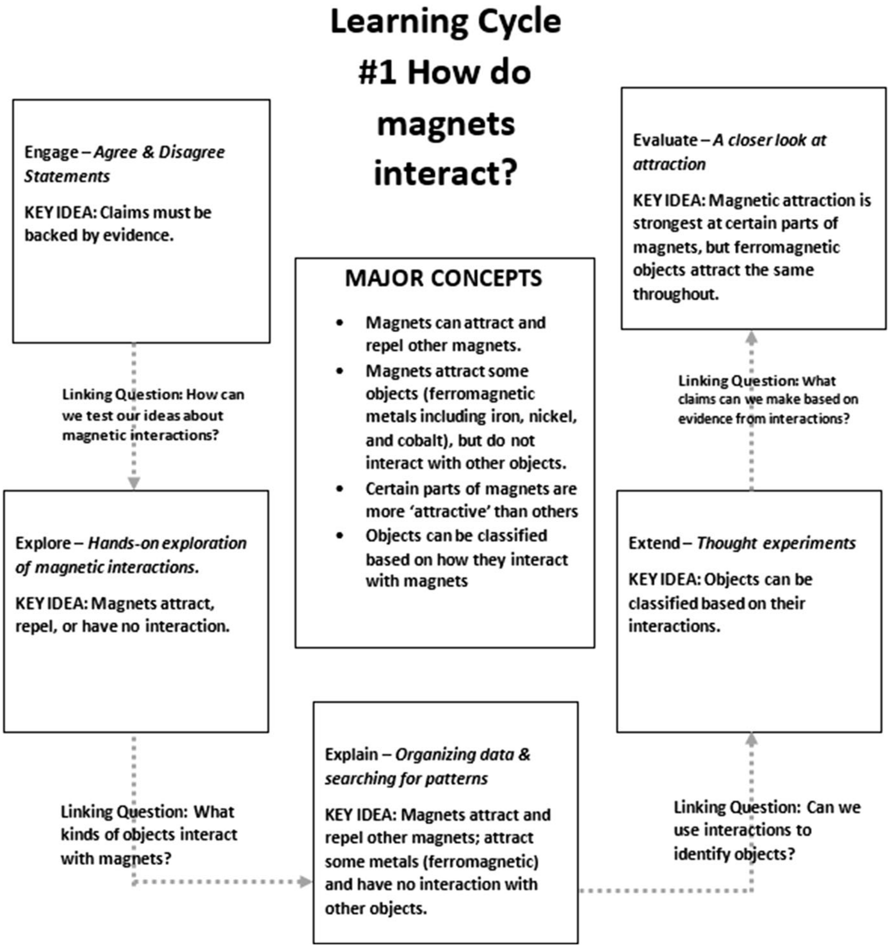
Appendix

Sample Conceptual Storyline Probe

Version #1	Version #2
As a group, students brainstorm everyday items they know that use magnets. They discuss what the item is, how it works, and what role magnets play	As a group, students brainstorm everyday items they know that use magnets. They discuss what the item is, how it works, and what magnetic interactions are involved
The teacher then provides each pair of students with a magnetic object to explore (e.g., magnetic fishing game)	The teacher then provides each student a compass and asks them to explore and determine whether the compass is magnetic
S/he asks them to focus on the types of interactions (attracting/repelling) and whether magnets are interacting with other magnets or other objects. Afterward, pairs present their items to the class, explaining how they work	Building on students' observation that the compass needle moves when a magnet is brought near it, the teacher asks students to record the maximum distance from the compass that different magnets influence its direction
The teacher then shares a proposal for a 'magnetic recycling sorter' that claims to sort metal and nonmetal items for recycling, and asks groups to discuss whether they think the invention would work	Students then use this as evidence to support their arguments about which magnet is the strongest. Students agree that the farther the distance from which a magnet affects the compass needle's direction, the stronger it is
Students critique this product and decide that it would not attract all metals and might accidentally trap nonmetals between the magnet and iron objects	Students then watch a video on YouTube from the National High Magnetic Field Laboratory called *the World's Strongest Magnet.* In this video, scientists share how they build an electromagnet
Each student is then challenged to come up with their own working magnetic invention. They build prototypes and create a 'product pitch' to share at an Invention Convention	Afterward, students are able to build their own electromagnets by wrapping wire around steel bolts and attaching these to a battery

Sample Conceptual Storyline Map from Program Curriculum (Adapted from Bybee, 2015)



Sample Conceptual Storyline Maps

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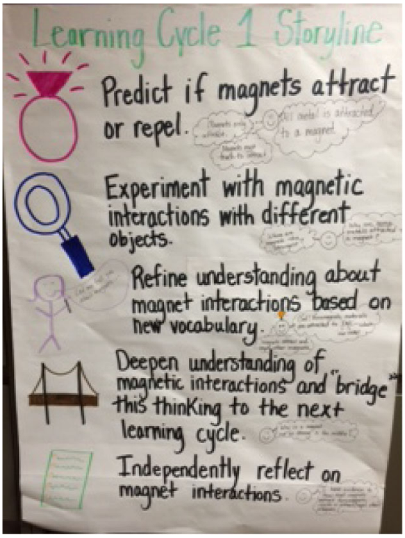

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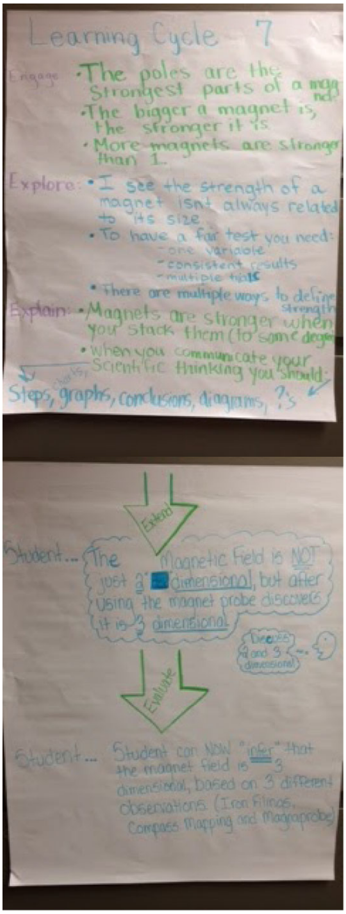

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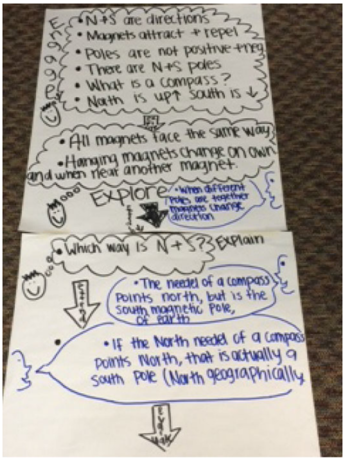
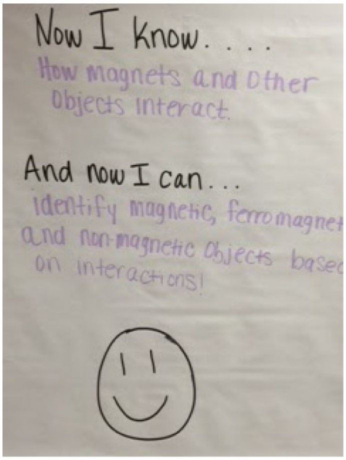
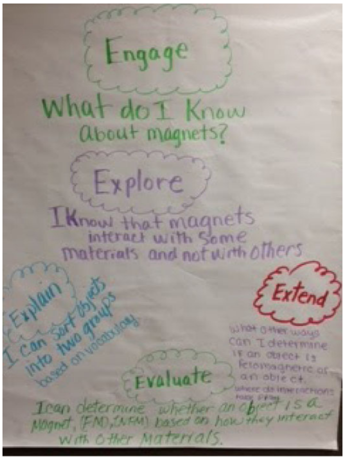
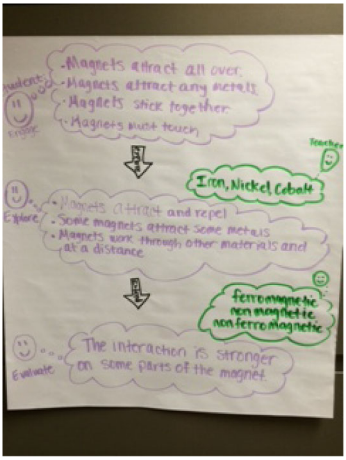




Poster 5

Poster 6





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