Current k-8 science instruction: Similarities and differences with the science practices

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Introduction

Recent reforms (NGSS Lead States, 2013) in science education have advocated for a new vision of learning where students are engaged in science practices (Osborne, 2014). Engaging in these science practices allows students to mirror the types of thinking, talking, and acting used by scientists as students develop and revise scientific knowledge (Bybee, 2014). These new reform-based standards require a significant shift in instruction away from memorizing factual knowledge to demonstrating knowledge in use (Krajcik et al., 2014). To better support this transition, the field needs a stronger understanding of current science instruction and how it is similar and different from these reform efforts. Although previous work has examined science instruction when schools pilot new curriculum (Berland & Reiser, 2011), technology tools (Marco-Bujosa, González-Howard, McNeill, & Loper, 2017), and other resources targeting specific science practices, there has been little work capturing more naturalistic science instruction. Due to on-going state and district attempts to align science education to the vision of NGSS and the science practices, there is an acute need to take stock of current science instruction. Without a firm understanding of what current science instruction looks like, it is difficult to support teachers in the persistent and incremental improvement process required to align instruction to the vision of the NGSS.

Consequently, in this study we explore the research questions: (1) What does the k-8 science instruction look like in practice? and (2) How is this naturalistic science instruction similar and different from the science practices? In so doing, we also consider the implications of this research for school improvement concerning the instructional shifts intended by the NGSS for science in k-8 schools.

Theoretical Framework

Science Practices as a Learning Goal

The view of science as a set of practices stems from the values and normative criteria that scientists use to establish reliable scientific knowledge (Windschitl, Thompson, & Braaten, 2008). These practices focus on developing evidence-based explanations of how the natural world works and why it works that way (Krajcik, et al., 2014). In education, the Framework for K-12 Science Education (NRC, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013) describe eight science practices as the primary activities of science, and as essential learning outcomes for students (Osborne, 2014). The emphasis on science practices builds on past reforms that promoted inquiry as an essential goal of science education (Osborne & Quinn, 2017). Inquiry-based science education generally amounted to students exploring the relationship between two variables in order to support or disconfirm hypotheses (Reiser et al. 2017). In contrast, the science practices focus more on students constructing and critiquing knowledge (Pruitt, 2014). As such, the practices place the processes of inquiry (e.g. planning and carrying out investigations) into the broader assemblage of science activities involved in the building of explanatory models and theories to make sense of the natural world (Russ, 2014).

The science practices work synergistically to support students to make sense of the natural world (Schwarz, Passmore, & Reiser, 2017). The practices can be conceptualized into three groups: investigating practices, sensemaking practices, and critiquing practices (McNeill, Katsh-Singer, & Pelletier, 2015; McNeill, Lowenhaupt, & Katsh-Singer, in press see Figure 1). The investigating practices focus on asking questions and conducting experiments about the natural world to produce data. The sensemaking practices analyze the data for patterns and relationships in order to construct explanations and develop explanatory models. The critiquing practices focus on argumentation and the evaluation of different explanations and models in order to improve understanding of the natural world. Together, these three groups of practices can support students' understanding of the nature and function of the discipline and push them toward deeper conceptual understanding of science ideas (Schwarz, Passmore, & Reiser, 2017). Recent research has supported this notion, as students who engaged in science-as-practice have demonstrated significant improvement in their understanding of core science ideas and science practices compared to students who were taught using more traditional instructionist methods (e.g. Marshall, Smart, & Alston, 2017; Strimaitis, Southerland, Sampson, Enderle, & Grooms, 2017).

Figure 1: Science Practice Grouping Diagram

	Investigating Practices	**Sensemaking Practices**	**Critiquing Practices**
Science Practices	1. Asking questions	2. Developing and using models	7. Engaging in argument from evidence
	3. Planning and carrying out investigations	4. Analyzing and interpreting data	8. Obtaining, evaluating, and communicating information
	5. Using mathematical and computational thinking	6. Constructing explanations	

Science Practice Instruction

The Framework (NRC, 2015) and the NGSS (NGSS, 2012) highlight the essential role of the science practices in science teaching. Central to this vision of teaching science-as-practice is the shift from teaching students *about* scientific ideas to teaching students to *figure out* science ideas (Schwarz, Passmore, & Reiser, 2017). This instructional shift envisions science teaching as the process of engaging students in the practices to build and use knowledge (Edelson & Reiser, 2006). As a result, the instructional demands of science teachers have changed substantially with the adoption of the Framework and the NGSS. Specifically, this rethinking of science instruction necessitates a three-fold change (Reiser et al., 2017). First, it requires teachers to change the kinds of science ideas they teach. Teachers are required to move away from the presentation of content and toward the explanation of phenomena via disciplinary core ideas (Reiser et. al 2017). Second, teachers must change how these science ideas are constructed and evaluated in their classrooms. Teachers need to engage students in the science practices in order for students to apply and explain disciplinary core ideas (Osborne & Quinn 2017). Lastly, teachers must present a coherent storyline of science ideas over time (Reiser, Fumagalli, Novak, & Shelton, 2016). By sequencing engagement in science practices in a coherent progression throughout units, teachers support students to construct explanatory ideas.

These changes represent a major departure from the instructional methods that currently dominate many science classrooms (Windschitl et al., 2008). Despite the new focus on disciplinary core ideas, current instruction overemphasizes the presentation of factual content and teacher-centered pedagogy (Banilower, et al., 2013). Further, many science classrooms still predominantly employ learning activities that verify rather than construct scientific knowledge (Banilower, et al., 2013; Roth et al., 2006). As a result, teachers generally use inquiry (e.g. observations, experiments, simulations) as a means to expose students to ideas they have already taught (Windschitl et al., 2008). This form of 'inquiry' instruction offers students few opportunities to engage in critical thinking, evaluate competing explanations, or design experiments and solutions to practical problems (Osborne, 2014). Furthermore, students rarely have the opportunity to build their understanding of science ideas incrementally over time. Instead, the presentation of science ideas in instruction is typically reliant on teacher choice, the organization of the textbook, and the logic of the discipline (Banilower, et al. 2013; Reiser et. al, 2017).

Coherence in Systems of Science Education

Taken together, these trends produce an image of k-8 science instruction that is substantially at odds with the instructional shifts envisioned by the Framework and the NGSS. To mediate this, teachers must receive considerable support to improve their understanding of the science practices in instruction. Furthermore, teaching practices, curriculum resources, and assessments must be aligned to the vision of the Framework and the NGSS (NRC, 2015; Trygstad et al., 2013). Therefore, the successful implementation of the practices in science instruction requires that all school components are aligned to support this vision (NRC, 2015). This alignment manifests in a variety of ways. First, it necessitates that all instruction-curriculum-, and assessment-related policies and practices highlight the essential role of the practices in science education (NRC, 2015). Second, it requires that schools and school systems have a shared understanding of which science ideas and practices to teach, when to teach them, and how these ideas and practices develop across grade levels and science subjects. Lastly, it requires that the goals for science teaching and learning and the purpose and use of assessment are coherent across all systems in science education (i.e. classroom, school, school district, state).

Coherence in science education will not occur accidently. According to the NRC (2015), "it takes planning, political will, professional time, and ongoing management." Furthermore, it requires an expectation of ongoing collaborative work among the stakeholders and school systems to understand and implement the changes required by the NGSS. In recent years, there have been substantial efforts by 19 states to align their newly-adopted NGSS framework with the development of curriculum and state assessments (NGSS, 2013). Despite this progress, substantial incoherence across multiple levels of the science education system and among various stakeholders remains (Braaten, Bradford, Kirchgasler, & Fox, 2017). These sources of incoherence threaten the usability, scalability, and sustainably of the NGSS. Data-centric initiatives in education (i.e. increased data use, accountability, performance management) have been a major source of incoherence with the vision of the Framework and the NGSS. Specifically, the growing emphasis of test-based accountability in education has prompted the narrowing of curricular content to tested topics, the fragmenting of subject area knowledge into test-related pieces, and the increased use of teacher-centered pedagogies to cover the breadth of test-required information (Anderson, 2012; Au, 2007). Furthermore, these accountability policies have elevated mathematics and literacy and have prioritized these subjects as core content areas to be addressed across other school subjects (Rivera Maulucci, 2010; Spillane, 2005).

Consequently, schools and districts possess fewer teachers and instructional leaders with expertise in science than teachers and instructional leaders with proficiency in mathematics and English language arts (Trygstad, 2013; Halverson et al., 2011). Likewise, this prioritization of math and ELA is further amplified at the elementary level. According to a national survey of science education (Trygstad, 2013), "39 percent of elementary classrooms did not include science every week and elementary teachers spent, on average, only 20 minutes on science every day. In comparison, elementary teachers spent 55 minutes for mathematics and 88 minutes for reading." In summary, these findings exhibit how the framing of data-centric educational reforms can compromise attempts to establish a coherent vision of NGSS-aligned science teaching and learning. Therefore, in an attempt to capture naturalistic science instruction, this study focuses on how teachers, school leaders, and contexts contribute to to current state of instruction.

Methods

In this study, we utilized a multiple-case study methodology (Stake, 2000; Creswell, 2013) to explore naturalistic science instruction in several school cases. The case study approach was ideal to explore science instruction as this methodology provided the opportunity for in-depth empirical inquiry within a real world context in order to develop an explanation for how or why particular science instructional features occurred. Further, multiple cases allowed for concurrent comparisons to explore how differences occurred under different school contexts (Yin, 2013). Specifically, in this study, the multiple case study methodology allowed for a rich qualitative description of science instruction in each school case, and provided a means by which comparisons were made between school cases in relation to science instruction. Additionally, these cases proved interesting to compare as each school was involved in the same statewide science reform. This reform involved the adoption of a new set of NGSS-related science standards and a future shift to new k-8 science state assessments. To create these cases, we observed instances of science instruction from teachers in four diverse k-8 school cases.

Sample and Context

To document science instruction in the field, we worked closely with four schools during the spring semester in 2016. These schools were involved in a larger study that documented k-8 science supervision as instructional leaders incorporated new tools to support their observations and feedback about science instruction. Due to the exploratory nature of the study, we sampled from different school contexts (See Table 1). Two schools were in the same large urban district, one school was in a small urban district, and one school was in a suburban district. Three of the four schools served primarily low-income students of color, with high percentages of students classified as English-language learners (ELLs). The fourth school was in a more affluent context serving primarily white students, although the school's district was experiencing demographic change at the time of the study. Two of the schools were k-8 contexts, one was a k-5 school, and one was a middle school. In terms of the science instruction, we observed 13 science teachers from grades 1-8 across the four school settings.

Table 1: Context of School and Science Instruction

School	Ethnicity	Free & Reduced Lunch	Science Class Time	Number of Science Observations	Science Instruction Observed
K-8 Public School J	45% Hispanic 29% White 14% African American	48%	Grades K-4: ~45min-1 hour every other day Grades 5-8: 45 min daily	8	3rd general science 6th life science
5-8 Public School S	77% White 7% Hispanic 5% Asian	9%	Grades 5-8: ~ 50-55 min daily	8	5th physical science 6th life science 7th physical science 8th earth science
K-5 Public School T	56% Hispanic 27% African American 10% Asian	76.5%	Grades K-5: 45min- 2-3 times a week	9	1st general science 4th general science 2nd general science 5th general science
K-8 Public School E	71% Hispanic 24% African American	90.4%	Grades K-5: 45min- 2-3 times a week Grades 6-8: 45 min daily	4	5th general science 7th life science 8th physical science

Data Collection

Our study establishes a perspective on science instruction in practice via ethnographic field notes (Emerson, Fretz, & Shaw, 2011). Our methods allowed us to observe science instruction in real time in k-8 schools. Specifically, we observed science instruction by shadowing the four schools' principals as they observed instances of science instruction. Before and after observations, we also conducted brief interviews to elicit the principals' thoughts about the instruction. These conversations were audio-recorded and transcribed. During observations, we focused on documenting multiple aspects of classroom instruction, including student and teacher activities, as well as classroom context. To ensure minimal intrusion, we documented these observations via paper and pencil, typing up ethnographic field notes directly after each visit. In total, we drew on field notes and interview transcripts from 10-15 hours of observation for each school during the spring semester. During this time, we observed 29 total instances of science instruction.

Data Analysis

We analyzed field notes and interview transcripts through an iterative process using evidence from multiple data sources to develop key findings in the science instruction observed. Independent coders examined the multiple data sources and drafted case summaries for each principal. These case summaries were generated to organize all school context information and research findings in one place for each case. They consisted of information on each cases' district and school context, principal's background, and science instructional and supervisory themes observed at the school. After creating these case summaries, they were then shared with the larger research team who reviewed them to establish overarching themes across each case.

We looked for patterns that were internally consistent and yet divergent from each other to develop and refine themes (Johnson, 1997). We focused on science instructional features that were prevalent across all of the science observations in the four case studies. Specifically, every research team member came up with themes for each school's science instruction. We then did a cross-case analysis (Miles, Huberman, & Saldana, 2014) to establish common themes across the four school cases. Through this process, we identified themes that were strongly evident in each school and that cut across the four school cases.

Results

The results of our data analysis suggest three key themes related to the science instruction we observed (Table 2): (1) teacher-driven instruction focused on content memorization, (2) an emphasis on literacy, and (3) a focus on 'hands-on" science - investigative practices (see table 2). Each key finding is further divided two sections: 1) what does this instructional finding look like in practice? and 2) how does this finding relate to the systems of science education at these schools?

Table 2: Themes from Science Instruction Observed

Theme 1	Teacher-driven and focused on content memorization
Theme 2	Emphasis on literacy skills
Theme 3	Focus on 'hands-on" science - investigating practices

<u>*Theme 1: Teacher-driven instruction and focused on content memorization*</u>

What does this instructional finding look like in practice?

Across the four cases, science instruction was largely teacher-driven. These instances of instruction were characterized by tight teacher control over classroom discourse and the types of interactions accepted during science activities. In each school context, the majority of science instruction we observed was comprised of mostly teacher to student interactions rather than student to student interactions. For example, this type of teacher-student interchange was observed at school S during a 6th grade life science lesson on selective breeding. In this lesson, students took turns reading from their textbook while Ms. G (teacher) occasionally paused to ask recall questions:

- *Ms. G: Who else in our discussions was a selective breeder?"*
- *Student: "Gregor Mendel. The pea guy."*
- *Ms. G: "What did he select?"*
- *A student names some traits and then Ms. G mentions more traits, such as pea pod shape.*
- *Ms. G: "Scientists do this. They select different traits."*
- *A student raises her hand and Ms. G calls on her. The student mentions selecting traits in dogs.*
- *Ms. G: "Darwin was not selecting traits." She says that he was trying to figure out what happened in nature to these traits.*
- *Ms. G calls on a student to continue reading the textbook. Student reads.*
- *Ms. G calls on another student to read. Student reads.*
- *Ms. G: "I'm going to summarize this last paragraph because it's little wordy." She tells students about Darwin also getting his ideas from farmers and geologists.*

In this instance, Ms. G maintained control over how science ideas developed in her classroom. Ms. G controlled classroom discourse by selecting who would participate, when they were permitted to contribute, and how they should respond when called upon (e.g. read the textbook, answer recall questions). Additionally, she dictated what knowledge was to be valued in the classroom. She did this by evaluating the correctness of students' recall responses (e.g., *"Darwin* *was not selecting traits"*) and through her own interpretation of valuable information from the text (*"I'm going to summarize this last paragraph because it's little wordy"*).

Observations from school J echoed this type of teacher-driven instruction. In a 3rd grade physical science lesson about the moon, Ms. S (teacher) fostered interactions that promoted low-level student thinking. Like Ms. G, she generally controlled classroom discourse by asking recall questions. Furthermore, she often gave students answers when they did not come up with them on their own:

> *She asked, "Did anyone notice if the moon makes it's own light?" No one responded to her. After a pause, she asked them to complete her sentence, "The moon reflects like a…" Again, no one answered, so she filled in the blank, saying "mirror". She then began clapping her hands and saying, "Mirror – words" and said, "Mirror". The class repeated her in unison, "Mirror". Then she said, "Mirror – actions" and mimed a mirror, which the students sort of approximately repeated.*

In this example, Ms. S. had the students answer her question by repeating the term "mirror" after she said it. Additionally, it appears that this teacher-centered practice is quite familiar to her students as they readily echoed her response. This strict control over the development of science ideas continued for the remainder of the lesson as Ms. S verbally presented characteristics of the moon via a PowerPoint presentation. Students in turn, recorded these characteristics verbatim into their science journals. In the latter part of this lesson, Ms. S moved away from student participation completely and solely relied on students copying information about moon based on characteristics she deemed important prior to class (e.g.*"It has different phases").*

In each instance of instruction discussed above, the teacher directed all classroom activities and controlled the direction of discourse in service of students learning *about* science ideas. In fact, the overwhelming majority of science instruction observed across all contexts involved learning about science ideas rather than students figuring out science ideas using science practices. In each context, the most common instructional vehicle for this type of learning was content memorization. Science teachers overwhelmingly tasked students with memorization of content through direct instruction or through textbook use (e.g. find particular information in the textbook chapter). Central to both of these processes is the act of students taking notes to record information. During one observation, the principal at school E observed 8th grade students as they copied definitions into their notebooks while the teacher lectured about solvents, solutes, and solutions. This principal later discussed how this style of information transfer was common in that teacher's classroom: "*Copying the notes verbatim is something that I've talked to him frequently about…it would be more engaging for students to construct their own notes, so they listen to him when the slide goes up*."

This same emphasis on content memorization was reflected in many of the daily objectives for student learning across each school context. In one case, a 7th grade teacher at school S posted a daily objective to *"identify and differentiate between physical changes and chemical changes."* The fulfillment of this objective involved students recording definitions of science vocabulary. During the class, the teacher prompted students at various points to add their definitions for physical and chemical changes to their science worksheet. At the end of class, the teacher then asked the class to recite these definitions. After the students provided their definitions, the teacher then repeated their answers to communicate that their responses were correct. Similarly, at school T, several instances of instruction were guided by content-based objectives. For example, in one 5th grade class, a lesson on simple and complex machines was guided by the objective: "*What are the compound machines found in the tool shed? What is a compound machine? Define them.*" Students defined and looked for examples of simple and complex machines online. In both of these examples, the students were not engaged in any science practices, but still successfully embodied the content-memorization goal at the heart of each objective. As a result, these lessons were often deemed successes by the teachers who enacted the lessons and instructional leaders who observed them.

Furthermore, the focus on content memorization in instruction can promote misconceptions about the nature of science. Specifically, the misconception that science is a body of facts to memorize and that scientists confirm ideas that they already know. In several lessons by a third grade teacher at school J, these two misconceptions were observed frequently in instruction. First, the teacher promoted the idea that science is a body of concrete, indisputable facts, referring to the word "fact" eight times during the 25-minute lesson. Her actions and statements also implied that authority figures (e.g., textbooks and teachers), as opposed to students, got to determine which facts are important. The teacher even stated during the debrief, she wanted to make sure students were "*capitalizing on the facts that I want*" while taking notes, as opposed to writing down everything that she said or making their own judgments on what was most important. Furthermore, in another lesson, the teacher noted that she used a rap song because *"they're learning as they're seeing or memorizing it. For me it was really just another way of presenting the facts without just standing up there reading from the Magic School Bus book that we have been reading from too."* These examples clearly illustrate the strong emphasis placed on memorization of facts in her classroom. An emphasis on learning 'facts' was present in all four observations of this teacher. As a result, her instruction was characterized by her control over the science topic covered, how it would be discussed, who would participate, and what responses would be counted as legitimate answers.

How does this finding relate to the systems of science education at these schools?

Emphasis on teacher-based content and pedagogy was strongly related to the test accountability pressures present in three of the four school settings. The principals at schools T, E, and J all acknowledged the influence of the state accountability system on the prevalence of teacher-driven instruction and content memorization in science instruction at their schools. Specifically, the principal at school E noted his school's reliance on test scores to drive decisions about teaching and learning:

> *"Living in such a test driven context at the moment, and given that this school is a school that's been at risk of becoming a Level 4 turn-around school for the last however long the law's been around…We're always getting pressure, whether it's from above or from families, [on] what does the data look like, which then drives me and my fellow administrators' work to focus on the areas that are heavily assessed."*

School E's teachers were forced to narrow curricular content to topics included on the state tests, and were compelled to use more lecture-based, teacher-driven pedagogies to convey the breadth of test-based material.

Additionally, the implementation of teacher-centered pedagogies was often a necessity based on the dearth of resources allotted to science instruction in these schools, particularly in the elementary school contexts (i.e. school E, T, J's contexts). For example, during multiple interviews, the principal at school T highlighted instructional issues that stemmed from the small science staff she employed (e.g. "*they get to see up to a hundred kids a day, and that is not easy"*), the limited instructional time and space devoted to science (e.g. "*science is a stepchild"*), and the lack of budgetary support to hire accredited science teachers (e.g. "*you don't have too many people at the elementary level with that certification, and so with the budget cuts and stuff that goes on*"). As a result, science was infrequently taught in the school, and when it was, it was generally carried out by over-tasked science specialists in classroom spaces where there were minimal resources to engage students in investigations or other science practices. Therefore, out of both comfort and necessity, the majority of school T's teachers taught using the less resource-intensive methods of direct instruction and content memorization.

Even in a more affluent school context, like school S, there was still a strong emphasis on the direct instruction of content. In this context, the direct instruction appeared to stem from teachers' level of comfort with these familiar pedagogies and their perceptions that particular students would not be able to effectively participate in a more collaborative, student-centered lesson. For example, during a debrief between the principal of school S and a 6^{th} grade science teacher, the teacher stated that she understood the value of students constructing their own explanations about the natural world, but found that "*under the circumstances, presenting it (information) in a simple manner tends to work the best.*" Further, she stated:

> *There are some [students] that are ready to fly with a lot of [student-centered] thinking. I have the some that are struggling just to do the basics, and retain some of the information we talk about, even for a short period of time… I agree, it's definitely something that they could work on, to kind of explore the information themselves and come to it. Like I said, that group in particular I would probably have half of them that aren't ready for that yet.*

In these excerpts, the teacher is not resistant to the *idea* of student-centered instruction, but is generally hesitant to actually enact such instruction in her classroom. This hesitance to alter instructional methods was echoed by 7 out of the 8 teachers observed at this school. In each case, teachers discussed the students' inability to work collaboratively with one another as the main road block preventing their adoption of a more student-centered, exploratory-based pedagogies. Contrary to the other teachers, Ms. F, a first-year science teacher at school S, showed little hesitance in her enactment of student-driven lessons. As a result, her students engaged in a number of investigating and sensemaking practices at a sophisticated level. Furthermore, it was the most highly rated lesson by the principal and the researcher across the 8 observations at the school. Overall, this finding suggests that accountability pressures and teachers' comfort with traditional pedagogies served as sources of incoherence in science teachers' adoption of science-as-practice teaching methods.

<u>*Theme #2: Emphasis on literacy*</u>

What does this instructional finding look like in practice?

Much of the science instruction observed across these four school contexts prioritized literacy skills above student engagement in the science practices. These instructional activities generally highlighted skills that were highly transferable and valuable to reading and writing instruction. For example, in one instance of instruction from school S, 7^{th} grade students read a short article about Scott Kelly, an astronaut who had just returned from a year in space. Afterward, they answered simple recall questions posed by the teacher to elicit the main points of the article:

> *Mr. B: Let's begin. What happened yesterday?*
> *Student: Scott Kelly landed*
> *Mr. B: Who is Scott Kelly?*
> *Student: Guy in space for a year*
> *Mr. B: Why is Scott Kelly so important?*
> *Student: They can compare him to his twin brother*

Although this article covered a science topic, reading the article was centered on a larger learning goal of understanding a non-fiction text for its main points. The teacher (Mr. B) did not ask students to explain why comparing the twin brothers was important scientifically, or what science ideas may have explained any observed differences between the brothers (i.e. gravity). As a result, students' understanding of the major science ideas from the article was of secondary concern to the process of summarizing the main ideas from the text. In turn, several students were observed simply reading highlighted portions of the article rather than explaining what they had read.

Similarly, the principal at school J observed several instances of instruction where students rehearsed vocabulary or read and analyzed non-fiction texts. When referring to one literacy-heavy lesson, she said the following: "*The gist of the lesson is getting kids to pull information from the different books at their levels, and then pick out key information [to] categorize them under the three categories*." The principal viewed this instance as a success due to the instructional priority she placed on the development of literacy skills across subjects at her school. Consequently, the observed teacher also echoed the importance of building literacy skills in science instruction. She stated that students would soon start "*a fun writing project"* and were going to participate in *"a reader's workshop, where they will learn text marking and those strategies."* Consequently, the majority of this teacher's lessons contained more literacy than science and only one of her lessons engaged students in any science practice.

While many of the science teachers engaged students in activities around non-fiction texts, very few teachers engaged students in the science practice of obtaining, evaluating, and communicating information. In most cases, the students read text to obtain scientific information, but did not critically evaluate this information. For example, at school S, students were observed reading a textbook chapter and recording specific definitions in their notes. The teacher then posed factual questions based on the definitions the students recorded. In this example, students were never explicitly tasked with evaluating the strength of scientific evidence or the core science ideas included in the text. Further, there were no instances of instruction across all school contexts, where students compared or combined information from multiple texts to consider the strength of the information and the sources.

Another common occurrence across school contexts was the use literacy scaffolds in the science instruction. In a 6^{th} grade science class at school J, students learned about Charles

Darwin's life. Specifically, students read out loud from a textbook and took notes using a scaffolded worksheet that asked students "*who, what, where, when, w*hy" questions about Charles Darwin. This literacy strategy directed students to focus on Charles Darwin's personal history, rather than the big science ideas related with his scientific research (i.e. natural selection and evolution). Likewise, one of school E's teachers employed a literacy strategy to support students in answering open response questions. The teacher used a strategy from their ELA class called RAP, which stands for "Restate the question, Answer the question, Prove your answer." The RAP method provided general supports to help students construct an open response. Overall, this literacy strategy was not content-specific in its approach and lacked guidance on how to construct a scientific explanation using scientific evidence and reasoning.

How does this finding relate to the systems of science education at these schools?

The emphasis on literacy in science instruction again appears to be directly influenced by the state accountability measures. The principals at schools T, E, and J's have prioritized heavily tested content areas like mathematics and ELA over other subjects like science and often utilized science instructional time to teach literacy. For example, the principal at school T described the large discrepancy in the time dedicated to science compared to math and literacy at her school: *"You have literacy, you have 90 minutes of reading and writing every day, an hour of math every day…Science is a stepchild."* The principal at school E also echoed this school-wide focus on math and ELA in relation to supervision and instruction at his school. The emphasis on math and literacy skills was largely a result of the school's weak performances on math and ELA standardized tests and the potential risk of the school being designated as low-performing by the state. As a result, he focused his supervision "*on the areas that are heavily assessed, which are* *math and ELA*" and prioritized ELA and math instruction (e.g. "*ELA and math still take up the majority of the teaching day.")* Furthermore, budget cuts at school E resulted in the loss of elementary science specialists. These budget cuts forced the elementary teachers to take on science instruction on top of their other teaching duties. As a result, the principal at school E believed that elementary teachers relied on content and process skills with which they were more familiar (e.g. literacy, math) when teaching science.

Similarly, the principal at school J has stated that district-wide pressures, as a result of standardized tests, have lead to a focus on literacy in her school:

> "*the district has specific focus lessons and common assessments that the expectation is every single teacher delivers the common assessment, and that occurs in ELA, in reading, writing and math. There's nothing like that in science. With that, and all of the testing, like we do the STAR assessment, we do Fountas & Pinnell, the DIBELS. All of that is reading based. All we have at the district level (for science) is the units of study."*

Consequently, the principal at school J primarily supervised ELA and math instruction. Furthermore, when she did observe science instruction, she frequently emphasized reading, writing, and vocabulary use in her feedback. In one example, she provided feedback to a teacher, stating that a student "*used the word crater and then you pointed out the three ways to call it, which is the use of vocabulary, which is really key,*" and encouraged her to "*keep pushing students on the vocabulary use*." The principal's explicit references to literacy motivated her teachers to continue to prioritize literacy instruction in science class.

Moreover, unlike ELA and math, which have ample state test data to work from, there is a lack of science data in the district for teachers to build science learning goals around. For instance, the principal at school J stated:

> *"the goals that teachers write for the education evaluation, we have data around—more specifically, we have student learning goals. We have data around reading and math, lots of it, but we don't have it in science. It's sort of like they don't have science data to analyze to be able to get to a goal kind of thing. That's something that they would need—like we would need to have something like that in place"*

As a result, teachers developed student learning goals based in literacy and math test data only. The principal posited that the lack of explicit science goals has led her k-4 teachers to perceive science teaching as secondary to math and ELA instruction. Further, with no explicit goals to improve their science teaching, she believed that k-4 teachers may lack a growth mindset when it came to improving their science content knowledge and teaching practices. Taken together, the district's prioritization of literacy over science has resulted in a domino effect where both school administrators and teachers focused strongly on literacy skills in instruction. Due to this prioritization, science teaching as well as general supervision, instructional feedback, and instructional goal-setting were all strongly tied to the promotion of literacy skills in students.

The principal at school S also discussed the significance of literacy at her school. She echoed the other school leaders regarding the breakdown of instructional time (e.g. *"I feel like a lot of what they do is focused on the literacy and the math, and very little time is given to the science"),* and she primarily provided her teachers with literacy-based feedback on their instruction (e.g. *"That's really one of our focuses, so that they're getting more out of their reading when they're doing it*"). In contrast to the other school leaders, this principal did not frame the importance of these literacy skills in pressures related to state accountability measures. Instead, the emphasis on literacy skills appears to be derived from her instructional vision for the school. She readily described math and literacy as the main focus areas. Further, in discussion of science education, she said one of her main goals was to *"support teachers in actually really incorporating the literacy and the math into the science curriculum"* As a result, this principal consistently framed literacy skills as the main learning goal for students across all subjects at her school. Overall, this finding suggests that the focus on ELA in state accountability measures has resulted in the prioritization of literacy skills across school subjects, including in science.

Theme #3: Focus on 'hands-on" science - investigating practices

What does this instructional finding look like in practice?

When teachers engaged students in the science practices, they primarily focused on the practice of planning and carrying out investigations. These activities rarely provided students with the opportunity to design their own investigations or to make decisions about the experimental variables, controls, or investigational methods. Instead, students generally carried out predetermined investigations where they closely followed a step-by-step procedure. These types of investigatory activities were common across each school context. For instance, the principal at school J noticed the investigation practice during all four lessons she observed. The researcher noted that each of these investigations were largely procedural:

> *"Students did not seem to partake in the planning of their investigations, rather they focused on conducting investigations. For example, during lesson 2, students were testing the effect of physical activity on heart rate by following procedures in the textbook and collecting data in small groups."*

The same type of procedural investigation was prevalent at school T. In one instance, a 4th grade science teacher had student groups build an identical habitat for a hermit crab based upon her directions. This is reflected in the following field note:

- *Ms. J (the teacher) tells the students to send one person from their group over to her in order to collect their materials. She explains to the students that they will be adding 4 cups of soil/sand to their habitat. She then tells them where to place the water bin in the habitat and explains that the soil should be slopping up on the side of the bins… Ms. J next explains to the students that once their soil is in place that they need to add their plants 1 inch from the water basin.*

After the students developed their identical habitats, they then went on to record identical, teacher-determined observations about their habitats. While this activity technically engaged students in the practice of "carrying out investigations," it was completely teacher-driven and provided little opportunity for students to design the experiment or utilize other science practices to make sense of the habitat observations.

In a more extreme example, the principal at school E observed a teacher carrying out a procedural investigation on solutions, solvents, and solutes. Students were expected to follow the steps of the experiment as the teacher offered explicit verbal directions for each step:

> *MN (the teacher) asked that the class go step by step together. He said to get out the scale and turn it on. Then to place an empty cup on the scale and reset it so it accounts for the weight of the cup. He assigns each table one of the ratios from the data table and tells them to measure out respective amounts of water and magnesium sulfate and then mix them into the cup and stir with the plastic syringe…MN sets a 5-minute timer for students to measure and asks a couple students to wait until everyone is finished with their measurements.*

In this instance, the teacher engaged students in an experiment to reinforce content he already taught his students. Specifically, this investigation served to confirm what the students learned about solutions and the measurement of concentration previously. To do so, the teacher curated the entire experimental process to ensure the 'correct' confirmatory observations were experienced by his students. As a result, students were not provided the opportunity to develop their own explanatory ideas about the concentrations of solutions from this investigation. This style of teacher-driven, confirmatory-based experiment was the primary way teachers engaged students in science ideas.

These instances of instruction were indicative of the manner of student engagement in the science practices across the 29 lessons observed. Due to the absence of student ownership over the investigation's data products, students rarely engaged in the sensemaking practices (e.g. constructing explanations). For example, when the researcher asked a student at school J how he knew which variable was the dependent and independent variable, the student merely pointed to his data table and said *"we just get it from our variable chart*." In this case, the teacher determined the "important" data to include and gave students data charts with pre-filled labels, rather than having students determine variables and create their own data tables. As a result, there was no discussion pertaining to the organization or grouping of data and this likely contributed to students' difficulty with recognizing patterns from the data table. For example, when the researcher asked another group of students from the same class to discuss the patterns in the data, they said they were unsure, and deferred to the teacher's analysis of the data when they were constructing their explanations for their conclusion. Lastly, the critiquing practices were not documented in any instance of instruction observed. As result, student interactions and discourse in the evaluation of evidence were largely absent from every instance of science instruction observed.

How does this finding relate to the systems of science education at these schools?

The focus on the investigation practice in science instruction resulted in part from the principals' ideas of "good" science instruction. The four principals often conflated "good" science instruction with inquiry and hands-on activities. While the principals described science learning as a hands-on activity, each had a different perspective on the meaning of "hands-on.". For example, when interviewed, the principal at school E stated: *"I think it looks different in* *science in that it should be much more hands-on… Kids do something. They might be able to talk about it or do it."* In a more specific vision of science instruction, the principal at school J outlined science teaching as an inquiry process where students figure out science ideas,

> *"I would want students to know the process of inquiry kind of thing. That would be part of—I think when I'm thinking about concepts, that's part of the concepts that I'm thinking about. Not just the factual information, but trying to figure out how to find out things."*

The principal at school T also discussed good science instruction as hands-on, but aligned this vision to a general workshop model of instruction:

> "*Well, it just like the workshop model where you might come in, you might do your mini lesson for no more than ten minutes…A huge bulk of time is spent on hands-on. While you're doing hands-on the teacher is circulating the room, interviewing kids and seeing where they are*."

Furthermore, each principal also described 'hands-on' science instruction in content-neutral terms. This included a vision of hands-on science learning where students were "*highly engaged in the science content,*" and were given clear expectations *"to think and struggle and have ideas come in and out."* Taken together, these school leaders prioritized a vision of science learning that most reflected to the "planning and carrying out investigations" practice.

Consequently, each principal was more attuned to recognize science instruction that was aligned to investigations rather than other sciences practices. In fact, despite the large volume of investigations observed across all contexts, each principal showed aptitude in noticing the investigations practice. Further, each principal misidentified or failed to notice science practices on multiple occasions. Practices like asking questions, developing and using models, and constructing explanations were particularly difficulty for each school leader to identify in instruction. As a result, the principals sometimes gave inaccurate feedback about the presence or sophistication of student engagement in these practices. For example, the principal at school E incorrectly noted the presence of the asking questions practice on several occasions. In one lesson, he mistakenly identified student engagement in the asking questions practice when the teacher actually did not provide opportunities for students to ask questions. In another example, the principal at school T had difficulties identifying the "developing and using models" practice across several lessons she observed. In one particular lesson, this principal viewed students labeling plant parts on a diagram using information from their textbooks. She decided this was a model, stating the following: *"I just put model because I was like, let me think a little more broadly about the model. At least that was good that they had something to reference"* In this example, the principal was grappling with the parameters of a model and came to the conclusion that students were engaging in the modeling practice. In actuality, this diagraming activity should not have been classified as a model, because students did not use these diagrams as a tool to describe, predict or explain a phenomenon in the natural world.

While each principal showed marked improvement in science supervision over the course of the study, this improvement was primarily grounded in the investigations practice and its related skills (e.g. choosing variables, research questions, data collection). For instance, all four principals were documented as using more science practice language by the researcher's final school visit. In each case, this growth was characterized by a deeper understanding of student engagement in the investigation practice and a more accurate gauge of what count as an occurrence of other practices. As a result, the principals improved their capacity to notice the level of sophistication in student engagement with the investigations practice. Additionally, they improved their ability to notice the absence of other science practices. Consequently, the principal's feedback related to investigations was often more nuanced than with other practices (e.g. *Do you see how you guided the students in the experiment because you had chosen the variables?*). Overall this finding suggest that the principals' deeper understanding of investigations likely contributed to a positive feedback loop where science teachers' emphasis on investigation in instruction was further reinforced by the leaders' investigation feedback. In turn, the teachers' enactment of the investigating practices were then more likely to be noticed and commented on by instructional leaders, thus bolstering the cycle further.

Discussion

Current reform efforts support a vision of science as practice in which students make sense of the natural world (Krajcik, et al, 2014); however, the results from our study suggest that current k-8 science instruction may not align with that vision. Instead, the science instruction we observed was frequently teacher-driven, focused on content memorization and was literacy-based. Furthermore, when instruction did include science practices, teachers typically only targeted the investigating practices. As a result, the bulk of science teaching we observed was aligned to an image of science instruction where students were taught *about* science ideas. These science ideas were often presented by teachers as disconnected facts and definitions to be learned. This science content was rarely linked to important disciplinary core ideas that would support students sensemaking abilities. Consequently, teachers rarely engaged students in the science practices to apply and explain disciplinary core ideas. Instead, student engagement in the practices was often represented as a separate inquiry activity where students made observations that confirmed what they had already been taught. As a result, this science teaching did not involve many instances where students were building a coherent knowledge base through engagement in the science practices.

As schools and districts shift to align more closely with science practices, it is important to continually improve our understanding of how teachers' instructional tendencies may interfere with the key learning goals of the science practices. The instructional features observed, including changing the activity structure of lessons from student-directed and collaborative to teacher-driven, can negatively interfere with reform efforts (Brown, 2009). Furthermore, our findings exhibit how the systems of science education in various school contexts can compromise a coherent vision for NGSS-aligned science teaching and learning. Specifically, we documented how the framing of accountability measures and instructional leaders' understanding of the science practices can serve as sources of incoherence in the adoption of science reform efforts. As a result, these features must be addressed to sustainably support teachers' adoption of reform-oriented instructional practices. Future research should explore the beliefs, values, and material realities that influence teachers' current instructional practices. This inquiry will help researchers to continue to identify potential levers to support teachers' adoption of the NGSS science practices.

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