Supporting k-8 principals' vision of science instruction: Shifting towards science as practice through professional development

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Recent science education reform efforts, such as the Next Generation Science Standards (NGSS), include a vision of science as a practice in which students engage in sensemaking about the natural world (Berland, Schwarz, Krist, Kenyon, Lo & Reiser, 2016). This includes a significant shift from learning about science facts to figuring out scientific phenomena in which students use science practices as they apply disciplinary core ideas (NRC, 2015). Educational policies, such as new standards like the NGSS, attempt to bring about changes in teaching and learning in k-12 classrooms (Cobb & Jackson, 2011). In order for these types of reform efforts to be successful we need to think about school *systems* considering not only students and teachers, but also school and district leaders (Fishman, Marx, Blumenfeld, Krajcik & Soloway, 2004). Instructional leaders, such as principals, play a key role in those educational systems. Yet instructional leaders have traditionally resided outside of the mainstream science education community. Consequently, we investigated the following research questions: How do instructional leaders' familiarity with and knowledge of science practices change while participating in professional development?

Theoretical Framework

Instructional Leadership

Reform efforts, such as the NGSS, require support from multiple levels of the educational system including district and school leaders (NRC, 2015). The role of district and school leaders has changed over time and increasingly includes a focus on instructional leadership in which leaders are responsible for implementing reform efforts and supporting teacher learning. Instructional leaders play a key role in providing time, curricular and professional resources for teacher growth broadly, but also specifically for science instruction (National Academies of Sciences, Engineering and Medicine, 2019). Furthermore, new systems of teacher evaluation frequently result in school leaders observing and providing feedback to teachers on discipline specific instruction, such as science (Sergiovanni, Starratt & Cho, 2013). This more rigorous evaluation system can result in formative and summative evaluations linked to curriculum planning and instructional improvement. Yet instructional leaders in k-8 schools often do not have a background in science (McNeill, Lowenhaupt & Katsh-Singer, 2018) and have many competing demands on their time outside of science such as external accountability pressures emphasizing literacy and mathematics (Lowenhaupt & McNeill, in press). If instructional leaders do not understand the goals of new science reforms, they may be hesitant or provide conflicting messages about what constitutes effective instruction (National Academies of Sciences, Engineering and Medicine, 2019).

Science Practices

One of the shifts in recent reform documents and science standards has included a focus on science as practice (NRC, 2012; NGSS Lead States, 2013). Instead of a classroom in which students are primarily studying and recounting facts and definitions, this vision highlights instruction in which students are actively involved in questioning, investigating and explaining the world around them (Schwarz, Passmore & Reiser, 2017). Although there are eight distinct science practices in the Next Generation Science Standards (NGSS Lead States, 2013), they work synergistically and share common characteristics such as the connection to the natural world, importance of evidence, and the active role of the students McNeill, Katsh-Singer, & Pelletier, 2015). Seeing science as a set of practices highlights the specialized ways of reasoning, talking and writing that are essential to knowledge construction (NRC, 2012).

Leadership Knowledge about Science

Many school leaders do not have expertise in science or science pedagogy, which can result in challenges in supporting teachers in this work (NRC, 2015). From our previous research with principals, we found that they had limited understandings of the science practices, and science in general, which made supervision difficult (McNeill, et al, 2018). Instructional leaders need to develop greater expertise around these science reform efforts before they can support the needs of the science teachers in their schools.

Specifically, we are interested in supporting instructional leaders' leadership content knowledge for the science practices. Recent scholarship has sought to develop a construct of "Leadership Content Knowledge" (LCK) to determine the cognitive underpinnings of instructional leadership and define the knowledge principals draw on to improve instruction, including subject-specific knowledge as well as knowledge about how to support teacher learning (Overholt & Szabocsik, 2013). To support these shifts, we developed a set of tools integrated into professional development (PD) for instructional leaders targeting the science practices. This focus is in contrast to more common supervision observation protocols, such as "the Danielson framework" (Danielson, 2002), that do not consider subject-specific features of supervision. By highlighting key elements of the science practices, our goal was to impact principals' LCK in disciplinary specific ways.

Methods

During the 2016-2017 school year, we worked with 25 instructional leaders from K-8 schools to support their science supervision practices. We investigated their familiarity and LCK of the science practices as the engaged in PD that used tools designed for instructional leadership for the science practices.

Professional Development Context

The instructional leaders participated in three PD sessions, for a total of 13.5 hours, with approximately 1 to 2 months between each session (See Table 1). The overarching goals of the three sessions included supporting instructional leaders in their understanding of the science practices, their approach to science supervision, and the use of the leadership tools. The first PD session focused on discussing the shift in science education prompted by the adoption of the NGSS, introducing the science practices, supporting the development of noticing of the science practices, and introducing leadership tools. The second and third PD sessions concentrated on further supporting the development of noticing of the science practices, practicing the use of science specific feedback for teachers, using the tools, and developing a school-based plan to support teachers in integrating science practices in their classrooms. After the first and second sessions, instructional leaders practiced using the tools and their knowledge from the training when observing and providing feedback to science teachers in their schools. The second and third sessions began with a debrief on these supervision experiences.

Table 1: Goals and activities during the 3 PD sessions

Session	Goals	Activities
Session 1 (7.5 hours)	• Understand shifts in science standards – not just the memorization of content but the actual engagement in science practices	• Engage in a 1st grade science investigation exploring how shadows changing over the course of the day. • Discuss current science instruction in their k-8 schools

	• Increase familiarity with the 3 groups of the science practices as a way to think about what is and is not occurring in their schools • Develop the ability to notice the science practices when examining science instruction – start to move beyond just general feedback to include science specific language	• Be introduced to the new science standards and the shifts in those standards. • Analyze and compare language in old versus new standards. • Analyze video from a 3rd grade classroom creating and revising models for– Why can a singer shatter a glass with his voice? • Be introduced to the three groups of science practices: investigating, sensemaking and critiquing. • Analyze the initial 1st grade lesson using the investigating science practices. • Analyze a vignette of a 5th grade classroom investigating chemical reactions focusing on the sensemaking practices. • Discuss philosophy of supervision • Analyze a 2nd grade video focused on the impact of wind and water on a sand castle using the critiquing science practices. • Analyze a middle school video (students are discussing -What kind of allele causes the glowing trait?) using all 8 science practices.
Session 2 (3 hours)	• Continue to develop the ability to notice the science practices when examining science instruction – consider differences between practices and levels of quality • Practice providing teachers with feedback around the science practices • Plan a process to support your teachers in moving towards the science practices	• Share science observations in your school since last meeting. • Analyze a 3rd grade video (Students are designing physical science investigations) using all 8 science practices. • Be introduced to instructional strategies aligned with each of the science practices. • Critique and offer revisions for a 4th grade lesson on light using the instructional strategies. • Watch a 5th grade video of students investigating membranes. Engage in a feedback role play using the video as the context including three roles: supervisor, teacher and observer. • Draft a plan with colleagues around introducing and supporting teachers in this work.
Session 3 (3 hours)	• Continue to develop the ability to notice the science practices when examining science instruction – consider differences between practices and consider ways to support stronger	• Share science observations in your school since last meeting. • Analyze a middle school video (Students are analyzing data about how food affects a runner's performance) using all 8 science practices.

	integration of the science practices • Consider how changes to a lesson can be made to better integrate the science practices. • Practice providing teachers with feedback around the science practices • Plan a professional development for your teachers focused on the science practices.	• Order four variations of the same lesson in terms of the quality of analyzing and interpreting data. • Watch an upper elementary video of students investigating the effect of salt on ice. Engage in a feedback role play using the video as the context including three roles: supervisor, teacher and observer. • Design a professional development session with colleagues to use with teachers in your school

Participants

All twenty-five participants worked in public schools serving children in k-8, but this included different types such as k-5 (n = 9), k-8 (n = 4), 6-8 (n=4), and other categories (n=7) such as k-3 and k-4. Furthermore, the schools served a range of children in terms of those eligible for free and reduced lunch and the percentage of second language learners. The majority of participants had either bachelor's (n = 10) or master's degrees in education (n = 22) and all of the participants had administrative credentials as an assistant principal or principal. The majority of the participants' backgrounds were not in science: 1 participant had an undergraduate degree and 1 had a master's degree in science.

Table 2: Principal Demographic Information (N=25)

Type of Teaching Credentials	Science	Elementary	TESOL/ESL	Special Ed	Other
# of principals	2	12	3	6	5
Level of Education	Bachelor's Science	Master's Science	Bachelor's Education/Other	Master's Education/Other	Doctorate Education/Other
# of principals	1	1	20	26	6
Administrative Credential	Principal	Superintendent	Other		
# of principals	25	9	1		

Data Sources

Throughout the PD sessions, we collected data from the instructional leaders to investigate the impact of the experience on their familiarity and LCK of the science practices. The data sources included: pre and post surveys of LCK, pre and post surveys of familiarity, and video recordings of all PD sessions.

Pre and post surveys. To measure the instructional leaders' LCK of the science practices, we developed an instrument that incorporates "scenario simulations" to exemplify observing science instruction within the context of an online survey instrument. Participants responded to written cases to reveal their understanding of the science practices. Similar instruments have been developed and used in other education studies (e.g. Spillane, White, and Stephan, 2009) to approximate practice-based skills. Specifically, the science practices instrument focused on two characteristics – noticing and feedback. In terms of noticing, we examined participants' ability to identify different aspects of classroom instruction and interpret them in meaningful ways (Sherin & van Es, 2005). The other characteristic focused on participants' ability to provide constructive feedback in relation to integrating science practices into classroom instruction.

The final LCK-SP measure consisted of 16 multiple-choice items and 3 open-ended items. The multiple-choice responses were scored (correct = 1, incorrect = 0) and tallied for a maximum possible score of 16. Open-ended responses were scored using a rubric for each item. These rubrics utilized a coding scheme where open-ended responses were rated from 0-2 based on the quality of the science practice noticing and feedback. Two independent raters scored the open-ended items overlapping on 20% of the responses. The inter-rater reliability was between 90% and 100% for each of the three items with an average inter-rater reliability of 93%. The Cronbach's alpha for the post LCK-SP assessment was 0.811.

The instrument also included Likert scale items evaluating the participants' familiarity with the science practices. The instrument included items for each of the science practices in order to evaluate whether the participants' comfort was consistent across all of the science practices or varied for particular areas. The instructional leaders were asked about their familiarity with each of the science practices using a 4 point Likert scale item (1 = not at all familiar, 2 = not familiar, 3 = a little familiar, and 4 = very familiar). The scores were summed for a maximum possible score of 32. The Cronbach's alpha for the post survey was 0.935.

Video recordings. The three PD workshops were video recorded. All video recordings were observed, time stamped and segmented by activity structure such as small group investigation, whole group discussion, individual reflection etc. Since we were specifically interested in the full group of instructional leaders, we focused our analysis on whole group sessions. All whole group sessions were transcribed resulting in the following minutes of transcription for each workshop: Workshop 1 for 210 minutes, Workshop 2 for 70 minutes and Workshop 3 for 57 minutes. Across the three days of workshops, 5 hours and 37 minutes of video were transcribed and analyzed. All participants' names in the transcripts are pseudonyms.

Data Analysis

For both measures of LCK and familiarity, we conducted a paired-samples t-test to determine if there were significant changes in the instructional leaders' familiarity and LCK after participating in the workshop series. We also examined the descriptives from the surveys (e.g. mean, standard deviation) to look for trends for specific science practices as well as strengths and challenges in responding to the open-ended items in relation to the principals' noticing and feedback. We used these trends to develop initial themes focused on the principals' familiarity with and knowledge of the science practices.

In order to challenge, refine and enhance the validity of our initial themes, we tested their viability by looking for confirming and disconfirming evidence across the data sources (Erickson, 1986). Specifically, three independent raters analyzed the transcripts for each of the three workshops one at a time. The raters identified examples and quotes from the workshops that either supported or challenged the themes. After analyzing each workshop, the team then met to discuss the patterns and revision of the themes before looking at the data for the next workshop. During these refinement processes, the themes were subjected to skepticism and to conceptual and empirical testing (Does it make conceptual sense? Do we see it elsewhere in the data? Are there counterexamples? Is there disconfirming evidence?)

(Miles, Huberman, & Saldaña, 2013). We analyzed the data looking for patterns that were internally consistent yet divergent from each other to develop more nuanced themes that offered greater insight into our phenomenon of interest (Johnson, 1997).

The initial themes were created solely using the survey data. In examining the transcript from Workshop 1, all three raters felt that these initial themes did not capture the range of ideas and beliefs that the principals begin with during the professional development workshop series. For example, one of the initial themes included the idea that "Principals' views of science instruction shifted away from memorizing science vocabulary." The discussions during professional development Workshop 1 illustrated the principals used a range of resources from other disciplines (e.g. English Language Arts and Mathematics) and from content neutral visions (e.g. classroom discourse and talk) to make sense of science instruction. Consequently, all of the initial themes were extensively revised to better align with the Workshop 1 data. Because of this considerable revision, the three raters did a second round of data analysis of the Workshop 1 transcripts with the revised themes. Therefore, after the initial development of the themes, the themes were subject to four rounds of revision and refinement (two rounds for Workshop 1 and one round each for Workshop 2 and Workshop 3). This analysis resulted in final themes that illustrate how the instructional leaders engaged with the science practices and how their knowledge about science instruction changed as they participated in the professional development series.

Results

The results from the pre and post survey illustrate that overall instructional leaders experienced positive changes in their knowledge and familiarity of the science practices. For familiarity, there was a significant difference in the scores from the pre-test ($M = 23.32$, $SD = 3.52$) compared to the post-test ($M = 29.72$, $SD=3.02$); $t(24)= 7.13$, $p < .001$ suggesting the instructional leaders became more comfortable with the science practices. Figure 1 breaks down these results for each of the eight science practices.

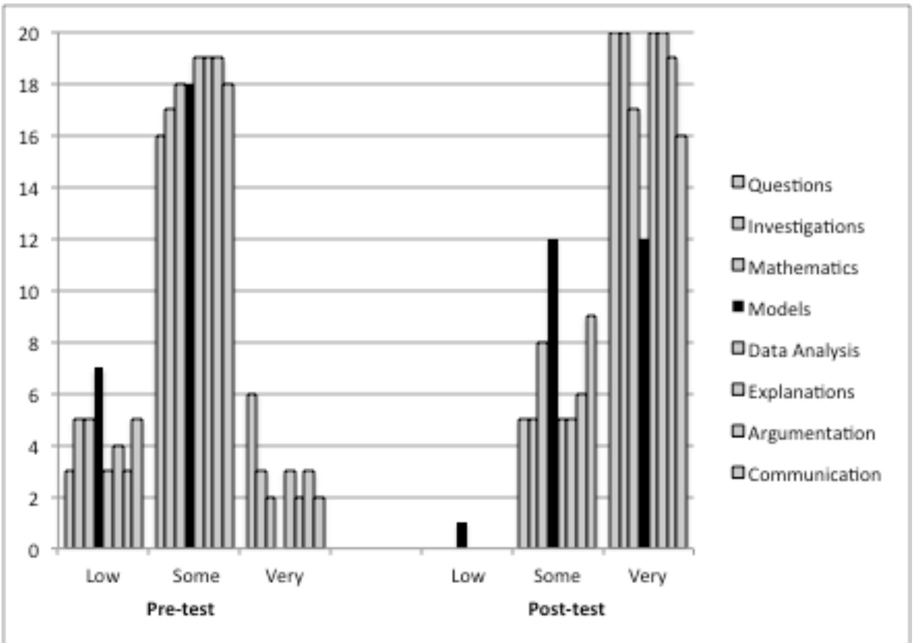

Figure 1: Principals' Pre and Post Familiarity with the Science Practices

The results of the survey suggest that the principals felt more familiar with the science practices after participating in the PD. However, this did vary by science practice, with models showing the least amount of change.

For the LCK of science practices instrument, there was also a significant difference in the scores from the pre-test ($M = 12.04$, $SD = 3.25$) compared to the post-test ($M = 16.28$, $SD=4.12$); $t(24)= 6.24$, $p < .001$. Principals were more likely to notice and reflect on the science practices when reading and making sense of the vignettes of science classrooms after the professional development. For example, in the post survey after reading a vignette one principal commented that "This would be a good opportunity to focus on the practice of obtaining, evaluating and communicating information. Be sure there is plenty of opportunity for all students to reflect on how well they critiqued scientists' arguments." This quote illustrates how the instructional leader used the language of two of the science practices when evaluating k-8 science instruction.

Overall, the survey analyses highlight positive trends. These trends are supported in the transcripts from the professional development; however, the discussions during the professional development offer greater insight into how the instructional leaders' familiarity and knowledge changed over time. Table 3 synthesizes the themes that emerged from our data analysis. We will discuss each of these in more depth providing examples from the professional development to illustrate these themes.

Table 3: Instructional Leaders Knowledge of the Science Practices

Theme 1	Principals initially used their understandings from other disciplines and content neutral visions of classrooms to make sense of science instruction.
Theme 2	Some principals thought of the science practices as separate from science content.
Theme 3	Principals use of the language of the science practices became more frequent and sophisticated shifting from identification or definition to considering the quality and support of the science practices.

Theme 1: Principals initially used their understandings from other disciplines and content neutral visions of classrooms to make sense of science instruction.

As the pre-survey suggests, the principals began the workshop series with lower knowledge of and comfort with the science practices. Furthermore, only two of the twenty-five participants had a background in science to pull from. Yet as part of the Workshop 1 (see Table 1) we asked them to analyze and critique multiple examples of science instruction with their peers as well as discuss science instruction in their schools. In doing this work of making sense of science instruction, many of the principals drew from either their understandings of other disciplines (e.g. ELA and math) or from content neutral visions of classrooms (e.g. general learning theories and pedagogical approaches). Drawing from these other non-science resources occurred more frequently in the first workshop compared to the second or third. We first share examples from other disciplines and then content neutral visions of classrooms.

Understandings from other disciplines. In discussing the standards and science instruction during the first workshop, the principals made explicit connections to other disciplines. For example, at the beginning of Workshop 1, one of the facilitators introduced the new vision for science and the list of the eight science practices. In response to this introduction, one participant Kelly asked, "My question's just around the math." Kelly was trying to understand the similarities and differences of the science and math practices (See

Table 4) resulting in a brief conversation about whether modeling and argument were similar or different from math and ELA.

Table 4: Transcript about math and ELA in Workshop 1

Kelly	But there's a using models in math also. Do they mean the same things? Do we unpack them the same way? I just think that in itself is going to take a lot of work.
Facilitator 1	I agree. I agree. I think the shift is important, but then we have all these nomenclature things, which make it challenging.
Matt	Argument from evidence comes up in a lot of disciplines, obviously. But to your point, are we cool that we mean the same thing, or do you need something different here in science versus math versus literacy in making arguments for evidence?

The instructional leaders were trying to make sense of the science practices using their understandings of other disciplinary practices.

Later in Workshop 1, the principals discussed what science they were and were not seeing in their k-8 schools. One principal brought up that she thought a challenge in science is that "teachers are uncomfortable with science". Another principal responded to this idea and connected it to his experiences with the math program in his school. Brian stated

> *Building on the point about comfort level with content knowledge, to get to (inaudible), I think you need to let—you need to be confident enough to let the kids take you where they want to go. We have noticed that in the learning math program. And I see it in science, as well. It's not about getting the right answer. It's about the process that the kids are working on to come up with it.*

This suggests that Brian connected the student directedness and the shift away from focusing just on the answer to "the process" as being similar to what he experienced in math instruction in his school. A number of principals appeared to connect to elements of instruction or learning goals, which they saw cutting across the disciplines. For example, in Workshop 1 Diana also stated

> *there is common ground among the various disciplines. The common ground is, then, you're working with students to develop dispositions and attitudes and mind sense, as opposed to just remembering stuff.*

Consequently, although the principals did not have strong backgrounds in science, we saw them connecting to their rich experiences in ELA and math and as instructional leaders to make sense of this new vision in science.

Content neutral visions. Many of the connections the instructional leaders made, were not explicitly linked to a discipline but rather focused on teaching and learning in k-8 schools more broadly. These were content neutral visions of instruction that focused on general pedagogy or elements that were important across disciplines. This occurred most frequently in Workshop 1, but the instructional leaders continued to make some connections in later workshops.

The instructional leaders brought up other general pedagogical approaches or learning theories as they discussed the science instruction. For example, in Workshop 1 while discussing an investigation focused on how shadows change, one instructional leader, Janet said "We were wondering about the constructivist approach, or just saying pick a flashlight and move it all around and just – what do you notice?" Later in that same workshop a different principal, Kadisha, stated "It brought me back to what - overall to what your looking at with universal design and increasing the level of questioning". In these two examples we see principals connecting to "constructivist" theories and "universal design" as important for thinking about how to create instruction that aligns with the science practices. We also observed the instructional leaders connecting to more cognitively demanding learning goals as they talked about "letting the kids do the heavy lifting", "develop children's higher learning skills" and having it not be "teacher driven". The principals connected the science practices to other reform efforts with some shared common characteristics.

Although the majority of these examples occurred during the first workshop, there were still a couple of examples in Workshop 2 and 3 in which principals drew from content neutral visions. The strongest of these occurred in Workshop 3 when an instructional leader stressed that she felt that fundamental general skills were more important than science specific feedback or strategies for a video we watched of an upper elementary classroom in which students were investigating the effect of salt on ice. Table 5 includes the instructional leaders' initial idea and the response from her colleagues.

Table 5: Transcript of discussion about fundamental general skills in Workshop 3

Samantha	I posed that same question to Facilitator 2 cuz I was like I'm confused, I don't even know what her [teacher in video] objective was. At our table, we talked about this is kind of what a barrier is to [*inaudible*] this school and talk about science practices with a teacher that doesn't have some fundamental skills when they're teaching. Like a clear learning objective. That's what you need to focus the conversation. Facilitator 2 said we can kinda just start by saying tell me about what the purpose of your lesson was, or just asking that general question. Then, using that answer and say, here are the science practices and what can you do to—I don't wanna say improve, but work on really incorporating those more clearly into your objective or lesson. But I do feel strongly that, if the teacher doesn't have some planning or instructional skills, then this is secondary for me. Which I hate to say to you guys, but they need to learn those.
Matt	I see this as an avenue or a method or a framework to do that, to have that conversation.
Samanatha	Yes, I agree.
Facilitator 1	Matt, how would you start this conversation?
Matt	I'd say what my impressions were. My impressions are that she is trying to help the students explain the experiences they had. Yeah, I mean, if she's probably a first- or second-year teacher, I would not be surprised *[inaudible]*. She is *[inaudible]*. I think it's, she was enthusiastic about getting student contributions. She doesn't know that she's doing it really inefficiently and ineffectively. Yeah, I would agree you do got some work ahead with this teacher, but that's how it would start, is the very small statement or impression and then calibrate with her. I got that way, that what you were after.

Deirdre	I think, in some ways, she gave us the out for starting the conversation, she said—the one thing we did pick up on was she said we're gonna talk about constructing an explanation around what happened. I think that's the starter, is to use that as the in with her. Then to probe with questions about - What were you hoping they'd be able to explain? Did you get that to that level?

In this example, Samantha prioritizes providing feedback about fundamental general skills, such as creating a learning objective, over feedback that is science specific. But two of her colleagues, push back on that idea arguing that the science practices are a way to support the teacher in thinking about her objective. Specifically, Matt and Deirdre talk about using the science practice of constructing explanations as a way to support the teacher in developing an objective or goal for her instruction. Consequently, although we did still see some instances of instructional leaders using content neutral visions to make sense of science instruction in the later workshops these are now occurring as principals are also using and making sense of the science practices.

Theme 2: Some principals thought of the science practices as separate from science content.

As the principals made sense of the science practices over the workshop series, some of the principals appeared to see the science practices as separate from the science content. Instead of seeing the science practices as an intended learning goal for students, which could be assessed, they saw them as layered on top of the content. For example, at the beginning of Workshop 1, the principals discussed the current science instruction in their buildings. One principal, Paul, stated

> *at least in the experience having for our teachers that, similarly in math, that some of these practice standards are being laid on top of equal amounts of content understanding. To me, not coming from a science background, I'm trying to help them to determine what is most essential as far as content and concepts and try to elevate the practice standards that transcend it all. But I'm not sure to what degree the standards are put out that way, or again, does it seem like a more of a layered on, which is hard to convince teachers that it's okay to cover less content and come to less content understanding*

In this section, Paul refers to the eight science practices as the "scientific practice standards" suggesting that he views them as separate standards compared to the disciplinary core ideas. Since this was how the previous science standards had been written in this state (separate inquiry standards versus disciplinary core idea standards), it is possible he is carrying that understanding over to the new standards. He also explicitly identifies as "not coming from a science background" which was true of many of the principals in the room. In math, the "standards for mathematical practice" are separate from the "standards for mathematical content" so it is also possible that this structure from math is influencing his understanding of the science standards. Another teacher, Kelly, made a similar connection to math and talked about the science practices as being separate from the content about twenty minutes later during Workshop 1. Kelly stated

> *Three years ago, four years ago, we rolled out mathematical practices, and now we have the science practices that aren't exactly the same, K-2 and 3-5. Are we seeing this in something that's going to make it a little more*

convoluted when you have 16 practices teachers are now still supposed to master and overlay on content?

Similar to how Paul talked about the science practices "being laid on top", Kelly discussed how they "overlay on content." Suggesting that at least in this first workshop, they saw them as separate and not a part of the performance expectations for students in the science standards.

Some similar comments about the science practices as being separate from the content also came up in Workshop 2 and 3. For example, at the very beginning of Workshop 2 principals were asked to share their experiences around science instruction since the last meeting. The first instructional leader who volunteered, Tammy, shared the following experience

> *I had a copy of the practices with me just so I could refer to them because I certainly haven't memorized them and I met with the science team at our school and just said that this was something that I was doing. This was helping me to learn the standards as well as the practices and that I would be doing these observations and it was more about what I was seeing.*

In discussing her meeting with her science team, Tammy stated "This was helping me to learn the standards as well as the practices" suggesting that the two were separate. This type of language is similar to what Paul and Kelly used in Workshop 1.

Workshop 3 began with a similar share-out about their science experiences since the last meeting. Another principal, Alison, shared challenges about integrating these into instruction because of assessments and grading.

> *I think, in my building, actually the teachers are really working hard at trying very hard to make sure that these practices are there. I think, in some cases, it's a huge success, and others, they're off the mark a little bit. But, I do think that one of the things we butt up against as we do so much in education is in the end they have to put a grade on the report card. In the end they have to give an assessment that they decided is their common assessment. They're hesitant, sometimes, to totally let go, or to dive into something, into an investigation without making sure that at the end they get to the "that's lovely, but here's the answers that you need to know, and we're gonna get what we need to get." I'm not sure how we change that, there's lots of things that have to change for that to happen. I do think that's part of it, that they only dive so deep. Then they slide back into the well, now you're gonna get a quiz, get a grade, and move on to the next thing.*

Alison's discussion is different in that she does not explicitly talk about overlaying the science practices on the science content. However, her discussion suggests that she does not view the science practices as something that could be assessed or given a grade. Instead, she appears to see the disciplinary core ideas as the assessable piece of the science standards. This suggests a challenge when working with some instructional leaders is they may not see the science practices as integrated in the science standards and really part of the learning goal for students to achieve and be assessed on.

Theme 3: Principals use of the language of the science practices became more frequent and sophisticated shifting from identification or definition to considering the quality and support of the science practices.

As the principals participated in the workshop series, they used the language of the science practices more frequently as they took up the language to make sense of and discuss k-8 science instruction. Yet they continued to grapple with the language of the science practices as it became more prevalent in their discussion of science instruction. During the beginning of the workshop series, their questions and comments were more likely to center around whether an example counted as a science practice or what the definition of that science practice was. Towards the end of the series, those questions shifted to ones about the quality of the science practice or how to best support students or teachers in that science practice. The progression of their language-use illustrates more sophisticated understandings as they grappled with these key elements of science instruction.

Identification or definition of a science practice. During the beginning of the workshop series, particularly Workshop 1, principals grappled with what counted as the different science practices and the differences between the science practices. For example, when examining the new standards, the participants discussed one of the state specific science standards[1]. The 5th grade science standard stated "Compare at least two designs for a composter to determine which is more likely to encourage the decomposition of materials." The discussion in Table 6 illustrates how the principals were grappling with the difference between a model versus an engineering design.

Table 6: Transcript of model versus engineering design in Workshop 1

Jackie	It is interesting, though, that I don't see the design component in this. I see compare to designs. I mean, I suppose you could design by putting someone—couldn't I teach to the standard and give students a model and so I—and not have them do the designing?
Matt	I saw it as developing a model.
Multiple participants	Yeah
Jackie	No, I see the develop a model. But I feel a model is different than design a composter.
Matt	Oh, I see.
Jackie	Maybe it's in my lack of understanding, but my understanding of a model is different than an application.

Jackie was trying to articulate how she saw an engineering design as an application and different than a model, but this was unclear to other participants and she appeared to be grappling with how to articulate even stating that "Maybe it's in my lack of understanding." This question of whether or not something was a model came up a number of times in Workshop 1 and in Workshop 2. Furthermore, Figure 1 from the pre and post surveys illustrates that of the eight science practices "models" were the one the principals were still the least comfortable with at the end of the workshop series.

Approximately three hours later during Workshop 1, the principals analyzed a vignette from a 5th grade classroom focusing on the three sensemaking science practices of analyzing and interpreting data, constructing explanations, and developing and using models. After analyzing the vignette in small groups, when we came back together a number of

[1] The state had "adapted" NGSS rather than "adopted" the standards as is. This included the addition of some state specific standards such as this example.

principals asked about what counted as a model such as “Not strictly a table?” and “Can the tree be a model?”. One participant, Molly, shared how her group had struggled with whether there was a model in the vignette. She stated

> *I’m just thinking about the relationship stuff we talked about earlier. With this one, Facilitator 1 came over and helped us with the model thing, and we’re like, so is there a model? No. Then we had this discussion - well, for this particular investigation, a model wasn’t really necessary.*

The principals were using this language of a model and grappling with when it occurred in science instruction, but also finding it was not always clear.

At the beginning of Workshop 2 after watching a video in which elementary students are investigating membranes again we see principals debating whether an instance is a model or an engineering design similar to Jackie and Matt’s previous conversation in Workshop 1. In Table 7, we see Portia describing how her two partners, Deirdre and Boris had debated this issue.

Table 7: Transcript of model versus engineering design in Workshop 2

Portia	These two were going back and forth *(points to Deirdre and Boris)* over whether or not it was a model or wasn’t it a model. And then now I’m confused was that a model or was that an engineering design because they had—and now I don’t know.
Deirdre	I didn’t feel like it was a model. I was trying to tend away from thinking that it was.
Boris	So biology’s not my strength, but I thought that it was a model because it was replicating how a membrane would actually work.
Portia	I did too until she pushed back and now I’m confused.
Multiple voices	*Laughter*
Portia	Was that a model or more of an engineering design?

After this conversation, Facilitator 1 explains that “you can use a model to predict or explain something else” and uses the example of drawn model that explains how light allows us to see objects of different colors. This idea of what does and does not count as a model is a debate in the field of science education so it is not surprising that these principals were struggling with it. Furthermore, they often cited, as Boris does here with his comment “biology’s not my strength,” that they were not science experts. The principals grappled with the idea that building something or drawing something did not always count as a model and other characteristics (like predicting and explaining) need to be considered.

In addition to models, the principals also asked clarifying questions about some of the other science practices in Workshop 1. For example, after an activity in which principals were sorting different types a questions one principal asked for a definition of the practice of asking questions stating “How is it defined? So a wondering about scientific phenomena feels like scientific thinking, but does that not count?” A couple of minutes later another participant asked “What is asking questions? What are these [refer to examples]?” Other principals asked about the practices of constructing explanations (#6) and engaging in argument from evidence (#7). For example, one principal wanted clarification on the difference between the two stating, "How would you contrast six and seven?" Some of these questions continued into Workshop 2, though the level of detail and nuance in their questions began to shift. For example, in Workshop 2, Matt asked a clarifying question about whether or not 3rd graders were engaged in constructing explanations in a video of science instruction. He asked

> *Can I ask about that practice of number six, the explanations? I'm just wondering about—I was thinking about it differently. When one is generalizing out of some particular experiments of the explanation about the natural world, generally that that would be what an explanation would be whereas what I thought I was seeing was people analyzing and interpreting data about experiments that they did, but they weren't making an explanation, but I might not be getting that right.*

Here we see Matt trying to distinguish between when the "people" (i.e. students and their teacher) were analyzing and interpreting data versus constructing an explanation about the natural world. He talks about it as "generalizing out" but does not yet have the language of thinking of an explanation as *how* or *why* a phenomenon occurs.

Quality and support of a science practice. Over the course of the three workshops, as the principals used the language of the science practices their questions and comments became more nuanced. They shifted from focusing on whether an example was or was not a science practice to discussing the quality of the science practice and how best to support teachers and students with it.

In Workshop 3, the principals were asked to examine vignettes focused on the science practice of analyzing and interpreting data. In discussing the quality of the science practices in these vignettes, the principals talked about the quality of the science practice particularly focusing on how student-directed the examples were and students' abilities to recognize patterns and relationships. For example, Alison focused on whether students were making decisions related to the data analysis stating

> *I was mostly focusing on where they got the information from. Was it just given to them, or did they have to do any finding of information. The second thing I thought of is are they being given the table or graph that they're supposed to be filling in, or are they having a discussion about creating a table or graph*

Here we see Alison really focused on the role of the students in this process and if the students had the opportunity to make decisions about the data and how to organize them. Other principals, like Portia, focused on students' abilities to recognize patterns in comments such as

> *We thought the students were organizing the data, but they did not recognize patterns or relationships. So they were doing a data table or graph, but they weren't being pushed to recognize patterns.*

Portia discussed a challenge students can have in that they are creating a data table or graph, but not really identifying the patterns in that data. Susan discussed the quality of the vignette both in terms of students identifying patterns and the level of student directness. She stated

> *I think it's their ability just to be able to find patterns. Why are you doing this? We're always wanting students to find patterns in the subject area. In a couple there wasn't—there was none of that. There was also allowing the*

students to take control of their learning and make decisions instead of this is the graph you're going to do. One teacher said, you're going to do it.

Across these different quotes from Workshop 3, we see the principals have moved beyond just identifying whether or not a science practice is in a lesson to discussing specific characteristics of that practice (e.g. finding patterns) in relation to the quality of student engagement in the practice.

The principals also provided more ideas on how to support or integrate the science practices into instruction. For example, in Workshop 2 (See Table 8), the principals shared out from a small group discussion in which they read and critiqued a 4th grade lesson targeting NGSS standard 4-PS4-2 that focuses on developing a model to describe that light reflecting from objects and entering the eye allows objects to be seen (NGSS Lead States, 2013)

Table 8: Transcript of critiquing a 4th grade lesson on models in Workshop 2

Andrew	I was saying here at our table that if someone walked into this room and said to all of us draw a model *of a scientific phenomenon that you understand 75% of us would draw the* water cycle because we don't actually have a lot of models that we draw on to explain the natural world because we just don't have scientific backgrounds. So I think it's a really tall order. But I think if you can have the teachers begin to think in terms of the models they want children to build and design backwards from there—it also exposes the teachers themselves about the scientific content.
Jackie	We also did talk about *you could also predict*, so if you did predict how you think—like in the explanation, draw a model that predicts what will happen if you—how that light would get into your eye—if you have a mirror or something and *then kids could draw it and explain it and then they could get at some critiquing*, oh but your model doesn't explain or that doesn't match what you were saying, or oh, that would've been a better job because now I understand. So it doesn't have to be based in a formative assessment of what they know, but they're getting at model and critique.

Similar to previous examples, we see Andrew acknowledging the groups lack of "scientific backgrounds". But we also see Andrew valuing the importance of models and Jackie discussing models in that they need to "predict" and "explain" the phenomena the students are exploring. This language is in contrast to how Jackie discussed models in Workshop 1 (See Table 7), when she could articulate that she saw a model as different than an engineering design but could not clearly articulate how they were different. Furthermore, in this example Jackie is offering an idea of how to incorporate modeling into the lesson that only involved students conducting an investigation and the teacher presenting the related science idea. Jackie stated "if you have a mirror or something and then kids could draw it and explain it and then they could get at some critiquing, oh but your model doesn't *explain* or that doesn't match what you were saying." Jackie is offering a revised idea of how models could be integrated into this lesson plan in that she envisioned students drawing models and comparing and contrasting them with their peers.

Across the workshop series, the principals grappled with the science practices as they thought about how to better support the science instruction in their school. This grappling became more nuanced and sophisticated over time. During Workshop 2, Tessa reflected on using the science practices stating

What I liked about the practices and using that as a way to guide your probing questions on the key levers is that you don't have to be a content specialist to be able to help the teachers to grow in that area… I have never taught science and having taken it forever ago, I can't help you get really specific into the specifics of the science curriculum, but to be able to have these to help them better dig into science in a broader way just feels like it could be more useful in that area.

Tessa's comments reiterate a common thread across the workshops as the principals often noted their lack of knowledge or expertise in science. Yet the science practices offered them a lens to work with teachers that was science specific and help them dig deeper into their instruction.

Discussion

Systemic change for reform efforts such as the NGSS requires support for multiple stakeholders in the educational system, including instructional leaders (NRC, 2015). In our study, engagement in sustained professional development led to significant shifts in the principals' knowledge of the science practices as well as their vision of strong science instruction. Yet the way they made sense of the science practices and how this shift occurred is important to consider for future work with instructional leaders.

Using Other Disciplines and Content Neutral Strategies

Science-specific instructional strategies are essential ingredients of high quality teaching (National Academies of Sciences, Engineering and Medicine, 2019). However, principals often do not have a background or expertise in science. In our study, only two of the principals had degrees in science and many of them often references their lack of science knowledge or expertise. Consequently, as our results suggest they may initially use their understandings from other disciplines (e.g. ELA or math) or content-neutral strategies to make sense of science instruction. It is important to leverage these bridges for building understanding.

Science Practices as a Potential Lever for Leadership

We found that principals in the workshop picked up the language of the science practices relatively quickly, integrating the practices into their conversations about science curriculum and interpreting examples of instruction in terms of the practices. As such, the science practices seem to provide a compelling lever for supporting leaders and their work supervising science. However, it is important to recognize that their initial use of the language did not always demonstrate a deep understanding of the meaning behind the terms. The development of knowledge takes time. Providing the instructional leaders with images of science through videos, vignettes and experiencing science as learners appeared to be productive experiences. Principals took up the language of the science practices in more nuanced and sophisticated ways as they grappled with what the science practices mean for instruction.

Summary

High capacity instructional leadership is essential for supporting the shifts in recent science standards such as the focus on science practices (National Academies of Sciences, Engineering and Medicine, 2019). If we want to design effective tools for instructional leaders to support them in changing their practice, we need to develop tools that meet their needs given their limited backgrounds in science and the wide range of tasks that they need to accomplish within their schools. Instructional leaders with an understanding of the goals envisioned within three-dimensional science classrooms can better support science innovations in the classroom (National Academies of Sciences, Engineering and Medicine, 2019).

References

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082–1112.

Cobb, P. & Jackson, K. (2012). Analyzing educational policies: A learning design perspective. *Journal of the Learning Sciences, 21*(4), 487-521.

Danielson, C. (2002). *Enhancing student achievement: A framework for school improvement*. Association for Supervision and Curriculum Development (ASCD). Virginia: Alexandria.

Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook of research on teaching*. (pp. 119-161). New York: Macmillan.

Fishman, B. Marx, R. W., Blumenfeld, P., Krajcik, J & Soloway, E., 2004. Creating a framework for research on systemic technology innovations. *The Journal of the Learning Sciences, 13*(1), 43-76.

Johnson, R. B. (1997). Examining the validity structure of qualitative research. *Education, 118*, 282-292.

Lowenhaupt, R. & McNeill, K. L. (in press). Subject-specific instructional leadership in K8 Schools: The supervision of science in an era of reform. *Leadership and Policy in Schools*.

McNeill, K. L., Katsh-Singer, R. & Pelletier, P. (2015). Assessing science practices – Moving your class along a continuum. *Science Scope, 39*(4), 21-28.

McNeill, K.L., Lowenhaupt, R., & Katsh-Singer, R. (2018). Instructional leadership and the implementation of the NGSS: Principals' understandings of science practices. *Science Education, 102*(3), 452-473.

Miles, M., Huberman, A. M., & Saldaña, J. (2013). Qualitative data analysis: A methods source book (3rd edition). Thousand Oaks, CA: Sage.

National Academies of Sciences, Engineering, and Medicine 2019. Science and Engineering for Grades 6-12: Investigation and Design at the Center. Washington, DC: The National Academies Press.

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

National Research Council (2015). *Guide to implementing the Next Generation Science Standards. Committee on Guidance on Implementing the Next Generation Science Standards*. Board on Science Education, Division of Behavioral and Social Sciences and Education, Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC. The National Academies Press.

Overholt, R., & Szabocsik, S. (2013). Leadership content knowledge for literacy: Connecting literacy teachers and their principals. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *86*(2), 53-58.

Schwarz, C., Passmore, C., Reiser, B.J. (2017). Moving beyond "knowing about" science to making sense of the world. In Schwarz, C., Passmore, C., Reiser, B.J. (Eds.). *Helping students make sense of the world using next generation science and engineering practices*. (pp. 3-22) Arlington, VA: National Science Teachers Association Press.

Sergiovanni, T. J., Starratt, R. J., & Cho, V. (2013). *Supervision: A redefinition*. New York: McGraw-Hill, Incorporated.

Sherin, M. G. & van Es, E. A. (2005). Using video to support teachers' ability to notice classroom interactions. *Journal of Technology and Teacher Education*, 13(3), 475-491.
Spillane, J. P., White, K. W., & Stephan, J. L. (2009). School principal expertise: Putting expert-aspiring principal differences in problem solving processes to the test. *Leadership and Policy in Schools*, *8*(2), 128-151.