# Assessing Curriculum for NGSS Alignment: Oversimplification of Cognitive Load and Separation of the Three Dimensions

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**Abstract**

The adoption of the Next Generation Science Standards (NGSS) requires many teachers to drastically change both the curriculum they use and their methods of instruction. A number of curricular materials were released shortly after the NGSS claiming to be aligned with this new vision, but there are continued questions about the degree to which available curricula truly reflect the shifts required by the NGSS. This study analyzed one such middle school curriculum and its implementation in two classrooms to determine the degree to which it was designed to meet the vision of the NGSS. We found that the curriculum oversimplifies the complex vision of science learning required by using natural phenomena primarily as hooks or examples, creating lessons in which students engage in core ideas and science practices but separately in service of different goals, by placing the cognitive load on the teacher to do most of the sensemaking rather than the students, and by having the teacher build coherence between the lessons rather than the students. These methods of oversimplification inform the way we think about curricular design, implementation, and teacher learning in the NGSS era.

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## Problem

The Next Generation Science Standards (NGSS) represent a new approach to science education that equally values the practices of how scientists create knowledge with the knowledge they create (National Research Council, 2012; NGSS Lead States, 2013). Implementation of these new standards requires transformation of both the science curriculum and the instruction that implements that curriculum; this is not a set of simple tweaks to current practice, but rather a re-imagining of science instruction (Osborne, 2014). High quality curricular materials can support this transition (Penuel, Harris, & Debarger, 2015), but the speed with which many supposedly NGSS-aligned curricula were released after the standards were published calls into question the true quality of many of these materials. In addition, even teachers who are provided with well-aligned NGSS curriculum may make instructional choices and modification that revert back to traditional instruction (McNeill, González-Howard, Katsh-Singer, & Loper, 2017). Therefore, more work needs to be done to analyze available curricula that claim to be NGSS-aligned, how instruction from those curricula embodies the goals of the NGSS, and the ways in which implementation may work against this new vision for science education. In order to address this issue, this study focuses on one commercially available curriculum and its implementation by two sixth-grade teachers. Our research questions for this study were: How does a commercially available curriculum align with key features of the NGSS as written and implemented? What does this alignment tell us about how to write and analyze future curricula for the NGSS?

## Theoretical Framework

To assess both curriculum and instruction for alignment to NGSS, we propose four key elements of curriculum and instruction that is designed in service of the core goals of the NGSS: phenomenon-based, three-dimensional, student-centered, and coherent. Curricula and instruction that have these elements are likely, therefore, to be NGSS-designed.

The term *phenomenon-based* means that students engage in extended sensemaking around a natural or constructed phenomenon that they can observe either directly or through the use of technology (BSCS, 2017; Krajcik, Codere, Dahsah, Bayer, & Mun, 2014; McNeill & Berland, 2017; National Research Council, 2015). The important idea here is that the phenomena provide a context for which students learn and instruction focuses students on attempting to explain what they have seen rather than complete tasks only loosely connected to the real world (Berland et al., 2016; National Research Council, 2015).

We define *three-dimensional* as the meaningful integration of disciplinary core ideas, crosscutting concepts, and science and engineering practices. This is one of the key innovations called for by the *Framework* because it repositions science as an understanding of what scientists know and how they know it rather than a simple collection of facts to be memorized (National Research Council, 2012). At its best, NGSS-aligned curriculum and instruction asks students to come to an understanding of a key idea through a science practice and informed by (or informing) a crosscutting concept (BSCS, 2017; Krajcik et al., 2014; National Research Council, 2015).

To truly engage all students in *student-centered* science, students must be positioned as knowers and given opportunities to act as active co-constructors of scientific knowledge while engaging with each other and various resources (Putnam & Borko, 2000; Stroupe, 2014). This focus on the student includes asking students to engage in discourse communities to construct ideas (Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; McNeill & Berland, 2017), and encouraging writing and group assignments that position students as active contributors to science as a developing practice (BSCS, 2017).

Finally, we propose that NGSS-aligned curriculum and instruction must demonstrate *coherence* over time at the level of lessons and lesson sequences, positioning learning as part of a storyline that students build over time and allows students to explain *what* they are figuring out at any point in the class and *why* it is important they do that figuring out (BSCS, 2017; Zivic et al., 2018). Curriculum can achieve this coherence by building in steps in which lessons ask students to look back at what they have done so far and put multiple ideas together in service of explaining a phenomenon or solving a problem. At the instructional level, teachers can include these navigation pieces into the beginning and end of their lessons, regularly asking students to explain what they know so far and what they need to figure out next (BSCS, 2017). Curriculum and instruction that consistently support this small-scale coherence will build towards the year-to-year coherence initially discussed by the NGSS and related policymakers.

## Methods

### Context

This study took place in an urban public-school district in the northeastern United States. In order to facilitate more NGSS-aligned instruction in the classroom, the districted had adopted new curriculum units in K-8 classrooms for the 2017-18 school year. These units were from the Full Option Science System (FOSS) Next Generation, a commercially available curriculum that reports to be aligned with the NGSS. This study examined the FOSS Human Systems Interactions unit that was enacted in the 6$^{th}$ grade in the district. The study took place in the classrooms of two teachers in the same district: Mr. Nichols and Ms. Kearny[1]. Both teachers were teaching the Human Systems Interactions unit for the first time.

### Data Collection and Analysis

Previous work as established the importance of analyzing tasks both as they are designed and implemented to assess their impact on student learning (Kang, Windschitl, Stroupe, & Thompson, 2016). This study builds on those ideas by examining one curriculum as designed and as implemented in two different classrooms. We began by an analysis of the curriculum document itself, including the teacher guide and accompanying support materials. Throughout the teacher guide, the curriculum points out areas that it claims to be supporting student engagement in the science practices and crosscutting concepts required by the NGSS. Based on an initial analysis of the materials, we identified two lessons that we felt were most likely to provide students with opportunities to engage meaningfully in the science practices to come to an understanding of a core idea.

After selecting the two lessons, we did an in-depth analysis of the curriculum for both of those lessons, looking for ways it matched with the four key features of NGSS-designed curricula. Next, we video recorded both Mr. Nichols and Ms. Kearny deliver those lessons. Finally, at the end of both the entire unit, we conducted semi-structured interviews with both teachers to discuss their experiences implementing and reflections on the unit.

[1] The names of the teachers, as well as all student names in this paper, are pseudonyms.

The two lessons we analyzed are summarized in Table 1. The first one, which we call the “Patient Diagnosis” lesson takes place about one-third of the way though the unit. The lesson asks students to discuss the symptoms of a fictional patient they had been introduced to earlier in the unit. The students read information about three disease and then are asked to engage in argumentation about which disease is the most likely diagnosis for the patient. Next, the students discuss the question, “how do human organ systems interact?” The second lesson, which we call the “Touch Investigation” lesson, takes place near the end of the unit at the beginning of a set of lessons on the nervous system. In this lesson, students follow a set of instructions to collect data to determine if the fingertips or knuckles are more sensitive, and then do a reading about the nervous system and the sense of touch.

Table 1: *Summary of Focus Lessons*

| Lesson Title | **Patient Diagnosis** | **Touch Investigation** |
|---|---|---|
| Location in Unit | Lesson 13, 38 | Lesson 33/38 |
| Instructional Activities | Choose one of three possible diagnoses of a fictional patient<br><br>Write and discuss how human body systems interact | Investigate the sensitivity of fingertips vs. knuckles<br><br>Lecture and reading on sensory neurons and mechanoreceptors |

In order to assess both the curriculum and instruction for NGSS-design, we developed a coding scheme for each element on a scale from 0-2. The first author read the curriculum for the two lesson plans and came up with initial codes for all four elements in each lesson. He then met with the other authors to discuss these codes and the evidence he had collected for them to finalize the coding. In parallel to this analysis, the first and second authors independently watched the video of both lessons as implemented by both teachers and coded them for each element. The initial interrater reliability was 0.81. They then came together to compare the codes and discuss any discrepancies to arrive at the final 16 codes (one code per element per lesson per teacher). The coding scheme is shown in Table 2 below.

Table 2: *NGSS-Design Coding Scheme*

| **Element** | **0 (not NGSS-designed)** | **1 (somewhat NGSS-designed)** | **2 (more NGSS-designed)** |
|---|---|---|---|
| *Phenomenon-based* | Teacher focuses on skills or content without a connected phenomenon | Phenomenon used as hook or example but does not as a driver of goals or activities across the entire lesson. | A conceptually rich phenomenon is used as the central driver of the goals and activities of the lesson. |
| *Three-dimensional* | Students engage in 0 or 1 dimension<br><br>*Note: to get credit for CCC, the CCC and its connection to the lesson must be explicitly discussed with or by students* | Students engage in 2 dimensions | Students engage in all 3 dimensions |

| | | | |
|---|---|---|---|
| *Student-centered* | Lesson is mostly teacher talk and/or thinking | Students engage in hands-on activities but almost all cognitive work has already been done by teacher OR Students discuss ideas but teacher maintains primary control over discussion flow and connections | Students are actively constructing their understanding during the lesson OR Students discuss ideas as a group with little direct control by the teacher. |
| *Coherent* | There is no attempt to connect ideas in lesson to past or future lessons. | The teacher plays the main role in connecting the lesson to past and future lessons. | Students are the primary ones making sense of how the lesson is connected to past or future lessons. |

We used the coding scheme to highlight the ways in which the curriculum as written deviated from primary goals of the NGSS and how those deviations carried into instruction. Based on that coding, we constructed themes to summarize how the curriculum and instruction addressed or failed to address each key feature.

## Findings

Neither the initial written curriculum nor the enactment of the curriculum demonstrated that they were designed to be aligned with the NGSS (see Table 3 for summary of codes). But analysis of each element yielded themes that can inform how current curricula and instruction can oversimplify this vision.

Table 3: *Summary of Findings for all Four Elements*[a]

| **Element** | **Curriculum** | **Mr. Nichols** | **Ms. Kearney** |
|---|---|---|---|
| Phenomenon-based | 1, 1 | 2, 0 | 1, 1 |
| Three-dimensional | 1, 1 | 0, 1 | 1, 1 |
| Student-centered | 1, 1 | 1, 1 | 1, 1 |
| Coherent | 1, 0 | 1, 0 | 1, 1 |

[a] Note each cell includes 2 scores for the 2 separate lessons that were coded.

First, we found these lessons use *phenomena as hook or example* to illustrate a topic rather than as a central driver of activities for students as teachers. Secondly, the lessons were *two-dimensional but separated*, meaning students engaged in a SEP and learned about a DCI, but did not use the SEP in order to learn more about the DCI. Third, we found that these lessons placed the *cognitive demand on the teacher, not students*, meaning that the students engaged in some thinking, but it was mediated by the curriculum or teachers in ways that limited students' meaningful decision-making during lessons and positioned the teacher rather than students as the primary holder of knowledge in the classroom. Finally, the *coherence was driven by the teacher, not students*. When the lessons were connected to previous or future lessons, that was done by the teacher as summary or explanation, rather than by the students themselves. This limited the likelihood that students were making sense of these connections and seeing them in the work they did in the classroom. We next discuss each theme in more detail providing examples from both the curriculum and teacher enactments to illustrate these findings (see Table 4).

*Table 4: Summary of Themes Emerging from Lesson Analysis*

| Element | Theme |
|---|---|
| Phenomenon-based | Phenomena as hook or example |
| Three-dimensional | Two-dimensional, but separated |
| Student-centered | Cognitive demand on teacher, not students |
| Coherent | Coherence driven by teacher, not students |

## Phenomena as Hook or Example

### Curriculum analysis.

Although both lessons of the curriculum included a phenomenon for students to explore, neither of the phenomena drove the learning activities, serving instead as a hook to attract student interest or an example of the core idea of interest.

The patient diagnosis lesson uses the phenomenon of a sick patient that it asks the students to diagnose as part of a series of lessons on the organization and interaction of body systems. Although the curriculum asks the students to engage in argumentation about the possible diagnoses, its main objectives demonstrate that figuring out the phenomenon is not the primary learning goal of the lesson. The focus question of the lesson is listed as "how do human systems interact" (p. 109), which can be answered without diagnosing the patient. In addition, the bulk of the lesson, which is spent on reading about three possible diseases and asking students to match the disease to the patient's symptoms, does not actually contribute to answering this focus question. Rather, students can match what they have read with the information previously provided about the patient without coming to an understanding of the broader objective about how systems interact.

Rather than using the phenomenon as a hook, the touch investigation lesson instead uses its phenomenon as an example of a particular idea. While this use better integrates the phenomenon into the lesson, it is still does not motivate students' need to learn about the natural world. The lesson makes this framing clear by beginning with an explicit focus on the sense of touch. The first thing it asks the teacher to do is, "project or write the focus question on the board, and have students write it in their notebooks: *how does the sense of **touch** work in humans?*" (p, 174). This beginning with the science topic already frames the class around the idea rather than a phenomenon. Later in the lesson, the curriculum introduces the phenomenon of differential sensitivity of fingertips and knuckles as an example by saying, "tell students that they will work in pairs to explore the sense of touch in their fingertips and knuckles" (p. 174). Once students make the claim that fingertips are more sensitive than knuckles, however, that phenomenon is abandoned in favor of discussion and reading about sensory receptors generally without reference to the knuckles and fingertips again. Therefore, this lesson is driven by the topic of touch with a phenomenon being used as an example rather than truly driven by the phenomenon itself.

### Ms. Kearney's implementation.

Ms. Kearney's implementation of the two lessons tracked closely to the ways they were presented in the curriculum itself. During the patient diagnosis lesson she used the phenomenon of the sick patient as a hook for argumentation and then abandoned it during discussion of the ways that systems interact. For the first 27 minutes of the hour-long class, Ms. Kearney asked her students to attempt to diagnose the disease, which students did by matching the patient's symptoms to information they had been given about the diseases, saying things like "It says there was no rashes on her, so it can't be Lupus. HPS [Hantavirus Pulmonary Syndrome] matched all the things up there [gesturing to poster with list of symptoms].” Students never discussed why any of the diseases would cause the patient’s symptoms suggesting a lack of depth in exploring the explanation of the phenomenon of interest. When they finished the argumentation, Ms. Kearney transitioned towards the next phase of the lesson by saying, “we need to do a little more research, but before we do that, we need to go back to the focus question, which was on page 32 of your notebook.” While students were engaged in the diagnosis discussion, they did not use that discussion to develop their understanding of the focus question, and after Ms. Kearney transitioned to the focus question, neither she nor the students mentioned the patient for the rest of the class. These uses of the phenomenon demonstrate how it was used more as a hook for student interest than a true driver of the entire lesson.

In the touch investigation, Ms. Kearney expanded the phenomenon that was written in the curriculum by introducing the idea of how blind people are able to read braille. Despite this addition, she still uses the phenomenon as an example of the sense of touch rather than an observation to be figured out. Ms. Kearney introduced the lesson by saying, “We’re going to move on to the sense of touch and how it interacts with all the body systems that we have,” thereby following the lead of the written curriculum in framing the entire lesson around the sense of touch rather than a natural phenomenon. Ten minutes into the class, when Ms. Kearney brought up the phenomenon of reading braille, she did so by saying, “We’re going to do a little experiment…why do people who are blind read braille with their fingers instead of their elbow?” This framing of the phenomenon as part of a “little experiment” demonstrates how it is an example of the lesson’s topic rather than the focus of the lesson. Students were able to complete this experiment in order to illustrate an idea about touch rather than use this interesting phenomenon to motivate their discussions of the core idea.

**Mr. Nichols’ implementation.**

Unlike Ms. Kearney, Mr. Nichols demonstrated a wider range of use of the phenomenon as a central driver of his lessons, but his enactment demonstrates the way that external demands of teaching might impact the degree to which phenomena drive instruction. During his enactment of the patient diagnosis, Mr. Nichols spent the entire 50-minute session supporting his students’ argumentation about the patient’s diagnosis, but in order to achieve such focus on the phenomenon, he did not include discussion of the focus question at all. Mr. Nichols began the class by saying, “We as a class are going to come up with consensus with one disease that we think it is to suggest to the doctor and the patient,” thereby framing the lesson as focused around this phenomenon. He then spent 10 minutes discussing norms of argumentation, 20 minutes allowing the students to discuss in small groups, 22 minutes of whole group share out and discussion, and one minute of him wrapping up. At the end, he previewed the next class by saying, “The next step is a little bit more information from the doctor and regroup on this conversation briefly, and then after that the doctor is going to reveal a few more symptoms and explain her diagnosis of what the patient has. She’ll obviously have evidence to support her claim as well.” The entire lesson, then, was motivated by diagnosing a patient, but there was no mention of the DCI or the focus question written into the curriculum about the ways that human body systems interact. Therefore, Mr. Nichols demonstrated a strong focus on the given phenomenon, but at the expense of targeted DCI.

During the touch investigation, Mr. Nichols framed the lesson as a series of activities around the topic of the sense of touch. Because of this focus on disconnected activities, it was unclear the degree to which the phenomenon of differential sensitivity of the fingertips and knuckles was even highlighted or connected to the sense of touch beyond the fact that they both involved touching. When introducing the investigation 20 minutes into the class period, Mr. Nichols said, "we're going to do an activity investigating the sense of touch on two locations in your hand," framing the investigation as an activity about touch without highlighting the involved phenomenon at all. The conversation after the activity focused on students sharing data about which location, the fingertip or the knuckle, was more sensitive, and Mr. Nichols, rushed for time, finished that analysis by saying, "I was going to say 'why do you think the fingers are more sensitive than the knuckle' but you already answered it, so I'm going to go on to show you this [simulation of mechanoreceptors]." By emphasizing this data analysis here, Mr. Nichols did not open up space for students to connect their claims back to a natural phenomenon, reinforcing the idea that the investigation was more of an activity about touch rather than an exploration of something that occurs naturally.

## 2-Dimensional, but Separated

### Curriculum analysis.

Both lessons in the curriculum asked students to engage in two dimensions: a science practice and a disciplinary core idea. Although the students were addressing questions of systems, which is a crosscutting concept, the curriculum was not given credit for incorporating that dimension because it did not explicitly call out that ideas as a CCC nor ask students to use their understanding of systems to make sense of the DCI or practices. Both lessons involved a practice and a DCI, but they separated those two dimensions, spending a portion of the lesson engaging in a practice and then using more traditional means to figure out a DCI. In this way, the lessons as written do not truly engage students in figuring out a core idea through the use of a practice.

As discussed above, the patient diagnosis is written to split time between two tasks. The first half of the lesson asked students to "engage in argumentation" by "work[ing] together with the rest of the class to make a recommendation to the doctor about what they think is causing the patient's symptoms" (p. 107). The second half asked them to "answer the focus question…how do human organ systems interact?" (p. 109). During the first half, students are asked to use evidence from the readings and list of symptoms to make claims about the diagnosis and judge competing claims, demonstrating involvement in the practice of argumentation. But the results of this argumentation are unnecessary for answering the focus question, allowing students to think about the core idea without a science practice.

The touch investigation also split up the dimensions, but it asked students to analyze the data from an investigation and then separately to memorize vocabulary without the investigation or its analysis motivating a need for that vocabulary. After collecting data about the sensitivity of fingertips and knuckles, the students are asked to determine "which is better for sensing braille dots, your fingertips or your knuckles?" (p. 175). Here, the curriculum asked students to engage in analyzing and interpreting their data, but then the students are asked "why do you think fingertips are more sensitive than knuckles" before moving on to "introduce sensory receptors" (p. 175) and then read about sensory receptors (p. 176). This transition does not use the data analysis to motivate a need for this new vocabulary nor does it connect back to the larger DCI about the interconnection of human systems.

In both lessons, the portion of the lesson that is driven by the phenomenon motivates use of a science practice, but just as the phenomenon is not a central driver of the work of the students, neither are the science practices. As a result, both the phenomenon and the SEPs are abandoned when the lesson moves on to traditional forms of memorizing information about a DCI. In structuring the lessons this way, the curriculum did engage students in two dimensions of science learning, but did so separately and to achieve disparate goals.

**Ms. Kearney's implementation.**

Ms. Kearney's implementation made this distinction clear in the way she and her students transitioned between the two phases of each lesson. In the patient diagnosis lesson, Ms. Kearney ended the whole group conversation about the diagnosis by saying, "so we're going to go back now that you have more knowledge and ask the same question we did before: how do human body systems interact?" She immediately asked some students for an example, and a student responded that the skeletal and digestive systems are connected because "the bones have the teeth, and the teeth will chew the nutrients and break down the foods for the digestive system." Ms. Kearney's transition did not make clear why students would need to use their diagnosis-based argumentation to answer the focus question. The student response also demonstrated that student did not see a connection between those two activities. While the teeth are reasonable way for a sixth-grade student to connect the skeletal and digestive systems, it is unrelated to the cardiopulmonary diseases the students had just discussed.

In the touch investigation lesson, Ms. Kearney facilitated a data analysis conversation that had the potential to integrate the analysis with ideas about the interaction of the nervous system with other systems, but did not make that transition. During a whole group discussion of the investigation, the following exchange took place:

*Ms. Kearney*: Darren, what about your group? What other ideas did you have beside your evidence from your test that fingertips were better for reading braille? Why do you think the fingertips are better?

*Darren*: They have more nerve cells inside.

*Ms. Kearney*: You think there's more nerve cells inside?

*Alvin*: I think the fingertips have got more nerve cells to accommodate what we need to use.

*Ms. Kearney*: For what its job is.

*James*: I think the knuckles are like; there's bones there. You can feel the bones beneath, but your fingers you can't really feel as much because there's more nerves there.

*Ms. Kearney*: The other group over there thought it was because the bones were interfering. Well, I hear some people mention, so I'm going to skip to this right now. So I heard some people mentioning nerves underneath, and in case you've never seen or look what a nerve is, this diagram here is. Up here is your skin. Down here is the fat, those yellow bubbles are fat. So in between the fat and your skin are all these nerves, and each nerve has a different job. … [she continues to display and explain a diagram of mechanoreceptors].

Here, the students used the data analysis to make some initial claims about the connection between form and function – "the fingertips have got more nerve cells to accommodate what we need to use" – and the ways that the skeletal and nervous systems interact – "you can feel the bones beneath, but your fingers you can't really feel as much because there's more nerves there." Instead of picking up on these or extending the data analysis to further explore form and function, Ms. Kearney keys in to the mention of the word "nerve," and uses this to define for students the structure of nerves and mechanoreceptors, as was written in the curriculum. This moment of transition is provided no support in the curriculum despite its vital importance in integrating the dimensions together in this lesson. Ms. Kearney's exchange here demonstrates the rich discussions that were possible and might have happened if the teacher had been better supported to watch out for and facilitate them.

**Mr. Nichols' implementation.**

Like Ms. Kearney, Mr. Nichols was not able to connect the components of the lessons to create a three-dimensional learning experience. He demonstrated increased concern for developing his students' abilities to carry out the science practices, but in doing so limited their opportunities to develop understanding of the relevant core ideas.

When Mr. Nichols implemented the patient diagnosis lesson, he was concerned about his students' ability to engage in effective oral argumentation because that was a new skill for his students. Therefore, he spent 15 minutes at the beginning of class providing sentence starters and discussing norms for productive small group conversation. As a result, he ran out of time to discuss the question of how human body systems interact. Therefore, we ranked his instruction as only one-dimensional, as the lesson focused on supporting students' argumentation skills without a connecting DCI. This one-dimensionality was influenced by the separation of the argumentation from the exploration of the DCI. If the curriculum had integrated these two dimensions, Mr. Nichols may have been able to engage his students in both while also taking the extra time he felt he needed to support his students' argumentation.

In the touch investigation lesson, we also saw a focus on the practices limit the time available for the students to come to strong understandings of the DCIs. After spending 20 minutes discussing senses and the sense of touch, Mr. Nichols gave students 30 minutes to collect data, which only left 10 minutes to analyze the data and connect it to relevant DCIs. Even in that limited conversation time, however, his students demonstrated strong ability to make claims based on evidence they had collected. For example, one student said, "I got 8 correct for the finger and I got 5 correct for the knuckles….it says that I have more sense receptors in my fingertips than in my knuckles." Unfortunately, this was the extent of the data analysis, as Mr. Nichols had to then end class. Therefore, neither Mr. Nichols nor his students connected this claim to relevant crosscutting concepts like structure and function or use the claim to try to figure out something about the interrelationship of human body systems. Therefore, here again there was strong support for the science practices, but isolated from their primary purpose of coming to understand something about the natural world.

## Cognitive Demand on Teachers, Not Students

### Curriculum analysis.

Curriculum that is truly student-centered allows the students to make meaningful decisions about both the activities they engage in and the conversations they have about those activities. Those decisions about what to investigate and how or what to share, when, and with whom are part of the intellectual work of doing science as asked for in the NGSS. In the two analyzed lessons, the curriculum already makes many of those decisions for the students, thereby reducing the cognitive demand on the students.

In the patient diagnosis lesson, the curriculum asks students to engage in multiple discussions, but the results of none of those discussions has an impact on the lesson, thereby minimizing the degree to which they are student-centered. At the beginning of the lesson, the students are asked the following, "Think about the symptoms of the patient we are trying to diagnose. Do they affect any of the organ systems you have researched?" (p. 106). This conversation is intended to produce a list matching the symptoms and various systems, but nothing is done with that list, and students do not get to make any decisions based on it. The next whole-class discussion in the lesson involves the teacher reviewing the relevant vocabulary with the students. Again, this is written as a time for the teacher to explain information to the students, rather than students actively asking for terms to describe the information they have been working with or directing the review as relevant to the argumentation they had just completed.

While the patient diagnosis lesson demonstrated this theme in its treatment of conversations, the touch investigation's treatment of the activities revealed another way the curriculum took the cognitive load off of students. In the second lesson, the students are asked to determine whether the fingertips or knuckles are more sensitive, but provided exact step-by-step directions to answer this question, thereby removing students' ability to think deeply and make meaningful decisions about this investigation. In the follow-up lesson, the students are asked to collect data to determine if the receptive fields in the fingertips and knuckles are large or small, but once gain the curriculum provides all of the instructions as to how to test this question, and when the students are given choice to design an investigation, they have learned only one reasonable method to conduct the investigation, effectively eliminating any student-directed choice in investigation planning.

**Ms. Kearney's implementation.**

Ms. Kearney's implementation highlighted the way that the teacher was encouraged to take on the cognitive load during discussions in both lessons. During the patient diagnosis, all of the whole-class conversations were mediated through Ms. Kearney, and she maintained control over who spoke, when, and about what. Even when the students were sharing out their small group discussions about the diagnosis of the patient, Ms. Kearney maintained control over who spoke, resulting in the students speaking to her rather than each other. In this way, Ms. Kearney took on the cognitive load of determining how the pieces of the conversation connected together in the lesson and the results of the lesson, rather than requiring students to use the conversations to make meaningful decisions about the class.

In the touch investigation lesson, Ms. Kearney demonstrated another way in which she took on the cognitive load by taking on the role of determining what gets taken up and what gets ignored during discussion, identifying correct answers and rejecting incorrect ones. For example, after analyzing the investigation data, this exchange took place:

*Ms. Kearney:* How does the nerves send a message?
*David:* The blood?
*Ms. Kearney:* You think it goes in the blood? The message goes in the blood? Peter?
*Peter:* I think it sends an electronic pulse.
*Ms. Kearney:* Electronics. So you have an electronic system in your body?
*Peter:* Yep
*Ms. Kearney:* What system would be equivalent to the electronic system?
*Peter:* Nerves
*Alvin:* Electrolytes!
*James:* Nerve system
*Ms. Kearney:* You think it's the nervous system? The nerve system, nervous system. Well, we have a little video.

In this exchange, Ms. Kearny is asking her students their ideas, but she does the primary evaluation of those ideas, disregarding the incorrect ones and pursuing the correct ones. In directing the conversation this way, Ms. Kearny takes on the primary cognitive demand and does not allow her students to critically evaluate and discuss their peers' ideas.

**Mr. Nichols' implementation.**

Mr. Nichols' implementation mirrored closely with Ms. Kearney's. His first lesson demonstrated how he took on the cognitive load in processing the discussions of the class and the second highlighted a way in which he took on the cognitive work of determining how exactly students would engage in the investigative activity. In the first lesson, Mr. Nichols led three whole group discussions: one about argumentation norms and sentence starters, one in which each group shared the results of their conversation, and one in which students spoke across the small groups to try to agree on a diagnosis. For all three of these conversations, all of the talk flowed through Mr. Nichols and he determined who spoke, what they spoke about, and the evaluation of their contribution. In fact, most of the time most students were listening quietly during these portions of the lesson. For example, when Mr. Nichols introduced the third whole group discussion in which he asked students to talk across groups, the following exchange took place:

*Mr. Nichols:* Just having listened to people, let's open up now where I will stop talking and hopefully you all will start talking because we need to come up with one recommendation for the doctor of what we think it is. And clearly we have a few different recommendations. We have hantavirus, we have lupus, and we have Lyme disease, so that's all of them…Hopefully you engage in this and this involves you talking to the other groups. Or just reiterate yourself to the class, I think the patient has this and this is why, and somebody in the class can respond to that. Let's open it up. Right now, real quick. Kareem. So please everyone, active listening to the students. Right now, Kareem's got the floor.

*Kareem:* Katie said that when you have lupus and Lyme disease you have rashes, but she didn't experience that, so that's why we looked more deeply into the hantavirus.

*Mr. Nichols:* Kareem, that's great. So what does that make you think when you say that?

*Kareem:* It makes it easier, because when you have lupus and Lyme you have rashes, but when you have the hantavirus you don't have rashes.

*Mr. Nichols:* That's a great point. Why does that make you? Jennifer?

*Jennifer:* I feel like what he's trying to say is if you have lupus or Lyme you would have rashes, but the patient explained that she's just having inner body issues rather than outer issues, so that's why we don't think she has Lyme or lupus because she has no signs of redness or rashes.

*Mr. Nichols:* So, Jennifer, that group made an argument based on the evidence they provided. Does that help support your theory or change your mind? Did you originally think hantavirus?

*Jennifer:* Well, at first we thought lupus, but then we thought about the rashes.

*Mr. Nichols:* Great, so their evidence supported your thinking. And I think they want to respond to you all, or at least follow up.

*Eliza:* Well, mine's actually something about what Ericka's group said.

In this exchange, even as he asked students to build on each other's ideas, Mr. Nichols responded to students and made connections between groups for them rather than allowing students to do that themselves. In structuring the talk this way, Mr. Nichols ensured that each of the pieces that was written in the curriculum was completed, but he took primary responsibility for the conversation in the classroom rather than allowing students to construct meaning through discourse.

When Mr. Nichols implemented the touch investigation, he emphasized this removal of cognitive load from the students by spending more time explaining and demonstrating to students how to complete the task than he gave them to actually do it. In addition, part-way through data collection, he stopped the students saying "please stop collecting data. There seems to be a lot of…maybe I wasn't clear but I did say it when you were talking…you, on your paper should record your partner's results." This interjection in the middle of the investigation emphasized that Mr. Nichols, rather than the students, was the primary knower in the room and that he had done most of the cognitive work of planning and carrying out this investigation. Therefore, even though the students were physically collecting data, they were not forced to do significant scientific thinking about how or why they were collecting those data.

## Coherence Driven by Teacher, Not Students

### Curriculum analysis.

The two focus lessons took parts in different parts of the unit. Lesson 1 was in the middle of a set of investigations, and lesson 2 took part as the unit turned towards a new topic and set of investigations. Because of this difference in positioning, the two lessons presented different challenges in terms of maintaining coherence: lesson 1 needed to encourage students to connect the conversations to previous areas of study while lesson 2 needed to motivate the move to a new topic of study. Despite this difference, both lesson plans demonstrated an overreliance on teacher- rather than student-drive coherence.

During the beginning of the first lesson, the teacher is directed to remind students about the patient that they had previously discussed and think about her symptoms in an attempt to connect the work they had just done researching body systems to the phenomenon that started the unit. At the end of the lesson, the teacher informs students that the next day they will hear from the patient's doctor to understand her diagnosis. Both of these directions rely on the teacher being the exclusive navigator between lessons and do not allow students an opportunity to review what they know, build agreement on what they need to do next, and connect the learning activities themselves.

The second lesson also suffers from a lack of student-driven coherence, but here the curriculum struggles to bridge across topics. The lesson begins with the teacher posing the question "how do we as living organisms interact with the world around us?" (p. 173). While that might provide a logical introduction to a phenomenon related to the sense of touch, it has nothing to do with the previous topic they had just finished, which was aerobic cellular respiration. As a result, this transition does not support coherence between this lesson and the previous one for either teachers or students. The lesson ends with two readings about touch and sensory receptors, which were topics from the lesson, but does not include time for students to discuss what they want to know next after completing the investigation. Therefore, the students are not given time to connect to the next lesson or discuss what further ideas they need to uncover about touch. Overall, the second lesson has much weaker supports for coherence written in to it than the first, lacking clear connection to the previous lessons and not providing students an opportunity to summarize their learning and look forward at the end. This difference could be due to the placement of the lesson as the beginning of a new topic, demonstrating the difficulty of connecting different topics into one cohesive learning progression, especially when not framed in the context of an anchoring phenomenon across the entire unit.

### Mr. Nichols' implementation.

Both of the observed teachers' instruction followed the pattern written into the curriculum. When ideas are connected across lessons, that coherence was established and driven by the teacher, rather than the students. In his first lesson, Mr. Nichols worked to connect the lesson with the previous and next by summarizing those connections for his students rather than encouraging them to build the connections themselves. At the beginning of class, Mr. Nichols said, “Yesterday you finished researching the different diseases, lining it up with the symptoms the patient expressed. So you have information about the symptoms the patient is claiming to have and the diseases. Based on those two sets of information, you as a group are going to come up with a suggestion, but then as a class we are all have to decide on a disease we think it is.” At the end of the lesson, he also did another summarizing and previewing move, saying, “Tomorrow … the doctor is going to reveal two more symptoms and explain her diagnosis of what the patient has and see how ours matches up with her diagnosis.” At both the beginning and end of the lesson, Mr. Nichols followed the lead of the curriculum and provided a clear summary of the previous steps and preview of next steps. He made the place in the lesson clear, but did so purely by telling. Students did not have an opportunity to review for themselves what they had done previously or make decisions about what might make sense next, thereby limiting the opportunities the students had to see coherence from their perspective.

In the second lesson, Mr. Nichols also followed the lead of the curriculum and moved directly into the new material without connecting it to any previous material. He started the lesson exactly as written in the curriculum, with the question about how people interact with their surroundings and no mention of the previous lesson on cellular respiration. He ended the discussion of the fingertip and knuckle investigation with two minutes remaining, and then moved on to providing the vocabulary term mechanoreceptor and then ended the period without any summarizing or previewing. Like the previous lesson, Mr. Nichols’ support for the coherence of the lesson mirrored what was written in the curriculum, with minimal connection between this topic of study and the previous.

**Ms. Kearney’s implementation.**

Unlike Mr. Nichols, Ms. Kearney involved more students in speaking when connecting lesson 1 to previous lessons, but she still maintained primary control over the connections that took place between that lesson and previous. She began her lesson by directing students to look at “they symptoms from the patient in the video; we’re going to go back and review those, and do they affect any of the organ systems that you researched?” Then, she spent three minutes asking students to list symptoms and guess which systems those impact. Here, the students were making connections between two previous lessons, providing them an opportunity to build coherence, but the task was mostly in service of recall rather than explicit connection to the next steps in this lesson. Ms. Kearney did not take the next step in asking students to think, for example, about what new information they might need during this lesson to build on what they had just recalled and listed.

Ms. Kearney was able to construct some coherence in the second lesson that was not present in the curriculum by connecting the sense of touch to system interactions. At the beginning of the lesson, she said, “we’re going to move onto the sense of touch and how it interacts with the other systems.…Keep in mind we have been studying systems.” This move demonstrated an improvement on the lack of coherence in the written curriculum, but was still done by Ms. Kearney herself without any input from the students. This example, therefore, demonstrates that teachers can help to build coherence even when it is weakly present in their curricular materials, but it is particularly difficulty for teachers to support students in making these types of transitions between topics coherent when they are not written as such in the curriculum.

## Teacher Reflection

During their post-implementation interviews, both Mr. Nichols and Ms. Kearney reflected on their implementation of this new curriculum, highlighting factors that impacted their teaching. The main focus of Mr. Nichols' reflection was the impact of using a highly scripted curriculum and Ms. Kearney focused primarily on the issues with managing instructional time given her unfamiliarity with the new curriculum. Both of these reflections provide valuable insights into factors that may have influenced these teachers to implement the curriculum in ways that were less aligned with the NGSS.

**Mr. Nichols' reflection.**

During his reflection, Mr. Nichols reflected on the highly scripted nature of the curriculum he had been provided and the way it impacted his teaching practice. He demonstrated appreciation for the idea of having support, saying, "I actually kinda need a script in my head to really be comfortable, or really just a broad and deep understanding of things that are involved." Here, Mr. Nichols recognized that he needed a deep understanding of the material and how it would play out in order to effectively run his class. Elsewhere in the interview, however, he pointed out the problems he had with the particular supports included in this curriculum, highlighting a tension between supporting and over-prescribing instructional moves that might have contributed to Mr. Nichols' struggles implementing these lessons.

Although Mr. Nichols appreciated having an idea of what he was going to say, he was thrown off by the specific scripting of his words in the curriculum. He said that the, "specific 'say this' in quotes. It's just like…I was getting really lost. I couldn't see the forest for the trees sometimes. Just say this, and then this, and then this, and then, here's where we are at the end." Successfully allowing students to build coherence and deeply engage in all three dimensions of science around a conceptually rich phenomenon requires the teacher to have a broad but detailed understanding of the material and where students might go with it. Mr. Nichols reflected that the over-scripting of the curriculum led him to lose sight of that broad view.

In both of the lessons that we observed, Mr. Nichols struggled with pacing the lesson, which led to him running out of time and cutting short the planned learning activities. Mr. Nichols pointed this out during his reflection and connected this concern with his response to the scripted curriculum, saying, "I feel like when I'm trying to follow essentially a script, I assume it's perfectly paced and perfectly written, and I don't really reflect on it very much. I just try to stick with it." He later pointed out that after teaching the lessons, he realized they were not "perfectly paced," saying that the second lesson we observed "was a dense amount of material packed into a 45-minute period. Actually, we had a 60-minute period." The curriculum as written seemed to give Mr. Nichols a false sense of security in the timing. Furthermore, the curriculum did not encourage him to think about what the curriculum meant for his context or make appropriate adaptations for that environment. In addition, when he ran out of time in the lessons we observed was when he most frequently took on cognitive load himself, skipping important discussions, making decisions for students, or not building the coherence between lessons for them.

**Ms. Kearney's reflection.**

During her reflection, Ms. Kearney focused on the impact on her instructional time. Throughout the reflection, she commented on feeling "rushed" while teaching and wishing she had provided her students more time to complete much of the discussions, modeling, and argumentation. She reflected on this feeling of limited instructional time both in terms of how it impacted her ability to engage her students in the science practices and how she allowed or did not allow students to direct the ideas and activities of the class.

One of the key aspects of the curriculum that was new for Ms. Kearney and her students was the idea of student discourse and discussion. She pointed out that she tried to increase the amount of discourse that took place in her class, but she struggled to do so. She said, "I tried to do a little more discourse, but it seemed like time. Just try to get it in, and giving them time to really get comfortable talking, and know the subject well enough that their talking about. Time was a big problem." Here, Ms. Kearney pointed out that she was being asked to implement new ways of interacting without having time for practicing that transition built into her work. In order for instruction to truly be student-centered, students must also develop skills to take charge of their learning, make sense of ideas, and make decisions about next steps, and Ms. Kearny showed that without the time for that student support, it was less likely to happen.

Ms. Kearney also pointed out the ways that limited instructional time impacted her assumption of the cognitive load for students, especially around making sense of ideas and determining next steps. Ms. Kearney pointed out that during these sensemaking discussions she "did feel really rushed, and that I was kind of feeding some of it because of time constraints. In addition, she reflected that when they were talking about next steps and what they had learned in the class, Ms. Kearney "felt bad that I'm pushing it in my direction rather than theirs, so I wished I had more time." Ms. Kearney was able to explicitly point out how she took over some of the important cognitive tasks in sensemaking and coherence building because she felt like she did not have enough instructional time built into the curriculum.

**Summary**.

Both Mr. Nichols and Ms. Kearney reflected on their instruction of this new unit and in doing so shed light on some of the reasons behind the instructional choices they made. Mr. Nichols pointed out the tension inherent in having a highly scripted curriculum and illuminated the ways in which such a curriculum may actually inhibit NGSS-aligned teaching. Ms. Kearney, on the other hand, struggled with time to transition to new ways of acting in the classroom and when she ran short on time defaulted to traditional, teacher-centered methods of instruction.

## Discussion

The *Framework* and NGSS envision science instruction as a phenomenon-based, three-dimensional endeavor in which students are at the center of their learning and see coherence between their lessons as they use science practices to figure out things about the natural world (NRC 2012; NRC, 2015). A number of curricula have been published that purport to help teachers make this transition, but this study demonstrates that those claims should be analyzed more closely.

We have shown that one particular curricular unit that claims to be aligned with the NGSS does not demonstrate features consistent its design. Given that this unit was an adjustment on a previous, pre-NGSS version, these results call into question the efficacy of that strategy for creating high quality curricular materials in the NGSS era. Since shortly after the release of the standards, it has been well established that the NGSS represent a significant change in the national vision of K-12 science education (Bybee, 2014; National Research Council, 2015; Osborne, 2014; Pruitt, 2014). This study reinforces that understanding and emphasizes the need to take this significant change into account when designing curricular materials, raising questions about the efficacy of applying tweaks to pre-NGSS designs.

### Designing Curriculum to Support the NGSS

When teachers use curriculum that is not written to place high cognitive demand on students, it is unlikely that their implementation will do so (Kang et al., 2016). Our data here support a similar conclusion with respect to fulfilling the key features of the NGSS. The lessons as written were not designed to fulfill the goals of the NGSS. Consequently, it is not surprising that the teachers' implementation also lacked some key NGSS designed features. Looking at the ways in which the curriculum and implementation fell short of the goals of the NGSS can provide guidance for the field on how to move forward in designing curricula that avoid similar mistakes. Specifically, the results of our study suggest the importance of using phenomena as an anchor to support coherence over time, rather than as a hook or an example for students. In addition, it suggests considering how the three dimensions can be integrated to support each other in support of cohesive cognitive goals rather than being called upon in a lesson but separately

**Supporting Teachers in the Transition to NGSS**

In addition, the teachers' reflections provide initial ideas about how we might support practitioners in implementing the complex vision of NGSS. We have already seen that when teachers see curriculum as mostly a tool for student learning rather than teacher learning, they do not make full use of its educative features (Marco-Bujosa, McNeill, González-Howard, & Loper, 2017). Mr. Nichols' reflections expand on these ideas, noting that the extreme scripting of the curriculum might have framed it for him as more prescriptive than educative, limiting his ability to use it as a resource to support his own development. This idea requires more investigation in other contexts and with other curricula and teachers, but nevertheless provides a possible warning against the practice of providing too much scripting in curricular materials.

Ms. Kearney's reflection about time and rush also pointed out another possible inhibitor of NGSS-aligned instruction. When curriculum is too full of content and includes insufficient time for students and teachers to adjust to new ways of teaching, learning, and interacting, it may be harder to truly meet the demands of the NGSS. There have been discussions about the timing of adoption and implementation of the NGSS on the system-wide scale (Penuel et al., 2015; Pruitt, 2014), and this study suggests that those same concerns need to be attended to on the classroom scale as we continue to support our teachers in carrying out this ambitious vision.

This is an exciting time for science education nationally. We continue to describe what it means to empower all students to engage deeply with making sense of natural phenomena and thinking scientifically, and we have begun to design resources and tools that can support implementation of that vision. Although we need to be wary of claims that this vision has already been achieved, we can also use lessons learned from these examples to motivate stronger designs that do better in supporting students in learning about science.

## References


Achieve. (2016). *EQuIP rubric for lessons and units: Science*. Retrieved from https://www.nextgenscience.org/sites/default/files/EQuIPRubricforSciencev3.pdf

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. https://doi.org/10.1002/tea.21257

BSCS. (2017). *Guidelines for the evaluation of instructional materials in science*. Colorado Springs.

Bybee, R. W. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education*, *25*(2), 211–221. https://doi.org/10.1007/s10972-014-9381-4

Herrenkohl, L. R., Palincsar, A. S., DeWater, L. S., & Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. *Journal of the Learning Sciences*, *8*(3–4), 451–493. https://doi.org/10.1080/10508406.1999.9672076

Kang, H., Windschitl, M., Stroupe, D., & Thompson, J. (2016). Designing, launching, and implementing high quality learning opportunities for students that advance scientific thinking. *Journal of Research in Science Teaching*, *53*(9), 1316–1340. https://doi.org/10.1002/tea.21329

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the Next Generation Science Standards. *Journal of Science Teacher Education*, *25*(2), 157–175. https://doi.org/10.1007/s10972-014-9383-2

Marco-Bujosa, L. M., McNeill, K. L., González-Howard, M., & Loper, S. (2017). An exploration of teacher learning from an educative reform-oriented science curriculum: Case studies of teacher curriculum use. *Journal of Research in Science Teaching*, *54*(2), 141–168. https://doi.org/10.1002/tea.21340

McNeill, K. L., & Berland, L. (2017). What is (or should be) scientific evidence use in k-12 classrooms? *Journal of Research in Science Teaching*, *54*(5), 672–689. https://doi.org/10.1002/tea.21381

McNeill, K. L., González-Howard, M., Katsh-Singer, R., & Loper, S. (2017). Moving beyond pseudoargumentation: Teachers' enactments of an educative science curriculum focused on argumentation. *Science Education*, *101*(3), 426–457. https://doi.org/10.1002/sce.21274

National Academies of Sciences, Engineering, and Medicine. (2019). *Science and Engineering for Grades 6-12: Investigation and Design at the Center* (B. Moulding, N. Songer, & K. Brenner, Eds.). https://doi.org/10.17226/25216

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. https://doi.org/10.17226/13165

National Research Council. (2015). *Guide to Implementing the Next Generation Science Standards*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. https://doi.org/10.17226/18290

Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education*, *25*(2), 177–196. https://doi.org/10.1007/s10972-014-9384-1

Penuel, W. R., Harris, C. J., & Debarger, A. H. (2015). Implementing the Next Generation Science Standards. *Phi Delta Kappan*, *96*(6), 45–49.

Pruitt, S. L. (2014). The Next Generation Science Standards: The features and challenges. *Journal of Science Teacher Education*, *25*(2), 145–156. https://doi.org/10.1007/s10972-014-9385-0

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher*, *29*(1), 4–15.

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education*, *98*(3), 487–516. https://doi.org/10.1002/sce.21112

Zivic, A., Smith, J. F., Reiser, B. J., Edwards, K. D., Novak, M., & McGill, T. A. W. (2018). *Negotiating epistemic agency and target learning goals: Supporting coherence from the students' perspective*. Presented at the International Conference of the Learning Sciences, London, U.K.