

# Designing Coherent Three-Dimensional Assessment Prompts to Drive Student Sensemaking Across a Unit

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## Abstract

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Enacting the Next Generation Science Standards (NGSS) reform continues to pose opportunities and hurdles for educators. Across instruction and assessment, the NGSS ask teachers to ground students' learning in coherent, phenomenon-driven, and three-dimensional (i.e., integrating crosscutting concepts, science and engineering practices, and disciplinary core ideas) opportunities for sensemaking. Instructional and assessment resources to enact this vision have been increasing in number and availability, but they are not yet pervasively available and accessible due to a number of educational system barriers. Our team proposes a concise process that teacher educators might use in preservice and in-service learning settings to help boost this access and bridge instruction and assessment. The scaffolded, educative process is designed to yield both teacher learning and usable bell-ringer prompts for students. The prompts and their educative development process target unit-integrated, phenomenon-based, coherent, 3D bell-ringers that provide formative gauges and practice for students' sensemaking. This article justifies the process in the literature, provides suggestions for teacher educators to use the process in their settings, and embeds an example middle school prompt set collaboratively developed by teacher educators and a teacher. We close in considering how expanding this process might support teacher learning going forward.

## A Decade with the Next Generation Science Standards

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As we close the first decade with the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), aligned classrooms immerse students in intriguing, often local contexts that drive their science learning. Students consider, for instance, *what has been causing the red skies on August mornings and evenings* or *why the pronghorn we typically see all over town have apparently gone missing now that it's January*. These and other relevant contexts equip K-12 students nationwide to pull in their experiences and questions to make connections, pursue investigations, and make sense of these complex scenarios over time. They do so by organizing their thinking around interdisciplinary ideas (crosscutting concepts: CCCs) and using disciplinary strategies (science & engineering practices: SEPs) to investigate and learn science ideas (disciplinary core ideas: DCIs), i.e., 3-dimensional (3D) learning (National Research Council [NRC], 2012). Meeting the vision of these standards means that teachers no longer share content and then ask their students to apply it; rather,

their role lies in orchestrating learning by anticipating student needs, preparing related investigations, and consistently responding to students' emergent ideas and questions (NRC, 2015; Robertson et al., 2015). While numerous groups have made open-source, NGSS-aligned instructional or assessment resources available (e.g., All Species Consulting, n.d.; Concord Consortium, n.d.; New Visions for Public Schools, n.d.; OpenSciEd, n.d.; Stanford University, n.d.; University of Colorado Boulder, n.d.), and others have made similar purchasable resources, two realities hinder their pervasive use.

First are the challenges of educator preparation. Large shifts require robust and sustained support for preservice, in-service, and administrative educators (Darling-Hammond et al., 2017; National Academies of Sciences, Engineering, and Medicine [NASEM], 2021). With the NGSS, educators must make shifts to align with the standards and their vision—a phenomenon-driven, coherent, and 3D approach to science instruction and assessment (NRC, 2012; Reiser et al., 2021)—when many have never experienced this approach themselves. This experience gap means that preservice and in-service teachers alike often lack the schema needed to readily grasp the 3Ds, NGSS, and instruction and assessment practices that match them. A team of science education researchers and policy advocates (NASEM, 2021) warn that teachers continue to leave preservice preparation underprepared for this instruction, and in-service teachers continue to receive insufficient support, especially in schools that serve communities of color, high-poverty communities, and rural communities. These researchers call for shifts in policy and practice to support all educators with strategies and materials in an effort to equitably improve retention and instructional quality.

Second are enduring patterns of resource (un)availability and (un)suitability. Despite the release of open-source and for-purchase resources, there are ultimately very few comprehensive curricular and assessment resources that meet NGSS alignment criteria laid out by groups like Achieve (NGSS et al., n.d.). Further, many schools continue to use out-of-date textbooks and curricular resources, exacerbating issues of equitable access to aligned resources, much less support to understand them (NASEM, 2021). This has implications for the preservice teachers who need to learn from quality resources in order to build schema for high-quality instruction and materials (Schwarz et al., 2008), in-service teachers who facilitate learning with these resources daily, and teacher educators who lack example materials to help their learners grapple with NGSS-aligned teaching and learning.

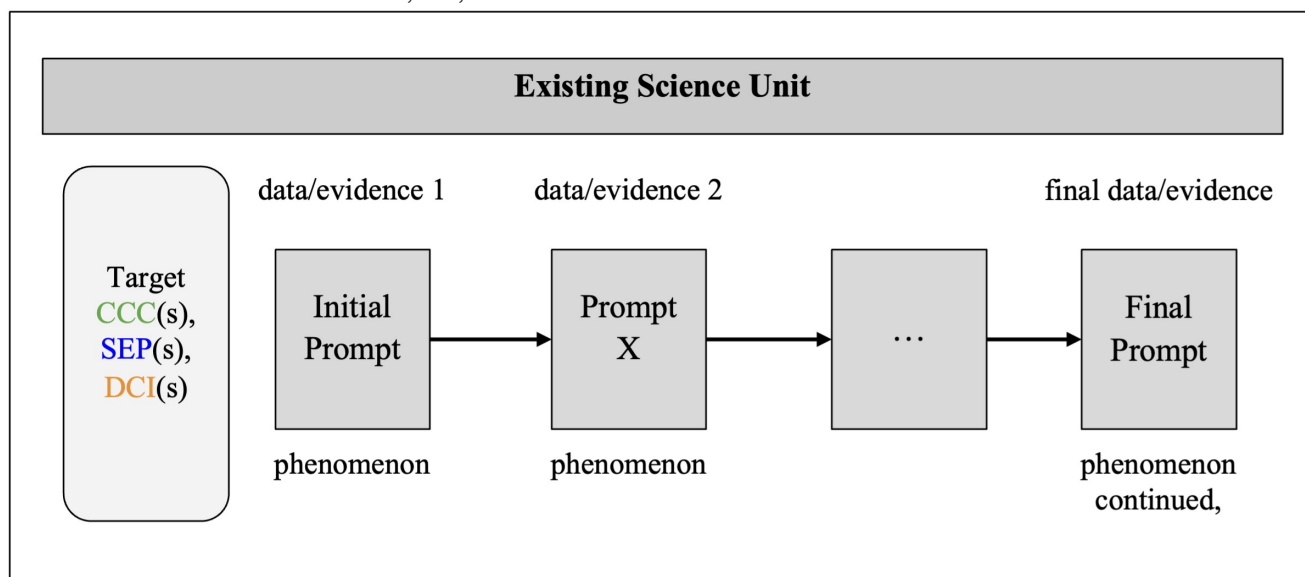
To confront these challenges, we propose a process for creating sets of formative assessment prompts that can be used as a guide for instructors or providers of preservice teacher training and/or in-service teacher professional learning. This approach requires less work and coordination than curricular overhauls while still providing important 3D, phenomenon-based support. The process is designed to yield prompt sets that are short in duration, provide multiple contact points across a learning unit (i.e., coherent), use a novel and relevant context (i.e., phenomenon), and provide students with multiple low-stakes opportunities to use the 3Ds to make sense of evidence. The prompt development process guide contains educative features (Arias et al., 2016) around key elements of aligned

science assessment, such that preservice and in-service teachers might build their knowledge and command of these science assessment elements. While these educative features themselves fall far short of an integrated approach to professional learning (e.g., a mix of on-site facilitation and digital follow-up with feedback over an academic year), we see an opportunity for teacher educators to use and extend the impact of these resources by helping to situate them more directly in teachers' practice (Davis et al., 2017) in sustained professional learning (Davis & Krajcik, 2005).

The present article shares the approach (summarized in Figure 1) that was co-designed, iterated, and tested by a team of teacher educators and an in-service teacher and names multiple opportunities where the process might be brought into a professional learning setting. It provides frameworks and research that justify the approach to bringing 3D, phenomenon-driven, coherent, and relevant ideas into concise assessment settings. We share one set of prompts that the teacher and teacher-educators collaboratively developed and several prompt development tips to bring into professional learning settings. We close by discussing how assessment sets resulting from this process might be expanded into more complete educative curricular resources.

**Figure 1**

*Process for Phenomenon-driven, 3D, Coherent Formative Assessments*



*Note. Each formative assessment set is rooted in the target CCCs, SEPs, and DCIs, and consists of multiple, small-scale prompts that span a unit, embed different evidence sources, and coherently build upon a central phenomenon in each prompt. In this way, students are engaged in transfer of their ongoing unit learning on separate prompts.*

## Building Blocks of Aligned Prompt Sets as Educative Curricular Resources

Our process yields bell ringer prompt sets that coherently build on one another, relate to the same phenomenon, and connect to a unit at key points in the learning progression. For instance, the prompt phenomenon differs from the unit's, so students have opportunities to extend and refine their thinking about similar ideas in novel contexts (Manz, 2015). In this process, prompt developers are walked through means to brainstorm and iteratively refine these phenomena so that they are meaningful to students. Prompts also embed explicit language connected to the CCCs, SEPs, and DCIs and provide opportunities for students to combine these dimensions through different formats and structures to meet their varied learning and sensemaking needs. Educative features of the process guide articulate how to unpack and break down the target CCCs, SEPs, and DCIs so that developers understand the depth of the needed dimension connections and also include cues for dimension-specific language to embed in prompts. Lastly, these bell ringers are designed as flexible tools to support short, equitable, 3D, and phenomenon-driven student learning and assessment. The process guide highlights opportunities for this flexibility. It provides a range of resources that help the prompt developer to pull together assessment pieces to meet their targets and students' learning needs.

These steps and their accompanying educative features in the process guide are intended for use in professional learning settings where teacher educators help pre- or in-service teachers develop prompts while noting, targeting, and discussing the above key elements. We expect that teacher educators will use their professional expertise to adapt and integrate this resource into their work in ways that suit their educator audiences. The process guide is set up to walk any resource user through prompt development, much like we try to walk students through reform-aligned science learning. Developers must consider and knit together the key elements (phenomena, 3Ds, coherence) to complete their prompts, much like students must consider and knit together the 3Ds in order to make sense of an anchoring phenomenon. In

this way, our prompt development process offers a ready-made tool for teacher educators to bring into professional learning settings where they aim to offer participatory experiences with the processes, ideas, and content of learning teachers will need to facilitate in their classrooms (Banilower et al., 2014; Kennedy, 2016). In this case, these experiences are in a smaller, more manageable formative assessment context than a full-fledged curriculum overhaul effort, and yield practical prompt resources to benefit teachers beyond the professional learning.

## Prompt Structures from the Literature

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Our distinct prompt approach extends from several existing frameworks. To start, aligned assessments across formative, interim, and summative scales tend to be considerably more time-consuming than traditional assessments (Furtak, 2017; Penuel et al., 2019), so we considered duration as a leverage point. While longer assessments are well justified for their learning and synthesis opportunities (Furtak, 2017), their time commitments pose problems for frequent use. Considering inequitable resource access, quality, and training, our group turned to a bell ringer format that retains key elements of longer assessments while relieving time burdens. Bell ringers, a popular, quick, and routine-based formative assessment type, provide space for students to connect or extend their learning at the beginning or end of a class (Conderman et al., 2020; Romano, 2011). Bell ringers can help set feedback, agency, and self-monitoring norms that might also support NGSS-aligned science learning on a smaller and more time-efficient scale.

We likewise targeted and extended other frameworks' calls for coherence in assessment. These existing formative, interim, and summative assessment frameworks target coherence by aligning assessments to target standards, asking students to transfer their 3D learning to new phenomena (e.g., Campbell et al., 2020; Furtak et al., 2016; Harris et al., 2016; Harris, et al., 2019), and tightly connecting learning progressions to formative assessments, performance assessments, (Furtak & Heredia, 2014; Furtak & Heredia, 2016; Furtak et al., 2014; Stanford, n.d.), and summative proximal transfer tasks (Penuel et al., 2019). In short, these frameworks assert that assessments need to embed the phenomenon-driven contexts and specific learning aims of the science education reform in order to be coherent and meaningful to students. Our prompt process aims to encompass these forms of coherence but extends to include a temporal level of coherence by connecting multiple prompts over time in a unit to the same phenomenon. In this way, the prompts provide scaffolds and opportunities for students to see, explore, and reinforce connections to learning in the recent and distant past. As such, students can see and build upon the unit's intended coherent learning progression at formative assessment checkpoints.

Lastly, our prompts aim to integrate calls for explicitness into formative science assessments in a novel and productive way. NGSS-aligned instruction is 3D, driven by phenomena, and coherent to learners and learning progressions (Krajcik et al., 2014; NRC, 2012; Reiser et al., 2021). We know that aligned assessment should do the same in novel contexts (Furtak, 2017; Harris et al., 2015; NRC, 2014; Penuel et al., 2019). Evidence suggests that assessments might further benefit from more explicit and coherent connections to the dimensions and learning progressions (DeBarger et al., 2016; Furtak & Heredia, 2014), which aligns with findings that explicitly including each dimension can help expose the roles of the 3Ds in learning. For instance, explicit reference to the CCCs can expose implicit science ideas and rules, promote scientific reasoning, and build learners' understanding of science as a whole in ways that support access and equity (Chen et al., 2014; Cooper, 2020; Quinn, 2021). Our prompt process explicitly uses language connected to each target dimension in an effort to better support students in making these connections. Together, this process offers a distinct formative assessment framework comprised of short bell ringer prompts, coherent and novel phenomenon sensemaking opportunities over time, and explicit 3D language.

## Educative Connections to Prompt Elements

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Making each of the above features clear to teacher educators who will facilitate this process and, in turn, eventual prompt developers is essential to the educative quality of this resource. Educative curricular resource guidelines suggest that making content, pedagogy, and instructional strategy intentions and rationales explicit can help teachers expand their practice, understanding, and capacity to adapt curricula to their needs (Davis et al., 2017; Davis & Krajcik, 2005). So that these resources remain directed, concise, and useful to preservice and in-service teachers, it is important that educative elements target critical areas of understanding (Davis & Krajcik, 2005). These educative connections might be demonstrated through a variety of formats, such as teacher tip callout boxes, typographical differences, conceptual relationship maps, and narrative vignettes (Davis et al., 2017).

For our prompts, we identified 3D connections, phenomena, and coherence as our critical areas of understanding, and we highlighted them typographically and with embedded explanations (see process guide). These foci extend from a number of calls in the literature to assist teachers in better understanding or accessing these ideas. For instance, Chen and colleagues (2014) suggest that helping teachers dive into the 3Ds across K-12 learning (especially the CCCs) makes embedded connections visible and builds teachers' interconnected views of science. Other groups have suggested supporting teachers with explicitly integrated materials to illuminate the 3Ds in practice (e.g., Harris et al., 2015). In terms of coherence, multiple groups have called for helping teachers to make formative assessments coherent with instruction and summative assessments (Campbell et al., 2020; Organisation for Economic Co-operation and Development [OECD], 2005) and named building shared understanding of coherence from the student perspective as an educative imperative (Roseman et al., 2017). Educative supports for teachers to understand coherence structures in resources can be difficult to balance with building teachers' agency to adapt resources to meet their needs, so seeking this balance is a key educative need (Cherbow & McNeill, 2022). Finally, phenomena can contribute to coherence when used appropriately to connect students' learning and student questions over time (Inouye et al., 2020). Educative resources should offer tools for teachers to parse the ways and places that phenomena operate to organize student thought and agency and should also assist teachers in identifying how these resources are accessible and adaptable to their students' needs and contexts (Davis & Krajcik, 2005).

Each section of the process guide targets at least one of these critical areas. Likewise, the entire guide embeds a suite of general educative features to provide varied formats and access points to the wide range of content, pedagogy, and instructional strategy considerations that are woven into the prompt development process. While educative resources like these have shown promise in supporting teachers (Davis et al., 2017), some suggest that curricular materials, even with explicit educative features, are often misinterpreted by pre- and in-service teachers. Barriers particularly come in the form of interpreting the key elements embedded in resources and translating them to their contexts (Schwartz et al., 2008). One strong suggestion to minimize these problems is to pair the educative curricular resources with sustained professional learning opportunities for pre- and in-service teachers (Davis et al., 2017; Pringle et al., 2017). Doing so with the proposed prompt development process would enable teacher educators to make a range of professional learning choices. For instance, they might:

- Facilitate their typical professional learning and then provide the prompt development process guide as an application opportunity for teachers to extend and apply learning in their contexts,
- Use the process as the professional learning structure, working through each step with teachers so they weigh the educative intentions of the resource and avoid being overwhelmed trying to do so independently (Pringle et al., 2017), or
- Alternate different professional learning structures and foci, including prompt development elements as embedded application and assessment opportunities for the teacher learners.

In short, teacher educators can weigh the educative features of this process, the target ideas, and their learning session needs in order to leverage the prompt process in their facilitation. The section below articulates the prompt steps in detail and illustrates their use with some embedded educative narrative examples.

## Assembling Formative Assessment Prompts

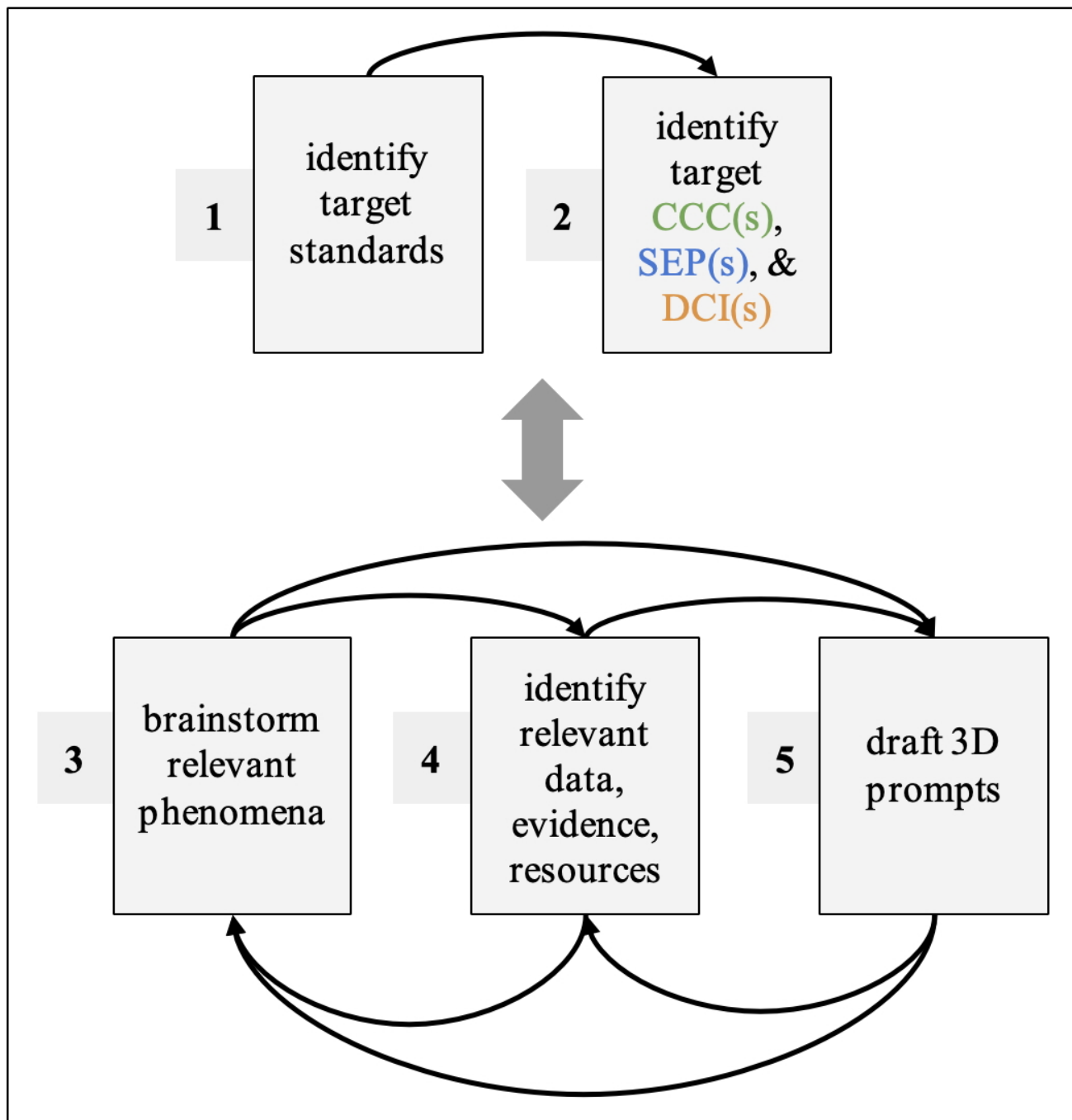
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The process for building these prompts (Figure 2) embodies elements of the frameworks cited above. The prompts are connected to learning progressions and developed using target standards for the unit (Furtak et al., 2014; Harris et al., 2016). They provide proximal transfer opportunities (Penuel et al., 2019) by intentionally linking formative assessment and learning progressions (Furtak & Heredia, 2014). They combat key challenges in providing tightly aligned resources for teachers to fall back on (Forbes et al., 2015) by ensuring efficiency (Penuel et al., 2019) and foregrounding all 3Ds in assessment (Furtak et al., 2014).

The following sections describe the steps to create these prompts and illuminate connections among the steps. Each step embeds an educative callout box to share summarized conversations, products, and thought processes behind developing a middle school prompt set, which is shared as a supplemental resource for this article. A final educative checklist callout box provides an end-of-process quick check tool, while the process guide includes detailed self-evaluative questions to use at each step of development, such as, “How might students use the CCC to make inferences about this phenomenon based on other events they’ve observed?” (Refer to the complete process guide and example assessment set in the supplemental materials for more detail.) This stepwise framework can be used in professional learning settings to help pre- and in-service teachers tease apart and implement these intersecting ideas in the bounded context of short, linked formative assessments. Teacher educators, whether facilitating in-service professional learning workshops or working with preservice teachers, can walk learners through these steps, hone them in on embedded educative features that address key ideas in science education, and encourage reflection around suggested self-evaluative prompts.

### **Figure 2**

*Process for Writing Coherent 3D Prompts*



*Note. Interactions and feedbacks among the five steps, in service of overall process targets (small-scale, coherent, and unit-embedded transfer opportunities). Identification in steps 1 and 2 guides the focus of steps 3-5. Steps 3-5 each inform one another (e.g., availability of relevant data in step 4 might drive the final phenomenon chosen from the list generated in step 3), but also include continued alignment checks back to the standards and dimensions identified in steps 1 and 2.*

### **Step 1: Identifying the target standards and dimension emphases**

Since one of the main purposes of these prompts is to provide short, coherent, formative, and unit-embedded transference tasks, they should be aligned with the unit's target 3Ds. To identify the target dimensions, prompt developers should consider prioritized standards as well as other heavy-hitting dimensions when they are developing a prompt set. While the prompts will target the unit's standards,



consider opportunities to emphasize other dimensions that might be important at a teacher, course, district, or state scale. For instance, a developer might target *mathematics and computational thinking* (SEP) in a middle-level prompt set since this practice begins to appear in earnest in this grade band's standards or *constructing explanations* (SEP) if that is a core practice in the course. Alternatively, developers might target dimensions that students have struggled with previously in order to provide them with chances to grapple and succeed with the dimension in new contexts. The developer should always deeply consider target CCCs so that these enigmatic dimensions are meaningfully integrated into the prompt set as well. In short, the developer should identify target standards and dimensions by taking into account the unit, school, district, or state priorities, as well as other factors that are unique to the classroom and students. The Step 1 self-evaluative prompts in the process guide help the developer to ensure they've selected the best-fitting and most relevant dimensions. Figure 3 shares a summarized sample conversation from this first step, when the teacher educators and teacher tried the prompt development process for a middle school context.

**Figure 3**

*Step 1: Middle School Example Summarized Dialogue*

**Teacher Educator, Juniper:** "What's an upcoming standard of yours that you'd like your students to grapple with in a formative assessment? We will focus on whatever standard you choose."

**Middle School Teacher, Sage:** "We hit several standards in our district assessment system, so I think making prompts for one of those standards could help my students practice the ideas first in a lower-stakes context. MS-ESS3-3 is one of those and is coming up at the end of the year in my human impacts unit."

**Juniper:** "Great! What are the 3Ds in MS-ESS3-3? Also, are there other dimensions you think would benefit your students – whether because they're emphasized in your class, they might help with other standards, or they are dimensions your students have struggled with in the past?"

**Sage:** "The standard targets *cause and effect* relationships (CCC) in examples of *environmental impact and mitigation* (DCI) and asks students to *design solutions* for problems (SEP). This year, *analyzing and interpreting data* (SEP) and *stability and change* (CCC) were also important dimensions that my students struggled with, so it would be good for students to practice more with those in new contexts, too."

**Juniper:** "Let's move ahead with these dimensions and start by unpacking both what they should look like at the middle level and where they might integrate with one another."

## ***Step 2: Unpacking the dimensions for 3D emphases***

Next, look carefully at all components of the target standards and dimensions identified in Step 1 to set clear boundaries around the prompts. Target standards' clarification statements and assessment boundaries can help frame the intended breadth and use of these standards, which provides direction for embedding dimension elements in prompts. Likewise, each dimension consists of several elements, so identifying a target element will narrow the prompt's scope and focus. For instance, *planning and carrying*

*out investigations* (SEP) includes numerous elements at each grade band, from planning an investigation to evaluating a plan's ability to answer the research question. A standard with this practice will only encompass one of these elements, and each grade band's dimension elements build in complexity. Treating the full standard like a resource, as well as consulting external dimension resources, can provide invaluable guidance on the focus and boundaries needed to address the target standard. The *Framework* (NRC, 2012) provides helpful framing for each of the dimensions, and its appendices (NGSS, 2013a, b, & c) articulate how each builds across the K-12 learning progression. Scholars in the *Framework* and its dimensions have compiled three resource books that allocate chapters to each dimension: one for the CCCs (Nordine & Lee, 2021), one for the SEPs (Schwarz et al., 2017), and one for the DCIs (Ravit et al., 2016). Consulting these resources during standard unpacking enables developers to clearly define the scope of the dimension connections we ask students to make, illuminates important nuances in the standards, and relieves the burden of trying to capture an entire dimension at one time. At the end of this unpacking, developers can use Step 2's self-evaluative prompts in the process guide to make sure they have already considered the ways these dimensions should look in action. Figure 4 shares the middle school example's target dimension unpacking, which was informed by MS-ESS3-3, the NGSS appendices, and the 3D reference books cited above.

**Figure 4**

*Step 2: Middle School Example Unpacked Target Dimensions*

|                                               | Target Dimension Elements                                                                                                                                                                                                                                                                  | Element Unpacked                                                                                                                                                                                                                                                                                                                    |
|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CCC: Cause &amp; Effect</b>                | Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. (NGSS, n.d.)                                                                                                                                                             | <ul style="list-style-type: none"> <li>• Distinguish between causal (i.e., one causes the other to happen) and correlational (i.e., related events, where one does not necessarily cause the other) relationships</li> <li>• Classify a relationship relevant to a phenomenon as causal or correlational</li> </ul>                 |
| <b>CCC: Stability &amp; Change</b>            | Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales. (NGSS, 2013c, p. 17)                                                                                                             | <ul style="list-style-type: none"> <li>• Identify changes in a system over time</li> <li>• Identify multiple scales of forces in a system</li> <li>• Explain where a system has remained stable and where it has changed over time and at different scales</li> </ul>                                                               |
| <b>SEP: Designing Solutions</b>               | Apply scientific principles to design an object, tool, process or system. (NGSS, n.d.)                                                                                                                                                                                                     | <ul style="list-style-type: none"> <li>• Identify scientific principles relevant to a problem</li> <li>• Use the scientific principles to design an object, tool, or process to address that problem</li> </ul>                                                                                                                     |
| <b>SEP: Analyzing &amp; Interpreting Data</b> | Analyze and interpret data to provide evidence for phenomena. (NGSS, 2013b, p. 23)                                                                                                                                                                                                         | <ul style="list-style-type: none"> <li>• Analyze data to determine the nature and relationship of the parts of the data set</li> <li>• Interpret data to explain the meaning or significance of the data to the related phenomenon</li> <li>• Use analyzed and interpreted data as evidence for a phenomenon explanation</li> </ul> |
| <b>DCI: Human Impacts</b>                     | Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. (NGSS, n.d.) | <ul style="list-style-type: none"> <li>• Human activities can alter the biosphere</li> <li>• Human impacts on the biosphere can have positive or negative impacts on living things and habitats</li> <li>• Negative alterations include destroying natural habitats and/or causing extinction of other species</li> </ul>           |
|                                               | Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise. (NGSS, n.d.)                                                                        | <ul style="list-style-type: none"> <li>• Human impacts on Earth tend to be more negative with increased populations and consumption</li> <li>• Activities and technologies can be engineered to minimize negative effects that human activities have on Earth</li> </ul>                                                            |

| Additional Resources and Connections                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
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| <p><b>MS-ESS3-3 Clarification Statement (NGSS, n.d.):</b><br/>Examples of the design process include examining human environmental impacts, assessing the kinds of solutions that are feasible, and designing and evaluating solutions that could reduce that impact.</p> <ul style="list-style-type: none"> <li>• The examples of the design process provide context for how students will engage in designing solutions (SEP)</li> </ul> <p>Examples of human impacts can include water usage (such as the withdrawal of water from streams and aquifers or the construction of dams and levees), land usage (such as urban development, agriculture, or the removal of wetlands), and pollution (such as of the air, water, or land).</p> <ul style="list-style-type: none"> <li>• The example human impacts provide guidance on the types of local systems (DCI) and their interactions (stability and change CCC) that students will investigate.</li> </ul> | <p><b>Nature of Science principles (NGSS, 2013d):</b></p> <p><b>Science is a Human Endeavor:</b><br/>Advances in technology influence the progress of science and science has influenced advances in technology.</p> <p><b>Science Addresses Questions About the Natural and Material World:</b><br/>Scientific knowledge is constrained by human capacity, technology, and materials.</p> <ul style="list-style-type: none"> <li>• The design process (SEP) can be supported by ideas about technology use that is driven by, and drives, societal and environmental contexts as well as scientific understanding.</li> </ul> |

*Note. The first panel shares and color codes dimension unpacking, while the second panel shares additional relevant information. Dimension elements and relevant additional information text was pulled directly from the NGSS appendices (NGSS, 2013a; 2013b; 2013c; 2013d) and MS-ESS3-3 (NGSS, n.d.). Bulleted unpacked element text represents authors' dimension unpacking and synthesis, with each bullet addressing a key aspect of the related element.*

### Step 3: Brainstorming relevant phenomena

In order to provide opportunities for students to explicitly engage and integrate the target dimensions, the prompts must embody key characteristics of contextualized science learning phenomena (e.g., be relevant to students, connected to a particular context, complex enough to have multiple possible solutions, connected to multiple science ideas, and intriguing (Inouye et al., 2020; Kang et al., 2014)). While

developing appropriate phenomena can be challenging (e.g., Penuel et al., 2019), existing resources and personal experience can help relieve this burden. For instance, teachers' own experiences of local, specific, and impactful events might be transformed into powerful, local phenomena for science learning that could also intrigue their students (Lee, 2020). These connections, for example, might include local development, telecommunications upgrades, wildlife migration and management, or agriculture practices. The key is for students to access these ideas with personal or easy-to-acquire experiences. If finding a relevant, local example is daunting, the standards' clarification statements often provide ideas. cursory searches of popular phenomenon databases might also spark ideas to build upon. To help streamline the work, keep student relevance and content complexity at the fore of the brainstorming process. The Step 3 self-evaluative prompts in the process guide provide helpful tips and checks for student and community relevance that a developer might consider during or after phenomenon brainstorming. Figure 5 shares another middle school example summarized conversation, this time from the phenomenon brainstorming step.

**Figure 5**

*Step 3: Middle School Example Summarized Dialogue*

**Teacher Educator, Aster:** “Alright, MS-ESS3-3 is pretty broad. How might we find guidance in the standard to limit or direct our phenomenon search?”

**Middle School Teacher, Sage:** “Like the process guide says, the standard's clarification statement sometimes helps. The one for MS-ESS3-3 talks about **human impacts (DCI)** connected to water usage, land usage, and pollution. Our community is definitely affected by all of these. We have mining nearby, air quality sometimes changes near the power plant, and there are multiple proposals to site solar and wind installations in nearby wildlife migration corridors. I could go a million directions with a local phenomenon that my students could connect to, especially since many students' families work in these industries.”

*In order to narrow the focus, the team decided to look for contexts and resources that would provide good access to their two target CCCs (cause and effect and stability and change) and two target SEPs (designing solutions and analyzing and interpreting data). They looked around digital and local resources and shared those connected to conservation techniques, rural land usage, extraction impacts, agricultural land use, and recent and historic boom and bust cycles. All of these were relevant to the rural and extraction-based community where the energy sector is a) a major driver of the community's development and economy, b) a major employer for students' families and friends, and c) a player in mitigating environmental impacts.*

**Aster:** “In what you identified, I see you focusing on **environmental offset** impact mitigation strategies like the ones energy companies have to make since students are likely to be familiar with some extraction industry practices. I like how you're thinking that could support students in using **stability and change** to make sense of how offsets are 'working' or not. Is there a local development here in town where students would be able to **see similar impacts** and **design their own offset strategies**?”

**Sage:** “There is a huge housing development that's converting sage flats into dirt patches right now. I bet we could connect all of our target dimensions to that context, and lots of kids will see that development on their rides to school. I even have a pre-photo of the area I could use to help them key in on **pre- and post-development changes** and then they could **propose possible offset strategies and justify them with data**.”

#### **Step 4: Identifying relevant resources**

In Step 3, developers might choose a phenomenon to pursue that ends up lacking related resources needed to address or make sense of it through the target dimensions. Therefore, iteration is needed between Steps 3 and 4 because it might be necessary to select a different phenomenon from Step 3 that

better connects to available data/resources. The search for these resources should be guided by the target 3Ds. For instance, *analyzing and interpreting data* (SEP) will likely dictate a search for a dataset or data representation, while *developing and using models* (SEP) might send the developer in search of a digital simulation tool. For students to be able to explicitly use *patterns* (CCC), the developer might seek several related pieces of evidence for them to synthesize. For them to employ ideas of *energy and matter* (CCC), a set of resources that highlight energy transfer may be more suitable. The target DCI will likewise guide the search, but prioritizing the SEP and CCC will enable better 3D integration in the assessment prompts. The open-access phenomenon resources from Step 3 can likewise be used to identify resources to tie into the assessment. Some may be usable in their original format, though others may need modification to tighten connections to grade band depth or student relevance. Be sure to refer back to Step 2 to align any modifications to the target standard(s) and 3Ds. Further, the process guide's Step 4 self-evaluative prompts will help a developer to envision and prepare for how these resources will provide access to the phenomenon and 3D thinking. Figure 6 shares a completed resource brainstorming table, along with the final resources included in the middle school prompt set.

**Figure 6**

*Process for Writing Coherent 3D Prompts*



**Step 4: Identify data, evidence, and/or resources** connected to the chosen phenomenon.

Now that you have selected your phenomenon, identify potential data, evidence, or resources that students would need to have in order to make sense of the phenomenon. This could be qualitative or quantitative data, text, data visualizations (tables, graphs), pictures, etc. Consider the same open resources as those suggested in Step 3 to find these resources, as well as primary literature databases, online search engines, and even personal resources (e.g., camera rolls, longitudinal class data, etc.).

Consider the SEP(s) you are targeting (Steps 1 & 2) to help you determine what types of evidence you should seek out.

Data and Evidence you will give students:

| Resource/Source: Include links, brief descriptions, etc.                                                                                                                                                                                                                                                                                                                                                                    | Connection/Reasoning: How this resource will support students' phenomenon sensemaking                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| New York Times "What's Going on in This Graph?" graphs/graphical related to development<br><del>the American bird pop.</del><br><del>to global city water stress</del><br><del>Private public development (USA)</del>                                                                                                                                                                                                       | Want Ss to interpret graphs/data, so want to include a graphic about development that allows them to do require links/relationships in data + for use as evidence for a development phenomenon. Dev. visual = conn to those initial ideas about development impacts/effects<br>→ direct link                                                                                                                                                                                                          |
| zu Ermgassen et al. (2019) article has lots of visuals showing ecological offset strategies, efficacy, + places across studies<br><del>map of place, scale, + outcomes</del><br><del>bioregion set</del><br><del>projects vs. outcomes</del><br><del>projects, outcomes, + scaling</del><br><del>to project outcomes, + arms</del><br><del>whether graphs above grade level</del><br><del>complexity, but interesting</del> | Want Ss to use context of offsets to consider instead of mitigating human impacts on environment. What if? → opportunities to consider system stability/changes how to manage intertemporally rather than offset stock<br>→ opportunity for Ss to evaluate how common (i.e., offset) did not address a problem (i.e., development/human impacts on env.)<br>→ opportunity to interpret relationships in data<br>→ explore links between human activities, biosphere/habitat impacts, + offset results |
| Images of local area<br><del>to bridge map street view</del><br><del>photos of undeveloped</del><br><del>photos of nearby undeveloped</del><br><del>Sagehen steppe</del>                                                                                                                                                                                                                                                    | Images locally will help Ss connect their ideas from NYT map + offsets required to a form, relevant context → photos taken recently are ideal to answer what Ss see. → from this, can propose a monitoring/mitigation plan                                                                                                                                                                                                                                                                            |



|                                                                      |          |          |
|----------------------------------------------------------------------|----------|----------|
| Adjusted "What's Going On In this Graph?" maps of US development<br> |          |          |
| Prompt 1                                                             | Prompt 2 | Prompt 3 |

Note. Upper panel shows example Step 4 mapping with the process guide scaffold, including color coding ideas for 3D connection, articulating coherence opportunities, and annotating the decision-making process for resource selection. Lower panel shows the resulting three resources integrated into the prompts. Left to right, placeholder for New York Times map (access original map via The Learning Network, 2021), the offsets study (zu Ermgassen et al., 2019), and the local photos of undeveloped and developed land (photos by Jessica Stephens).

## Step 5: Creating the 3D prompts

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3D prompts resulting from this step address target dimensions from Step 1, center the phenomenon emerging from Steps 3 and 4, use language that targets 3D nuances from Step 2's unpacking, and integrate resources from Step 4. As coherent bell ringers, the prompts should engage students quickly and effectively and provide opportunities to connect to their own experiences and previous prompts. The prompts' location in the unit should be informed by and aligned with the learning progression. They should also explicitly embed the 3Ds and provide opportunities for students to make increasingly deeper sense of the phenomenon using the target dimensions.

To scaffold students' integration of the 3Ds, developers will embed explicit language in one-dimensional (1D), two-dimensional (2D), and 3D combinations, each related to the phenomenon. For instance, one assessment component might ask students to *analyze data* (1D) for later use in a question that will ask them to *interpret those data* to explain *system components, mechanisms, inputs, and outputs* (2D). The ultimate goal of this assessment might be to have students *write an explanation of system interactions* based on *evidence obtained from data* about some *content* (3D). 1D and 2D questions provide scaffolds to reach 3D complexity, and color coding maps these dimensions visually so developers and users can track this scaffolding (Schneider et al., 2018), though student-facing versions might be in black text to avoid confusion.

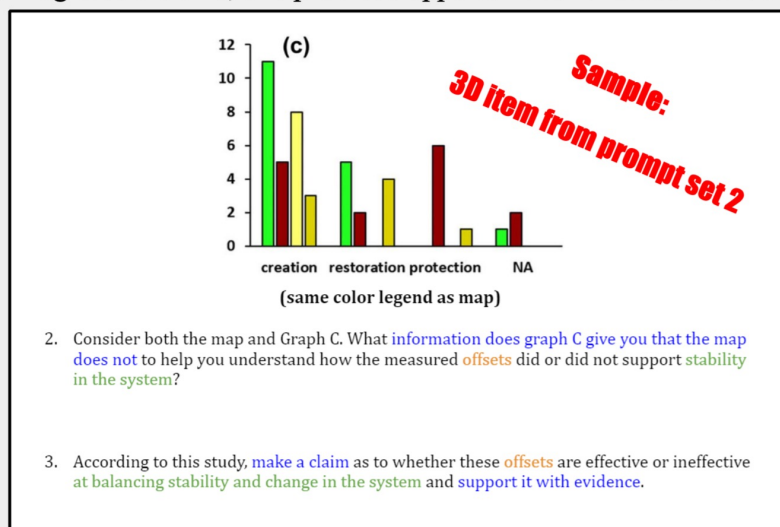
Drafting the prompts is highly iterative as developers create a scope and sequence that will engage and make sense to students, provide opportunities for them to refine their understanding, provide opportunities for them to demonstrate dimensional thinking and integrated sensemaking, and refer to earlier work. Scaffolds in the process guide help the developer break down the CCC, SEP, and DCI and integrate dimension-specific language. This language, in turn, helps set expectations for how students are expected to demonstrate how they've used and grappled with the dimensions. This specificity is especially helpful with CCCs, as it helps to clarify how this sometimes-challenging dimension should be used, integrated, and evaluated in the context of students' sensemaking. Seeking feedback from colleagues is an important part of this design process that can improve coherence, 3Dness, and relevance. The Step 5 self-evaluative prompts in the process guide offer a scaffold for deeply considering how the prompts individually and collectively meet the aims of this prompt drafting step. Figure 7 shares a narrative summary snapshot of how this iterative item drafting worked in the middle school example.

### Figure 7

*Step 5: Middle School Example Narrative with Sample Item*



The prompt drafting and revising portion of our middle school example started by identifying where the resources and related dimensions would fit within the teacher's unit and course. We drafted the phenomenon introduction to provide space for students to record their initial ideas, then to engage 2-dimensionally by *asking questions* (SEP) about *human development* (DCI). This built on a recent unit in which students explored resource availability and use in terms of human populations. From there, we framed a 2D scaffold around *cause and effect* (CCC) to address *human development* (DCI), which then led into a 3D opportunity for students to connect to problems in their community. We ensured each prompt set elicited students' 3D thinking (see example below) in terms of this context. Each set of prompts coherently built upon the initial phenomenon, integrated the 3Ds, and provided opportunities for student sensemaking.



graph reproduced with permission from zu Ermgassen et al., 2019

## Educative summary

As these steps demonstrate, we embedded a number of educative elements across the prompt development process and some specific to particular steps, each aimed at encouraging teacher learning about and application of our target ideas. Staple educative features that span all five steps include links to and explanations for resources and tools that share foundational theory and research in accessible and practical formats, such as the NGSS (NGSS, 2013a; 2013b; 2013c), phenomenon resources and suggested brainstorming processes, and STEM Teaching Tools (UW Institute for Science + Math Education, n.d.). Another key educative feature is the inclusion of scaffolds to help prompt developers to parse and identify evidence that they will expect from students. This is intended to encourage teachers' integration of these bell ringers into their instructional context. These scaffolds include things like breaking down what dimensions will look like for students to address and integrate (Steps 1 & 2), what phenomena will be compelling to students, and what a gapless or exemplar explanation could be (Step 3). Others include demonstrating how each resource will connect to student sensemaking (Step 4) and how the prompts will coherently map together (Step 5). Further, educative reflection self-check prompts appear in each step to help prompt developers to consider how these ideas will translate into their specific contexts and how their efforts align with the intention of the step. A summary educative scaffold comes in Figure 8, which provides an end-of-process checklist to help developers finalize their prompts.

### Figure 8

*Checklist to Finalize Your Prompts*

- ☐ Prompts cumulatively require students to address all three dimensions
- ☐ Expected responses in answer key cumulatively address all target dimension elements
- ☐ Students are asked to integrate multiple dimensions (i.e., few or no prompts ask students to only address one dimension)
- ☐ The prompts ask students to explicitly engage the 3Ds at grade-appropriate levels
- ☐ Prompts ask students to make sense of the phenomenon
- ☐ The phenomenon is relevant and accessible to students
- ☐ Prompts include framing to connect back to previous prompts

*Note. Use this checklist to answer the question, do your prompts achieve the following? If not, revisit steps 1-5 to bolster the missing elements.*

Consistently including these practical resources, implementation scaffolds, and reflective self-checks as key educative elements of our process guide allowed us to revisit our key ideas in multiple ways throughout the process guide. For instance, we target 3D understanding by ensuring that prompt developers give CCCs and SEPs equal (if not greater) emphasis to DCIs in identification and unpacking (Steps 1 & 2), consider how these dimensions fit into their classroom needs (Step 2), brainstorm how a phenomenon will or will not provide access to the target dimensions (Step 3), identify what sorts of resources will require students to use those dimensions (Step 4), and craft prompts that address and integrate these dimensions (Step 5). The steps and educative features within them sparked productive work, iteration, and learning conversations in our own development team, and we see parallel opportunities for teacher educators and teachers to employ this process and engage its educative features to bolster their own product-embedded learning.

## Where these Prompts Fit in the Science Learning Landscape

This article introduced a replicable, accessible process for developing formative transfer tasks that embedded educative elements such that teacher educators can incorporate this process to initiate, reinforce, or extend targeted ideas in professional learning. We contend that this process helps to address resource access and educator support challenges (NASEM, 2021) by addressing both understanding of the learning approach (educative elements) and the resources themselves (resulting prompts). The educative elements and resulting bell ringer prompts both target relevant and tangible contexts for students, center the local place, re-connect students with a phenomenon in coherent ways over time, and support their sensemaking through the target 3Ds. Regardless of whether a teacher has access to other NGSS-aligned materials and strategies, this formative prompt process is designed to be easily deployable. The design process is scaffolded to support developers with the phenomenon, coherence, and 3D intentions of NGSS alignment. Teacher educators who know their audiences can use and adapt this process to suit their learners' needs, pulling from the range of scaffolds, resources, and self-evaluative prompts embedded in the process guide.

Extending educative connections into deeper learning opportunities for teachers could be a meaningful next step that answers calls from many groups. We see an opportunity to compile and intentionally organize sets of prompts that emerge from the process and to develop these into more detailed educative curricular resources that break down key elements in multiple different contexts and compositions. While this would stay outside the realm of a coherent, unified curriculum with coherent educative features (Fortus & Krajcik, 2012), there is an opportunity to build a different type of within-material coherence that supports teachers who lack coherent curricula. Seeing the 3Ds in play in multiple formats and combinations, especially with an emphasis on CCCs, could equip teachers and teacher educators to tease

apart the K-12 connections that several groups have called for (e.g., Chen et al., 2014; Harris et al., 2015). Including vignettes or narratives could likewise offer a high-leverage educative opportunity to illustrate how prompts were designed, how they might be adapted to different settings, how they were enacted, and where and why CCCs and SEPs were explicitly targeted (Davis & Krajcik, 2005; Davis et al., 2017). Additionally, a large range of example prompt sets with educative elements could help more teachers envision ways their formative assessments could be made coherent with instruction and summative assessments, which could, in turn, buoy their professional learning around building student agency and equity (Campbell et al., 2020; OECD, 2005).

In this second decade with the NGSS, many teachers, researchers, and teacher educators continue to seek, test, and share ways to better enact equitable and aligned science learning. Our bell ringers embed the same underpinnings that teachers are asked to use in their phenomenon-based, 3D instruction and assessment, and so can boost this shift toward coherent, reform-aligned learning. Our process aims to contribute to this shared effort with an approach to developing sets of assessment prompts that are short, coherent, transference-based, 3D, and intended to be formatively embedded throughout a unit of instruction. We look forward to expanding this work, and encourage others to similarly build on the wealth of available frameworks and strategies to find other accessible ways to address persistent problems with reform adoption.

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