Journal of Science Teacher Education

ISSN: 1046-560X (Print) 1573-1847 (Online) Journal homepage: http://www.tandfonline.com/loi/uste20

Developing a Three-Dimensional View of Science Teaching: A Tool to Support Preservice Teacher Discourse

Michelle L. Sinapuelas, Corinne Lardy, Michele A. Korb, Christine Lee Bae & Rachelle DiStefano

To cite this article: Michelle L. Sinapuelas, Corinne Lardy, Michele A. Korb, Christine Lee Bae & Rachelle DiStefano (2018): Developing a Three-Dimensional View of Science Teaching: A Tool to Support Preservice Teacher Discourse, Journal of Science Teacher Education

To link to this article: https://doi.org/10.1080/1046560X.2018.1537059

Published online: 15 Nov 2018.

JOURNAL OF SCIENCE TEACHER EDUCATION
https://doi.org/10.1080/1046560X.2018.1537059

Developing a Three-Dimensional View of Science Teaching: A Tool to Support Preservice Teacher Discourse

Michelle L. Sinapuelas [a,b,c], Corinne Lardy [a,b,c], Michele A. Korb[a], Christine Lee Bae[a], and Rachelle DiStefano[a]

[a]Department of Teacher Education, California State University East Bay, Hayward, California, USA; [b]College of Education, California State University Sacramento, Sacramento, California, USA; [c]Department of Foundations of Education, Virginia Commonwealth University, Richmond, Virginia, USA

ABSTRACT

The Next Generation Science Standards (NGSS) and the Framework for K-12 Science Education (NRC, 2012) on which they are based, describe a new vision for science education that includes having students learn science in a way that more closely aligns to how scientists and engineers work and think. Accomplishing this goal will require teacher educators to make important shifts in the ways they prepare future science teachers (NRC, 2012). Many science teaching methods courses are being reformed to better support future science teachers to meet the ambitious goals of the NGSS. Specifically, these reform efforts require evidence-based and standards-aligned tools to help preservice teachers align instruction with the new science standards. This study utilized the methodology of Improvement Science "Plan, Do Study, Act" cycles in order to design a Three-Dimensional Mapping Tool (3D Map) as a visual scaffold for use in science teaching methods courses to support preservice teachers in unpacking the components of NGSS and to promote discourse related to the three-dimensionality of planning instruction. The 3D Map provides a visualization of key elements of the NGSS, while being flexible enough to accommodate established teaching strategies.

KEYWORDS

Preservice teacher education; science education; Next Generation Science Standards

The new vision for science education articulated in the Next Generation Science Standards (NGSS) and *A Framework for K-12 Science Education* (hereafter, "the *Framework*"; National Research Council [NRC], 2012), on which the NGSS are based, requires engaging students in contextualized instruction that emulates how scientists and engineers work and think, specifically how they draw from multiple disciplines and apply various science and engineering practices as warranted by the phenomena they are investigating or the problem they intend to solve. Intertwining knowledge and practice to advance the values underpinning the new standards requires science educators to shift their instruction away from prioritizing the memorization of key science ideas separated by discipline and isolating content from science practices in classroom activities toward a focus on multidimensional learning experiences that engage students in exploring ideas across the earth, life, and physical sciences to explain phenomena in the natural world (Hoeg & Bencze, 2017; NRC, 2012).

CONTACT Michelle L. Sinapuelas michelle.sinapuelas@csueastbay.edu California State University, East Bay, 25800 Carlos Bee Blvd., NSC 131, Hayward, CA 94542, USA.

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uste.

The NGSS specify three dimensions that science instruction should integrate: disciplinary core ideas (DCIs), science and engineering practices (SEPs), and crosscutting concepts (CCCs). Instruction that integrates all three of these is said to be three-dimensional and involves having students explore content-rich DCIs through more active engagement in SEPs and the lens of broader CCCs to generate understanding of a scientific phenomenon in the natural world. Taken together, the NGSS place great significance on what students are doing and understanding as they engage in science learning.

Across the United States, significant statewide interagency planning and resources have targeted kindergarten–Grade 12 (K–12) in-service teacher professional development to advance this new vision of science education. However, teacher preparation programs at the university level are making instructional shifts on a more individual basis to ensure that new teachers are prepared to implement the NGSS. These shifts commonly involve revising elements or replacing components of existing science teaching methods courses (Bybee, 2014). However, to accomplish these significant changes at the university level, science education faculty are in need of tools that assist teacher candidates in explicitly unpacking the NGSS to illuminate their underlying components, which can then have direct applications to practice (Krajcik, McNeill, & Reiser, 2008). Tools that have undergone systematic analysis and field testing in real education contexts are required to facilitate such understanding (Bryk, Gomez, Grunow, & LeMahieu, 2015; Lewis, 2015).

The Three-Dimensional Mapping Tool (3D Map) described in this article was designed to meet the needs of both science education faculty and preservice science teachers (PSTs) by providing a visual scaffold grounded in components of the NGSS to promote meaningful discussion related to the NGSS and instruction within a methods course. The 3D Map was intended not to replace the use of traditional lesson planning templates but instead to foster reflection and dialogue about how the components of the NGSS, including integration of the three dimensions, are accomplished, while linking these to larger topics generally discussed as part of instructional planning in a science methods course. In this context, the term *tool* indicates a material support (Vygotsky, 1978; Wertsch, 1985; Windschitl, Thompson, Braaten, & Stroupe, 2012) that facilitates preservice teachers' understanding of how to align instruction with the characteristics of the NGSS. This article describes the design and improvement of the 3D Map, includes the rationale behind the tool's structure, and provides suggestions for its use.

Background

Implementation of the NGSS in teacher preparation programs

The *Framework* states that "science teacher preparation must develop teachers' focus on, and deepen their understanding of the crosscutting concepts, disciplinary core ideas, and scientific and engineering practices so as to better engage their students in these dimensions" (NRC, 2012, p. 257). The authors of the *Framework* suggest that this shift will require changes to current preservice teacher training and acknowledge that these changes will be challenging. However, the *Framework* does not provide guidelines for designing curriculum or enacting student learning experiences to accomplish the NGSS learning goals. Bybee (2014) proposed three strategies for aligning teacher preparation programs with the NGSS: (a) revise elements of the current program, (b) replace components of the current program, or (c) reform the current program altogether. However, Bybee (2014) acknowledged that the first two strategies are more feasible and thus more likely to occur and that initial reform processes will probably focus on the science teaching methods course(s) in teacher preparation programs.

Windschitl, Schwarz, and Passmore (2014) also made suggestions for revising preservice teacher education experiences to include the NGSS. Consistent with Bybee (2014), Windschitl et al. (2014) suggested that the venue is most likely the science teaching methods course(s) and argued that science education faculty should engage their preservice candidates in the NGSS beyond just familiarity with their components or basic architecture. Specifically, science education faculty must support preservice teachers in understanding how curriculum should integrate the NGSS while considering current literature on best practices to support all students' learning of science (Windschitl et al., 2014). Following these recommendations, the 3D Map was designed as a support for revising elements of a science teaching methods course to integrate the NGSS alongside existing teaching strategies by supporting discourse around curriculum and instructional approaches that reflect the three-dimensionality and student-centered nature of the NGSS.

Practice-based approaches in teacher education

Practice-based approaches in teacher education aim to provide opportunities for preservice teachers to engage in authentic teaching activities. It has been suggested that this engagement in authentic activities and discussion is integral to providing a relevant context for supporting preservice teachers' pedagogical development as well as revising courses that promote a shift in teaching paradigms (Arias, 2015; Boerst, Sleep, Ball, & Bass, 2011; Thompson, Windschitl, & Braaten, 2013). A three-part framework of practice-based approaches in university contexts has been proposed consisting of opportunities to represent, decompose, and approximate teaching activities (Grossman et al., 2009). Representing the activity involves making the practices of teaching more concrete and could be accomplished by discussing exemplary teaching shown by example in class, from a video, or through lesson plans. Decomposing the activity involves breaking a complex activity into smaller parts, which allows more novice teachers to focus on and refine specific sections of a lesson and/or aspect of instruction. Finally, approximating the practice involves engaging in activities that closely represent actual classroom scenarios and can be accomplished through rehearsing teaching to peers and the instructor and receiving feedback (Grossman et al., 2009). Through this process, preservice teachers unpack an activity into its constituent parts and strategies while defining the rationale for salient problems/phenomena, objectives, and corresponding assessments (Lewis, Perry, Friedkin, & Roth, 2012).

To scaffold opportunities during a practice-based teacher education program, Ball and Forzani (2009) suggested identifying a set of high-leverage practices "that are essential for skillful beginning teachers to understand, take responsibility for, and be prepared to carry out in order to enact their core instructional responsibility" (p. 504). The course featured in this study took a practice-based approach that represented effective teaching practices from the science education literature with connections to lessons modeling components of the NGSS.

Discussion of how to explicitly align effective teaching practices with the goals of the NGSS is essential, yet complex, in courses using a practice-based approach such as the one in this study. For example, discussions required to understand a phenomenon such as coral bleaching require not only focusing on a variety of scientific concepts (e.g., ocean acidification, carbon cycle) but also engaging in science practices (e.g., analyzing and interpreting data from estuaries) to make sense of these concepts and drawing connections (e.g., cause-and-effect relationships) between different concepts being used. Representing various teaching activities in conjunction with the phenomenon-based, three-dimensional approach of the NGSS, in the context of a science methods course, is a complex challenge for instructors and preservice teachers alike.

Tools for preservice teachers and NGSS implementation

One way to support preservice teachers in the challenging task of creating connections among components of existing and new curricula is by providing scaffolding in the form of a material *tool* (Windschitl et al., 2012), defined as a "physical or digital object that [is] provided to students to support them to accomplish a task that they would not be able to do independently" (Arias & Fick, 2017, p. 4). Such a tool can provide a scaffold to novice teachers by breaking down a task into smaller elements, reducing the number of decisions or choices involved in the task, and prompting the user to consider the how or why of the task (Reiser & Tabak, 2014). Arias and Fick (2017) also noted that the overarching goal of many tools used in practice-based methods courses is to make teaching practices that beginners may not recognize as important explicit by prompting novices to (a) observe or notice, (b) reflect, (c) engage in authentic experiences, and (d) plan or prime. In a similar vein, Benedict-Chambers (2016) suggested that tools have the potential to play a particularly central role in practice-based methods courses to help preservice teachers "notice and interpret critical features of science instruction" (p. 39).

Other tools have been created to guide curricular development and/or to evaluate NGSS alignment with the existing curriculum. For example, some researchers have generated rubrics or tools to focus teachers' thinking on making connections among the three dimensions of the NGSS explicit (e.g., Houseal, 2015) and analyzing the alignment of lessons with the NGSS (e.g., Ewing, 2015). In addition, California's model state-level interagency collaboration between the California Department of Education and its two public university systems is using a train-the-trainer implementation model to disseminate supporting instructional resources and curriculum (http://ccsesa.org/next-generation-science-standards-rollouts/). Other efforts focus on designing curricular examples that align with the NGSS (e.g., Roseman, Hermann-Abell, & Koppal, 2017). These materials include an exemplar curriculum; tools to evaluate the existing curriculum for its inclusion of elements from each of the three dimensions of the NGSS; along with supports to consider some of the larger goals of the NGSS, such as what types of phenomena are best suited for anchoring lessons. However, these efforts are designed with in-service teachers, other science educators, and curriculum developers in mind. Thus, because the existing NGSS-related tools were developed for practicing teachers and experienced educators, it is assumed that the end user has an understanding of how to design curriculum or scaffold learning for students and is prepared to effectively align practices within the structure and philosophy of the NGSS.

What is missing from the repertoire of tools currently available are NGSS-aligned supports designed specifically for use with preservice teachers or novice in-service teachers.

Preservice teachers typically do not have the wide range of classroom-based experience in designing and enacting curriculum that these aforementioned tools assume, let alone knowledge of creating three-dimensional, phenomenon-based units. Therefore, with the needs of preservice teachers in mind, we designed the 3D Map to provide structure for visualizing and promoting the explicit discourse for which a practice-based approach calls (via representation, decomposition, and representation; Grossman et al., 2009) while addressing the complexity of the NGSS. In addition, the 3D Map is intended to support preservice teachers and course instructors in making explicit how a lesson integrates NGSS components while engaging in decomposition of a lesson represented as part of a course.

Methods

The improvement science (IS) framework (Berwick, 2008; Bryk et al., 2015; Lewis, 2015) informed the design of this study in terms of developing and revising the 3D Map. The IS framework was selected because it is committed to (a) joint definition of problems of teaching and learning practice by researchers and practitioners, (b) an iterative design process, (c) participatory evaluation in collaboration with the practitioner/end user, and (d) development of capacity for scaling and sustaining change in systems (Bryk et al., 2015). IS engages practitioners/end users not only during the testing and evaluation of the tools or programs but also at the inception of a project as knowledgeable others, beginning with the problem definition and continuing through the design process and iterative testing and improvement cycles. Equally important is the iterative participatory process, which begins during the design stage. It is argued that rather than implementing a tool for fast and wide use and then fixing problems later, designers accelerate learning by deploying the strategy of small, rapid, and iterative Plan, Do, Study, Act (PDSA) cycles (Bryk et al., 2015) along with practitioners/end users early in the design cycle, at low cost, to make rapid and incremental changes (see Figure 1). Recognizing the practitioners' contribution to knowledge building early in the design process was important for this study.

This study initially engaged various experts in the field to define the problem and generate an initial design for the 3D Map (PDSA Cycle 1; see Figure 2). This 3D Map was then used in science methods courses at a large public university associated with this study, and improvements were made based on its implementations (PDSA Cycles 2 and 3; see Figure 2). The first and later iterations of the 3D Map (Versions 1, 2, and 3) are shown in Figures 3–5. Figure 2 illustrates the PDSA cycles in this study, and Table 1 describes the participants included in each step of this iterative process.

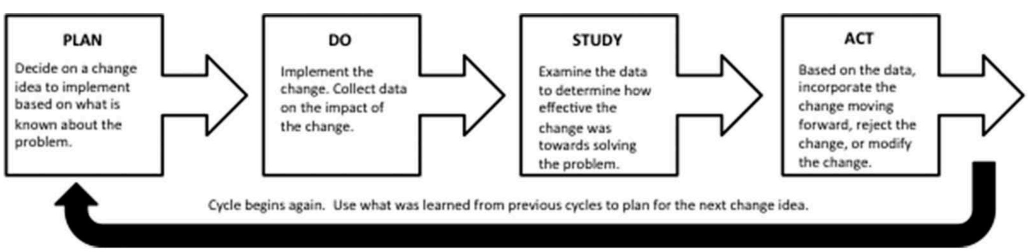

Figure 1. Plan, Do, Study, Act cycle for continuous improvement.

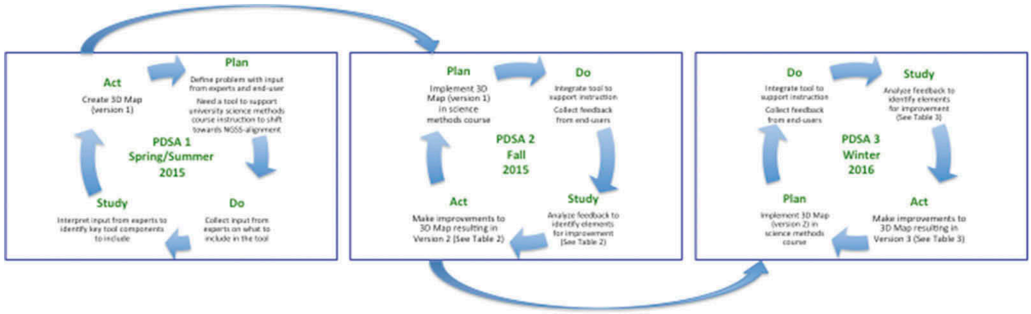

Figure 2. Illustration of the Plan, Do, Study, Act (PDSA) cycles of continuous improvement used in this study.

Science methods course

The science methods courses that facilitated the implementation and improvement of the 3D Map met as a sequence of four quarters in a year-long postbaccalaureate teacher credentialing program. During each of these 10-week quarters, the course met for five 3-hr sessions (i.e., a total of 20 meetings, or 60 hr). Implementation of the tool during PDSA Cycles 2 and 3 (see Figure 2) took place during the second (fall) and third (winter) quarters of this course. The courses included instruction around the 5E (Engage, Explore, Explain, Elaborate, Evaluate) learning cycle (Bybee et al., 2006; Trowbridge & Bybee, 1990), backward design (Wiggins & McTighe, 2001), and ambitious science teaching (Windschitl et al., 2018). Practices were represented through exemplar lessons to promote the integration of skills across a particular set of science concepts, promote student-centered learning, and provide opportunities for students to align objectives and outcomes. The instructor also utilized knowledge of simultaneous

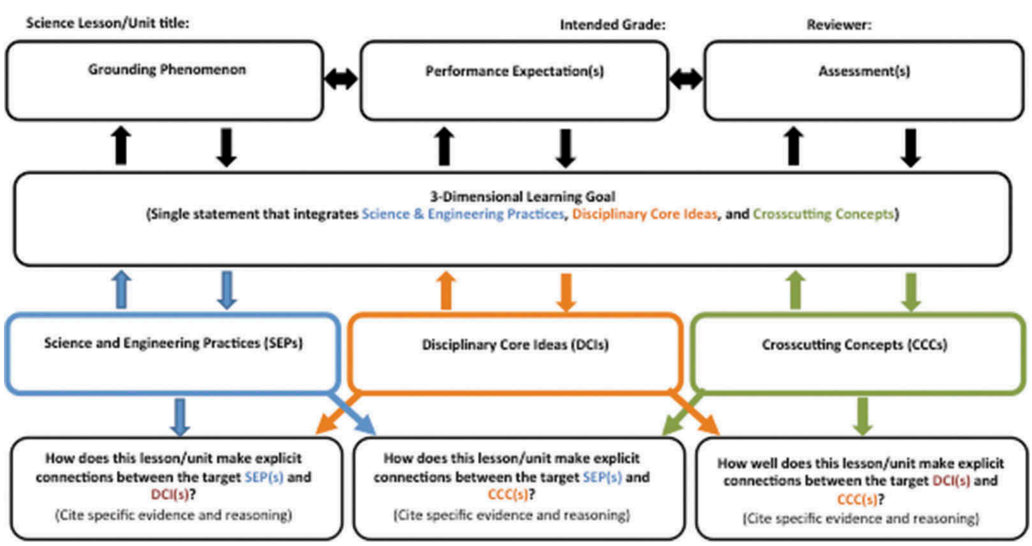

Figure 3. Version 1 of the Three-Dimensional Mapping Tool.

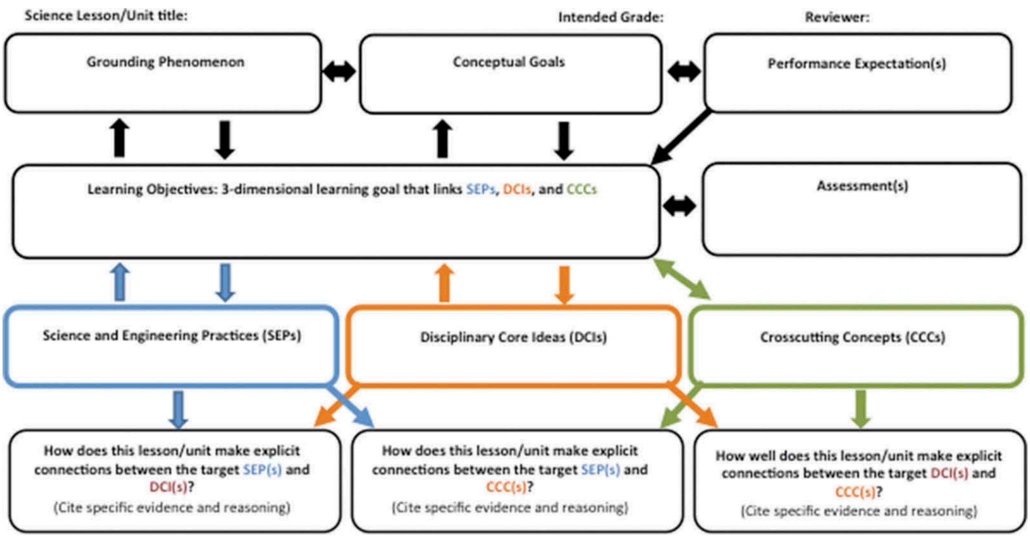

Figure 4. Version 2 of the Three-Dimensional Mapping Tool.

efforts taking place in the local school districts, aimed at aiding experienced in-service teachers to shift their practices to meet the NGSS. However, at the time of this study, although the instructor had integrated resources that provided general overviews of the structure of the NGSS, she lacked specific scaffolds to address the three-dimensionality of the NGSS from a practice-based approach. The 3D Map was integrated into the methods courses as a support when the represented lessons were decomposed to explicitly make connections from the lessons modeled to components of the NGSS.

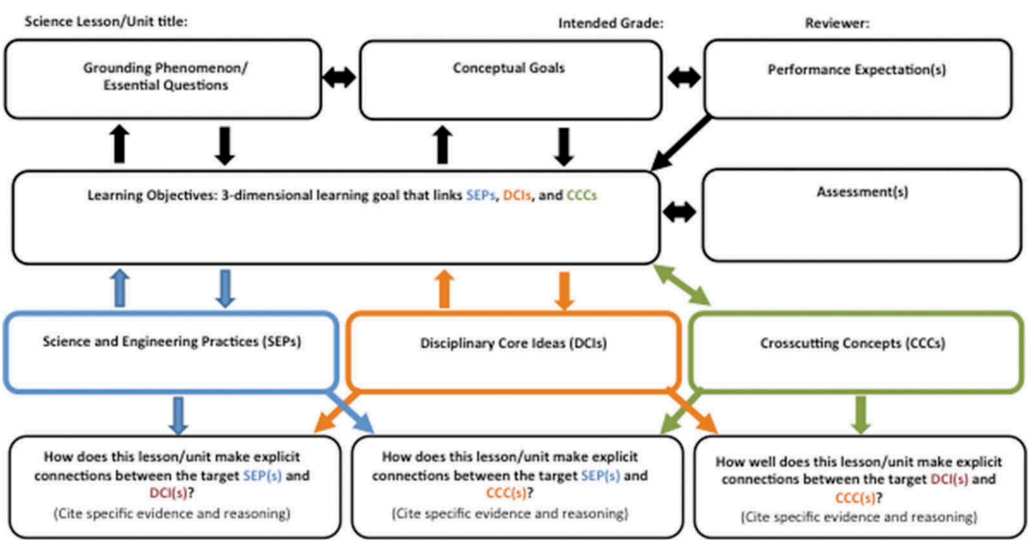

Figure 5. Version 3 of the Three-Dimensional Mapping Tool.

Participants

During this iterative process of developing the 3D Map, various groups and experts were engaged in the PDSA cycles as summarized in Table 1.

The research team consisted of three full-time researchers along with the project director. The advisory development team consisted of university faculty from various science, technology, engineering, and mathematics disciplines, including the science education faculty member who was also the science methods course instructor. Each of these faculty advisors was a member of the university campus where this study took place.

The K–12 science education leaders were a group of 15 individuals working on early implementation of the NGSS across eight California school districts. This group included 11 district K–12 science teacher leaders (with science leadership experience ranging from 1 to 10 years) and four state-level administrators or former administrators. They were selected for consultation based on their level of experience with the NGSS and potential understanding of the needs of future end users. They provided feedback on the initial tool design based on their experiences delivering professional development efforts for in-service teacher transition to the NGSS.

As mentioned previously, the science methods faculty member participated on the advisory development team and was also the science methods course instructor in this study. As is common at universities with K–12 science teacher preparation programs, the instructor was one of a few faculty members leading K–12 science teacher preparation reform efforts on her campus and was the only science methods instructor at the university. In keeping with the structure of the PDSA cycles, the science methods instructor was engaged in the Act phases of the PDSA cycle to ensure immediate implementation of the results from the Study phase.

Preservice teachers (PSTs) enrolled in the secondary science methods course (seven males/ 13 females) participated as end users in PDSA Cycles 2 and 3 (see Figure 2). The PSTs came into the program with varied teaching experiences, ranging from 45 hr of volunteer time to 2–3 years of experience as a substitute or emergency credentialed teacher. The PSTs were also, at the time of the study, either student teachers or full-time interns in secondary classrooms (Grades 6–12). PSTs in this study were considered to be novice teachers, as they all lacked training from an accredited university and had little to no background in designing and enacting NGSS-aligned science curriculum and instruction.

Table 1. Summary of participants in each PDSA cycle carried out during this study.

Phase	PDSA 1 participants	PDSA 2 participants	PDSA 3 participants
Plan	Research team Advisory development team[a] K–12 science education leaders[a] Science education faculty[b]	Research team Science education faculty[b]	Research team Science education faculty[b]
Do	Research team Advisory development team[a] K–12 science education leaders[a] Science education faculty[b]	Science education faculty[b] Preservice teachers[b]	Science education faculty[b] Preservice teachers[b]
Study	Research team	Research team	Research team
Act	Research team Science education faculty[b]	Research team Advisory development team[a] Science education faculty[b]	Research team Advisory development team[a] Science education faculty[b]

Note. PDSA = Plan, Do, Study, Act; K–12 = kindergarten–Grade 12.
[a]Participated as knowledgeable experts. [b]Participated as end users.

Materials and data collection

The materials generated in this study were three versions (see Figures 3–5) of the 3D Map implemented in the science methods courses. Data collection (Study phases) involved documenting feedback from the instructor of and the PSTs enrolled in the science methods courses. Researchers attended the course as observers, collected video recordings, and recorded field notes during each class when the 3D Map was used. PSTs in the course provided feedback through responses during class meetings and as a part of regular coursework, such as lesson plans, reflections on elements of teaching, mini-presentations, and written feedback on their understanding of the NGSS. After each class meeting, the utility of the 3D Map was debriefed between the researchers and the instructor of the course. In addition to the data collected from each class meeting, at the end of each 10-week academic quarter additional feedback was obtained from the course instructor and PSTs through written reflections and semistructured one-on-one interviews that lasted approximately 1 hr each. Interviews with and reflections from PSTs focused on how the 3D Map supported discourse related to implementing the NGSS.

Analyses

Consistent with the approach of IS research (e.g., Bryk et al., 2015; Edwards, Sandoval, & McNamara, 2015; Hannan, Russell, Takahashi, & Park, 2015), various qualitative data sources were used to inform each phase of the PDSA cycles and address questions guiding the design of the 3D Map. Data were examined throughout the 10-week cycles (quarter terms at the university) of implementation of each version of the 3D Map in a manner of continuous improvement (see Figures 1–2), which resulted in evidence-based adjustments to the tool following each cycle. During each of these cycles of data analysis, researchers independently reviewed written, audio, and video data collected during the implementation of each version of the tool. Categories in the data were identified using open coding (Strauss & Corbin, 1990) and grouped into major themes. Emergent themes were shared with the larger advisory development team, including the instructor of the methods course. Together changes to the tool were enacted in response to the findings that emerged from the data as well as related research literature. Results that emerged during the Study phases guided the final structure of the 3D Map.

Themes that emerged from each Do and Study phase informed the Act phases, providing a new focus for the Plan phase before the next version of the 3D Map was implemented. Feedback from the research team, members of the advisory development team, and K–12 science education leaders contributed to the first version to the tool, whereas subsequent revisions (Versions 2 and 3) were informed by the course instructor and PSTs (end users). From these continuous PDSA cycles (see Figures 1–2), researchers gained insight into not only how PSTs might engage with the tool as they decomposed aspects of NGSS-aligned instruction but also how course instructors could use the 3D Map to promote meaningful discourse around NGSS-aligned curriculum and instruction design.

Defining the problem

Key to the IS approach is defining the problem for the research study jointly between the researchers and end users/practitioners. Potential end users included the faculty member teaching the science methods course and the PSTs enrolled in the science methods courses. However, given the PSTs' novice understanding of the NGSS and strategies considered effective for science instruction, their input in the initial conversations to define the problem of developing a tool aligned with the NGSS was not included. Instead, the research team gathered input from experienced practitioners, including the K–12 science education leaders, the science methods instructor, and an advisory development team, to define the following practice-based problem: Tools are needed to support university science methods course instruction to shift toward alignment with the NGSS. More specifically, from discussions with the science education faculty and leaders, it was clear that to be useful within the context of a science methods course, this tool would need to complement existing course curricula. That is, the tool developed had to be flexible enough to support discussions that considered the teaching strategies already included in the course along with making connections to the components of the NGSS present in the curriculum. The 3D Map was intended not to replace the use of more traditional lesson planning templates or other supports but instead to complement and revise these efforts. Given the clearly defined practice-based problem of providing such a tool, the following questions guided the development of the 3D Map:

(1) What components are necessary as part of the tool to aid PSTs in identifying and anchoring the SEPs, DCIs, CCCs, and performance expectations (PEs) to a larger phenomenon, as well as connecting them to one another, in the context of science lessons or units in a methods course?
(2) How can the tool promote PSTs' meaningful discourse related to NGSS-aligned three-dimensional science teaching within the context of other evidence-based teaching strategies typically considered in teaching methods courses?

In line with these questions, this article documents the development of a tool that provides an overarching instructional planning scaffold to support understanding of the NGSS in relation to curriculum through discourse for PSTs and science methods instructors.

Results

In keeping with the characteristics of IS, a description of the findings from the PDSA cycles and the corresponding revisions to the 3D Map is woven into the discussion of the results. This section describes the 3D Map development process and specific problems identified from the data that influenced the design of the map in each cycle. The decisions that drove the changes at each of the PDSA cycles were grounded in the data and a review of the related literature.

Development of Version 1

The 3D Map was purposefully designed as a 1-page graphic organizer. The bottom two rows of this graphic organizer consist of text boxes for the user to list specific components of each NGSS dimension (i.e., DCIs, SEPs, and CCCs) present in the lesson and then to describe how connections among the dimensions are made explicit (NRC, 2012). This design mirrors the integration of the three dimensions provided in the *Framework* and the NGSS and is consistent with literature that underscores the importance of explicating connections among the dimensions for both content and learning objectives (Houseal, 2015; Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). The box above these rows was included for the user to describe the 3D lesson-level learning goal(s) (Bybee, 2013; Krajcik et al., 2014). The top row of Version 1 included boxes prompting the identification of "Grounding Phenomenon," "Performance Expectation(s)," and "Assessment(s)."

The original design of the 3D Map was informed by recent literature emphasizing the vision and intent of the NGSS (Bybee, 2013; Krajcik et al., 2014; NRC, 2015; NGSS Lead States, 2013). In addition, we designed the 3D Map to be flexible enough to support discussions that consider teaching strategies already represented in a course, and the value of graphic organizers in making complex connections among concepts and ideas more visible was considered (Moore & Readence, 1984). Therefore, the structure of the 3D Map included color coding to match the representation of SEPs in blue, DCIs in orange, and CCCs in green. The colors of the text boxes for the three dimensions of the NGSS and associated connecting arrows were chosen to align with the colors used by Achieve in the NGSS (NGSS Lead States, 2013) to provide a visual connection back to the standards.

The top row of boxes on the 3D Map link to larger topics generally discussed as part of lesson planning in a science methods course and arose from consideration of how this tool would integrate with the other course topics (e.g., writing clear instructional objectives, using academic language and concepts). The decision to include these boxes in the initial tool was the result of discussions with the course instructor and K–12 science education leaders on how to support PSTs in planning instruction aligned with the NGSS. These discussions revealed that it was not enough to consider the PEs or components within each of the three dimensions and how they are linked in a science lesson; one also had to consider how these relate more proximally to the lesson-level learning objectives, assessments, and other foundational concepts traditionally taught within a science methods course (Ewing, 2015; Krajcik, 2015; NRC, 2015). Thus, the boxes were intentionally included on the 3D Map to make explicit connections among key, discrete components of a lesson.

The "Grounding Phenomenon" box in the upper left corner of the map was intentionally positioned to prompt PSTs to explicitly consider phenomena at the beginning of the planning process and to promote anchoring lessons to a natural phenomenon while examining existing science instructional segments or planning for new ones. The *Framework* (NRC, 2012) calls for lessons that create learning opportunities for students that more closely resemble the way in which scientists and engineers work and think: answering questions or solving problems by investigating phenomena in the natural world through multiple disciplinary domains and application of various SEPs. Given that a phenomenon serves as the driver of the science lessons (NRC, 2012), teacher preparation programs need to include a focus on developing practitioners' abilities to engage their students in exploring and developing explanations of natural phenomena (Kloser, 2014; NRC, 2015; Windschitl et al., 2012).

The inclusion of a box labeled "Performance Expectation(s)" separate from the "3-Dimensional Learning Goal" box was also purposeful. The intent was to signal PSTs to consider the relationships and differences between this larger benchmark for proficiency in science (i.e., PEs) and the smaller lesson-level learning goals in an instructional segment (Krajcik et al., 2014). The NGSS literature indicates that PEs as written in the standards are not meant to be used as lesson-level learning goals (Bybee, 2013; Krajcik et al., 2014); "many lessons will be required for students to develop skills to reach proficiency for a particular NGSS performance expectation" (Houseal, 2015, p. 58). The separate box "3-Dimensional Learning Goal" was therefore included to prompt individuals to write more specific learning goals guided by, but more narrow in scope than, the PEs.

The inclusion of an "Assessment(s)" box in the top row of the 3D Map was in accordance with the structure of backward design (Wiggins & McTighe, 2001), an important component of the methods course in which the tool was implemented for this study. The inclusion of a box to prompt consideration of assessment was intended to support PSTs' understanding that effectively assessing learning goals for a lesson or unit is a key component of planning effective instruction (Davis, Petish, & Smithey, 2006).

Results from PDSA Cycle 2

The first version of the 3D Map (see Figure 3) was incorporated into the science methods course in the Fall 2015 academic quarter (PDSA Cycle 2; see Figure 2). Throughout the quarter, classroom observations and interviews with the instructor of the science methods course revealed key themes that guided the first round of revisions to the 3D Map. Changes to the 3D Map were also limited to NGSS concepts. The instructor and research team did consider other instructional elements (e.g., English language learner strategies, science literacy supports, summative and formative assessment structures). The team felt that although these are important strategies to overlay in the design of robust instruction, they were beyond the scope of the structure of the 3D Map. Table 2 thus outlines the improvements made to the 3D Map through this PDSA cycle, the rationale behind them, and the sources of evidence considered. Examples of instructor reflection and student actions that led to these improvements are detailed below. The resulting 3D Map based on these improvements is shown in Figure 4.

Improvement to relabel the learning goal

While trying to model for PSTs how to utilize Pes, the instructor discussed the importance of using PEs as a standard and not a lesson-level learning goal:

> The goal of one lesson is not a performance expectation … it might take you weeks to get there. It might be a unit, or you can even know that in pieces the students develop these larger ideas over the course of the year.

Using 3D Maps in groups, students attempted to fill in the three-dimensional learning goals based on an ocean science lesson. The instructor noted in reflection after a particular class that the label "3-Dimensional Learning Goal" was confusing to the PSTs. Student questions prompted her to restate and clarify the expectations of this box during instruction. In

Table 2. Summary of improvements, rationale, and evidence considered during PDSA Cycle 2.

Improvement made to 3D Map	Rationale	Sources of evidence
Box titled "Grounding Phenomenon" separated into two boxes: "Grounding Phenomenon" and "Conceptual Goals"	Students were conflating "phenomenon" with the scientific concepts behind the phenomenon (e.g., "properties of water" as the phenomenon). Separating spots to write notes emphasized that these were two different ideas. The wording "Conceptual Goals" was used to align with a backward map tool that students had been using for the past two quarters and were used to. By aligning the terminology in these two tools, the goal was to help students make explicit links between the long-term backward mapping tool (used to plan a unit sequence) and the 3D Map as it could be used to dig into a part of that sequence (i.e., for a lesson within the sequence).	3D Maps from the first class (whole class and individual) in which the majority of students wrote that the "phenomenon" was "properties of water" Student interviews from the end of the fall quarter: Students said that one of their biggest challenges was short-term planning in the context of long-term planning. Students also had a hard time using the 3D Map and figuring out where it fit. Discussions with instructor
Box titled "3-Dimensional Learning Goal (Single statement that integrates Science & Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts" was renamed "Learning Objectives: 3-dimensional learning goal that links SEPs, DCIs, and CCCs"	The wording "Learning Objectives" was used to align with the state-level credentialing requirements. The wording "Learning Objectives" was used to align with other lesson planning templates, such as those based on backward mapping. The wording "3-dimensional learning goal" was confusing to students (and others, including the instructor) and sounded complicated to them. The new wording placed the emphasis on the objectives of the lesson, which is a component of lesson planning that is typically used in educational contexts.	Student interviews from the end of the fall quarter Discussions with instructor 3D Maps from class (whole class and individual): This box was left blank every time—nobody knew what to do with it.
Box titled "Assessment(s)" was moved to second row next to "Learning Objectives"	This was done to make a more explicit link between learning objectives for the lesson and assessment (i.e., the goal of the assessment was to determine whether instruction met the objectives of the lesson: How will you know if the students learned what you wanted them to learn?).	Field notes recorded during class discussions Discussions with instructor

Note. PDSA = Plan, Do, Study, Act; 3D = three-dimensional; SEP = science and engineering practice; DCI = disciplinary core idea; CCC = crosscutting concept.

addition, during her interview at the end of the quarter she stated, "The PSTs had a really hard time filling out that box. They kept leaving it blank and seemed confused. I'm not sure I even get what a '3-dimensional learning goal' means enough to explain or model it for them." The research team identified this wording as problematic and noted that in educational contexts such goals are often termed *learning objectives*. The action taken to improve the 3D Map was to replace "Learning Goal" with "Learning Objective" to provide consistency with the language of credential requirements, such as state-level assessment rubrics, and lesson planning strategies typically addressed in a methods course.

Improvement to separate the "Grounding Phenomenon" box into two discrete boxes

After completing multiple mini-lessons related to a larger unit focused on ocean science, including topics of the ocean as a heat reservoir, thermal expansion of water, ocean currents, and seasonal changes in weather related to geographic proximity to the ocean, PSTs in the course were asked to fill in the top boxes of the 3D Map, including identifying a phenomenon related to the overall ocean science unit. After some discussion among PSTs, the consensus was that the phenomenon explored by the activities and practice-based experiences was "properties of water." It was at this point that the course instructor and the researchers realized that PSTs were confounding the grounding phenomenon with the science concepts that underlay or explained that phenomenon. The instructor expressed that "properties of water in the ocean" was a more fitting "conceptual goal." Thus, the instructor reflected,

> I'm thinking that one of the reasons that the PSTs are struggling to connect these lessons is they haven't been prompted to explore the broader scientific content knowledge that brings them together. [They aren't recognizing the difference between the phenomenon and the content that supports understanding of the phenomenon.]

Based on the instructor's reflections and expressed desire to explicitly prompt PSTs to think about the conceptual goals that underlay the phenomenon, the researchers separated the "Grounding Phenomenon" box into two separate and discrete boxes: "Grounding Phenomenon" and "Conceptual Goals." "Conceptual Goals" is to the right of "Grounding Phenomenon" to indicate that conceptual goals encompass the key science concepts of a lesson required to understand the larger phenomenon. The wording *conceptual goals* was chosen to align terminology with disciplinary concepts already being applied by the PSTs in other unit planning tools used in the course based on backward design (Wiggins & McTighe, 2001). This improvement was made to support reflection and dialogue related to the differences between a phenomenon and the content that can be used to make sense of the phenomenon.

Improvement to move the "Assessment(s)" box

While continuing to discuss the phenomenon of temperature differences between a coastal city and an inland city at the same latitude, and decomposing the lessons represented on ocean science, the PSTs identified the following PE as relevant: "MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates" (NGSS Lead States, 2013). However, when pressed to identify assessment strategies for this PE, the PSTs failed to identify lesson-level assessments related to the content and practices of the PE (e.g., creating flow charts as descriptions of energy flow, identifying connections between climate and the location of cities). The instructor reflected after the lesson that the PSTs "have a major misconception that you're supposed to teach a performance expectation in a lesson. Or the other major misconception is that the performance expectation is the only way that those three dimensions go together." Later in the course when reflecting again on the use of assessment with the 3D Map, the instructor was recorded saying, "The PSTs still have a hard time first of all understanding what are formative assessments and why they are important and why not just do a big standardized test."

As a result, the "Assessment(s)" box was moved to the second row of the map, making room for the added "Conceptual Goals" box as well as allowing for a more explicit connection between the three-dimensional learning objectives and the assessments in the lesson. The movement of the "Assessment(s)" box to the second row next to "Learning Objectives" was intended to provide an explicit visual reminder that assessments for a lesson should measure those smaller learning goals that build toward the PEs. In conjunction with this movement of the "Assessment(s)" box, the arrows connecting the boxes were changed. Originally double-headed arrows connected "Assessment(s)" to both "Performance Expectation(s)" and "3-Dimensional Learning Goal." This was changed to show one double-headed arrow connection only between "Assessment(s)" and "Learning Objectives." This deletion of the arrow between the "Assessment(s)" box and the "Performance Expectation(s)" box emphasized that the assessment within a lesson should focus on the learning goals of the particular lesson or group of lessons, not on the larger PE (end of grade band standards) toward which lessons are meant to build.

Results from PDSA Cycle 3

The second version of this tool, shown in Figure 4, included the improvements described above. The second version was implemented in the Winter 2016 academic quarter. This course enrolled the same PST cohort as in the previous quarter. In addition, a large, laminated version and smaller printed versions of the 3D Map were used for PSTs' reference. One further change was made to the 3D Map in response to the findings from this academic quarter/PDSA Cycle 3. Table 3 outlines the improvement made to the 3D Map, the rationale behind it, and the sources of evidence to support this change. Examples of instructor reflection and student actions that led to this are detailed below. The resulting 3D Map based on these improvements is shown in Figure 5.

Improvement to include "Essential Questions"

Again, the PSTs grappled with a phenomenon in which yearly temperature patterns were compared for two cities at the same latitude, one at the coast and one inland. Various average annual temperature data analysis activities were completed in class to illustrate some of the concepts related to the phenomenon. Field notes recorded during class discussions revealed that PSTs tended to pose questions in the "Grounding Phenomenon" box rather than describing the natural phenomenon that was being explored in the lesson. For example, in

Table 3. Summary of improvements, rationale, and evidence considered during PDSA Cycle 3.

Improvement made to 3D Map	Rationale	Sources of evidence
The "Grounding Phenomenon" box was further labeled "Grounding Phenomenon/Essential Questions"	When PSTs were asked to fill in the "Grounding Phenomenon" box on the 3D Map, they tended to write questions rather than describing the natural phenomenon that was being explored in the lesson. When the instructor then posed example questions, this led to a larger discussion of how these "essential questions" can help focus students on key parts of the phenomenon that they should be able to explain by the end of instruction.	Field notes recorded during class discussions Discussions with instructor

Note. PDSA = Plan, Do, Study, Act; 3D = three-dimensional; PST = preservice science teacher.

relation to the two cities phenomenon, rather than stating the phenomenon, PSTs posed a single question, such as "Why are yearly temperatures of two cities along the same latitude different?" The instructor discussed with the PSTs that this type of question narrowed the range of concepts required to approach three-dimensional investigations but was not what she intended as the phenomenon. She decided that more time was needed in the course to clarify the difference between a natural phenomenon and questions that could be posed to classroom students in order to unpack and support a phenomenon. To help clarify, the instructor identified essential questions for the PSTs (e.g., What are the causes of the temperature differences? What impact does the location of the city have on its yearly temperature trends? What impact does the ocean have on the yearly temperature trends of a city?). In response to the instructor's need to clarify the difference between the phenomenon and questions that help focus attention on a specific aspect of a phenomenon, the research team agreed to add "Essential Questions" to the "Grounding Phenomenon" box. When "Essential Questions" was added to the "Grounding Phenomenon" box, PSTs were prompted to identify and distinguish between the phenomenon and the essential questions while focusing activities, objectives, and assessments geared toward exploring the phenomenon. These essential questions were considered by the research team to include key questions that students should be able to answer about the phenomenon by the end of a lesson or a series of lessons. These can be posed by the teacher or generated by the students. The essential questions focus student attention on the key parts of the phenomenon that they should be able to explain by the end of instruction.

Version 3 of the 3D Map (see Figure 5) is the current and final version of the 3D Map. This version, with the added content in the top two rows developed through improvements from PDSA Cycles 2 and 3, aims to make more explicit the connections that are being prompted. The bottom row of boxes was intended from the beginning to drive detailed examination during the three-dimensional planning process to promote PSTs' meaningful discourse related to NGSS-aligned three-dimensional science teaching.

Table 4 summarizes the boxes included in this final version of the 3D Map and the reasoning that led to their inclusion or improvement.

Table 4. Brief descriptions of each box on the 3D Map and the reasoning behind the box.

3D Map box	Description	Reasoning that led to the inclusion and/or revision of this box
Grounding Phenomenon/ Essential Questions	In this box, users describe the real-world phenomenon that students should be able to explain (in part or fully) by the end of the lesson or unit. Users also list the key essential question(s) they plan to pose to their students (or guide their students to pose) about the phenomenon. These essential questions should focus on the parts of the phenomenon that their students should be able to answer by the end of the lesson or unit.	The importance of this component is backed by NGSS documents and feedback from K–12 district leaders and other early NGSS implementers. In the final version, "Essential Questions" was added to aid preservice teachers in focusing in their planning on aspects of the phenomenon and the key questions they would pose to their students.
Conceptual Goals	Conceptual goals are related to the NGSS DCIs. Whereas DCIs refer to more specific science ideas underlying scientific phenomena as described in the NGSS, conceptual goals are broader science concepts that the lesson or unit targets.	This box allows preservice teachers to think of their plans in terms of larger science concepts before focusing in on specific components of DCIs. This helps them to situate their lesson or unit in the larger picture of science concepts as well as the broader sequence of science concepts on a larger time scale.

(*Continued*)

Table 4. (Continued).

3D Map box	Description	Reasoning that led to the inclusion and/or revision of this box
Performance Expectation(s)	The NGSS are written in the form of PEs, or statements of what students should be able to do to demonstrate their knowledge by the end of a grade or grade band (NGSS Lead States, 2013). In this box, users identify which PE(s) the lesson or unit is intended to build toward.	This box gives users a place to identify the specific standard(s) toward which the lesson or unit builds students' competence. This box was separated from "Learning Objectives" to avoid preservice teachers' conflation of larger PEs and specific learning goals for a lesson or unit. The separation was also done to facilitate preservice teachers' decoupling of SEPs and CCCs identified in the PE(s) from those SEPs and CCCs chosen as the focus of the specific unit or lesson.
Learning Objectives	A learning objective is an explicit statement regarding what knowledge and skills students will be able to understand and demonstrate at the end of the lesson or unit. Learning objectives should focus on measurable and observable outcomes students will be able to demonstrate, not what form the instruction will take (Bybee, 2013).	This box existed from the beginning of the map as a place to identify the learning goals for students in the lesson or unit. However, the wording was changed over time. The final wording of "Learning Objectives" was chosen to align with the language most familiar to preservice teachers as part of a teacher preparation program. This box was also intentionally separated from "Performance Expectation (s)" to emphasize the differences in scope between the two.
Assessment(s)	In this box, users describe how they will assess the specific learning objectives of the lesson or unit through both formative and summative assessment strategies.	Assessment is a key component of preservice teachers' learning to plan lessons and units that are aligned or not aligned with the NGSS. Multiple and varied assessments, both formative and summative, are needed to comprehensively gauge students' understanding of DCIs through the application of the SEPs and CCCs. This box is intentionally only connected to one other box, "Learning Objectives," to emphasize the important relationship between these two components of a lesson or unit.
Science and Engineering Practices (SEPs) Disciplinary Core Ideas (DCIs) Crosscutting Concepts (CCCs)	In these boxes, users identify not only which larger SEP(s), DCI(s), and CCC(s) the lesson or unit targets but also which specific components of these dimensions are the focus of instruction.	The SEPs, DCIs, and CCCs are the three dimensions of the NGSS. A separate box was provided on the map for each of these to encourage preservice teachers to describe which specific components of each of the three dimensions are targeted in a lesson or unit.
Connections between SEP(s) and DCI(s) Connections between SEP(s) and CCC(s) Connections between CCC(s) and DCI(s)	In these boxes, users describe how the lesson or unit makes explicit connections between the specific components of the three dimensions targeted in instruction.	The three connection boxes were included to encourage users to move beyond identifying individual dimensions in a lesson or unit to identify and describe how the dimensions are explicitly connected in instruction.

Note. 3D = three-dimensional; NGSS = Next Generation Science Standards; K–12 = kindergarten–Grade 12; DCI = disciplinary core idea; PE = performance expectation; SEP = science and engineering practice; CCC = crosscutting concept.

Discussion

This article describes the development and improvement of the 3D Map, a tool designed within practice-based science methods courses (Grossman et al., 2009) to support science methods course revision toward alignment with the NGSS (Bryk et al., 2015; Krajcik et al., 2008; Lewis, 2015). In these courses, PSTs engaged in example lessons representing model curriculum and then decomposed activities through discussion of how each component of the lesson fit in the larger vision of the NGSS. The 3D Map was designed with the goal to be flexible enough to support discussions when decomposing a lesson that considered the teaching strategies already represented in the course along with making connections to the components of the NGSS. By engaging in iterative cycles of planning, implementing, studying, and improving the 3D Map, guided by the IS framework, we considered the needs of the end users of the 3D Map, making continuous improvements to the tool while addressing typical lesson planning strategies taught to PSTs and how these align with the goals of the NGSS.

The arrangement of boxes, the flow of key components from the grounding phenomenon/essential questions, to conceptual goals, to related PEs, was designed to expose thinking about three-dimensional planning while providing structure to a conversation about addressing the three-dimensional nature of PEs (Krajcik et al., 2014). The connection to the second row of boxes, "Learning Objectives" (with SEPs, DCIs, and CCCs in mind), was designed to prompt consideration of how these elements work together to anchor the curriculum to science phenomena (Hoeg & Bencze, 2017; NRC, 2012). The inclusion of elements specific to the NGSS (PEs, DCIs, SEPs, CCCs, and connections between dimensions) as well as more traditional lesson planning themes (learning objectives, assessment, conceptual goals) was purposeful to allow the course instructor flexibility in including related lesson planning ideas with discussions designed to explore how the NGSS are represented in a given activity.

The PDSA Cycles 2 and 3 resulted in four main improvements to the tool. The replacement of "3-Dimensional Learning Goal" with "Learning Objectives" focused on language alignment, whereas the other three improvements were grounded in the vision of the NGSS. The use of the term *learning objectives* was purposeful because it was found to be consistent with the language of credential requirements, such as state-level assessment rubrics and lesson planning strategies typically addressed in an education course. "Conceptual Goals" was added to the right of "Grounding Phenomenon" to indicate that conceptual goals encompass the larger science concepts on which a lesson is geared toward supporting the understanding of a phenomenon. The wording *conceptual goals* was chosen to align with terminology for disciplinary concepts already being applied by the PSTs in other unit planning tools used in the course based on backward design (Wiggins & McTighe, 2001). Moving the "Assessment (s)" box to the second row with the "Learning Objectives" box along with modifying how the arrows connected these boxes was done to reinforce the fact that PEs are to be demonstrated at the end of a grade and require multiple lessons and smaller scale assessments to be fully covered. The addition of "Essential Questions" to the "Grounding Phenomenon" box was meant to prompt PSTs to identify and distinguish between the phenomenon and the essential questions that might be posed to focus instruction within the phenomenon (Bybee, 2014).

Questions that continue to emerge from this study that consider the flow of the 3D Map's visual structure include the following: Which SEP would best illustrate the bundle of DCIs covered? Why would these DCIs support the phenomenon identified? How can the CCCs be used to assess student use of knowledge/DCI concepts to explain or illustrate the conceptual goals that support the phenomenon? Without the visual scaffold and the ability to make notes on a large laminated 3D Map or on large handouts in the methods classroom, the complex conversations around planning for the NGSS had previously been lost in a disconnected set of activities and course assignments.

Implications and limitations

The 3D Map is currently being implemented and studied within eight methods courses at six universities (2016–2018). In terms of the generalizability of the use of the 3D Map, preliminary discussions within this project's Networked Improvement Community (Bryk, Gomez, & Grunow, 2011) and in a webinar series have revealed that members of other university programs have similar needs to structure lesson and unit plans for PSTs around the three-dimensionality of the NGSS. It is important to emphasize that this is not a stand-alone tool or lesson planning template, nor is it a mechanism for deciding the sequence of lessons covered. It is also important to note that the 3D Map cannot simply be handed to a group of educators or to PSTs for implementation. The 3D Map is intended for use as an active learning tool as part of a course, providing a visual scaffold for discussion of the complexity of planning for the NGSS guided by the course instructor. The 3D Map appears to assist PSTs in generating curriculum aligned with the NGSS by navigating beyond the paradigm of isolated content ideas and skills toward using the process of science to deeply understand a natural phenomenon.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The research reported here was supported by National Science Foundation Discovery Research K-12 under Award No. DRL-1418440.

ORCID

Michelle L. Sinapuelas http://orcid.org/0000-0003-1750-0901
Corinne Lardy http://orcid.org/0000-0001-8516-8897

References

Arias, A. M. (2015). *Learning to teach elementary students to construct evidence-based claims about natural phenomena* (Doctoral dissertation). Retrieved from https://deepblue.lib.umich.edu

Arias, A. M., & Fick, S. J. (2017, April 22-25). *Scaffolding beginning teaching practices: An analysis of the roles played by tools provided to preservice elementary teachers*. Paper presented at the Annual International Meeting of the National Association for Research in Science Teaching, San Antonio, TX.

Ball, D. L., & Forzani, F. (2009). The work of teaching and the challenge for teacher education. *Journal of Teacher Education*, *60*(5), 497–511. doi:10.1177/0022487109348479

Benedict-Chambers, A. (2016). Using tools to promote novice teacher noticing of science teaching practices in post-rehearsal discussions. *Teaching and Teacher Education*, *59*, 28–44. doi:10.1016/j.tate.2016.05.009

Berwick, D. M. (2008). The science of improvement. *JAMA*, *299*(10), 1182–1184. doi:10.1001/jama.299.10.1182

Boerst, T. A., Sleep, L., Ball, D. L., & Bass, H. (2011). Preparing teachers to lead mathematics discussions. *Teachers College Record*, *113*(12), 2844–2877.

Bryk, A. S., Gomez, L. M., & Grunow, A. (2011). Getting ideas into action: Building networked improvement communities in education. In M. Hallinan (Ed.), *Frontiers in sociology of education* (pp. 127–162). New York, NY: Springer Publishing.

Bryk, A. S., Gomez, L. M., Grunow, A., & LeMahieu, P. G. (2015). *Learning to improve: How America's schools can get better at getting better*. Cambridge, MA: Harvard Education Press.

Bybee, R. (2013). *Translating the NGSS for classroom instruction*. Arlington, VA: NSTA Press.

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

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs, Co: BSCS*, *5*, 88–98.

Davis, E. A., Petish, D., & Smithey, J. (2006). Challenges new science teachers face. *Review of Educational Research*, *76*(4), 607–651. doi:10.3102/00346543076004607

Edwards, A. R., Sandoval, C., & McNamara, H. (2015). Designing for improvement in professional development for community college developmental mathematics faculty. *Journal of Teacher Education*, *66*(5), 466–481. doi:10.1177/0022487115602313

Ewing, M. (2015). EQuIP-ed for success. *Science Scope*, *38*(5), 13–15.

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. (2009). Teaching practice: A cross-professional perspective. *Teachers College Record*, *111*(9), 2055–2100.

Hannan, M., Russell, J. L., Takahashi, S., & Park, S. (2015). Using improvement science to better support beginning teachers: The case of the building a teaching effectiveness network. *Journal of Teacher Education*, *66*(5), 494–508. doi:10.1177/0022487115602126

Hoeg, D. G., & Bencze, J. L. (2017). Values underpinning STEM education in the USA: An analysis of the Next Generation Science Standards. *Science Education*, *101*(2), 278–301. doi:10.1002/sce.21260

Houseal, A. (2015). A visual representation of three-dimensional learning: A tool for evaluating curriculum. *Science Scope*, *39*(1), 58–62. doi:10.2505/4/ss15_039_01_58

Kloser, M. (2014). Identifying a core set of science teaching practices: A delphi expert panel approach. *Journal of Research in Science Teaching*, *51*(9), 1185–1217. doi:10.1002/tea.v51.9

Krajcik, J. (2015). Project-based science: Engaging students in three-dimensional learning. *The Science Teacher*, *82*(1), 25. doi:10.2505/4/tst15_082_01_25

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. doi:10.1007/s10972-014-9383-2

Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning goals driven design model: Developing curriculum materials that align with national standards and incorporate project based pedagogy. *Science Education*, *92*(1), 1–32. doi:10.1002/(ISSN)1098-237X

Lewis, C. (2015). What is improvement science? Do we need it in education? *Educational Researcher*, *44*(1), 54–61. doi:10.3102/0013189X15570388

Lewis, C. C., Perry, R. R., Friedkin, S., & Roth, J. R. (2012). Improving teaching does improve teachers: Evidence from lesson study. *Journal of Teacher Education*, *63*(5), 368–375. doi:10.1177/0022487112446633

Moore, D. W., & Readence, J. E. (1984). A quantitative and qualitative review of graphic organizer research. *Journal of Educational Research*, *78*(1), 11–17. doi:10.1080/00220671.1984.10885564

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

National Research Council. (2015). *Guide to implementing the Next Generation Science Standards. Committee on guidance on implementing the Next Generation Science Standards*. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: The National Academies Press.
Reiser, B. J., & Tabak, I. (2014). Scaffolding. In *The Cambridge handbook of the learning sciences* (2nd ed., pp. 44–62). New York, NY: Cambridge University Press.
Roseman, J. E., Hermann-Abell, C. F., & Koppal, M. (2017). Designing for the Next Generation Science Standards: Educative curriculum materials and measures of teacher knowledge. *Journal of Science Teacher Education*, *28*(1), 111–141. doi:10.1080/1046560X.2016.1277598
Strauss, A., & Corbin, J. M. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Thousand Oaks, CA: Sage Publications, Inc.
Thompson, J., Windschitl, M., & Braaten, M. (2013). Developing a theory of ambitious early-career teacher practice. *American Educational Research Journal*, *50*(3), 574–615. doi:10.3102/0002831213476334
Trowbridge, L. W., & Bybee, R. W. (1990). *Becoming a secondary school science teacher*. Columbus, OH: Merrill.
Vygotsky, L. S. (1978). *Mind in society: The development of higher mental process*. Cambridge, MA: Harvard University Press.
Wertsch, J. V. (1985). *Vygotsky and the social formation of mind*. Cambridge, MA: Harvard University Press.
Wiggins, G., & McTighe, J. (2001). *Understanding by design*. Upper Saddle River, NJ: Prentice Hall.
Windschitl, M., Schwarz, C., & Passmore, C. (2014). *Supporting the implementation of the Next Generation Science Standards (NGSS) through research: Pre-service teacher education*. Retrieved from https://narst.org/ngsspapers/preservice.cfm
Windschitl, M., Thompson, J., & Braaten, M. (2018). *Ambitious science teaching*. Cambridge, MA: Harvard Education Press.
Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education*, *96*(5), 878–903. doi:10.1002/sce.v96.5