Journal of Science Teacher Educati

ISSN: 1046-560X (Print) 1573-1847 (Online) Journal homepage: www.tandfonline.com/journals/uste2

Identifying Phenomena for NGSS: Using Preservice Teacher Data to Develop the ASET Phenomenon Tool for Use in Sci Courses

Michelle Sinapuelas, Lin Xiang, Donna L. Ross … Horvath

JOURNAL OF SCIENCE TEACHER EDUCATION
https://doi.org/10.1080/1046560X.2025.2506026

Identifying Phenomena for NGSS: Using Preservice Teacher Data to Develop the ASET Phenomenon Tool for Use in Science Methods Courses

Michelle Sinapuelas[a*], Lin Xiang[b*], Donna L. Ross[c], Meredith Vaughn[c], and Lawrence Horvath[d]

[a]Department of Chemistry and Biochemistry, San Francisco State University, San Francisco, California, USA; [b]Department of Science, Technology, Engineering, & Mathematics, University of Kentucky, Lexington, Kentucky, USA; [c]School of Teacher Education, San Diego State University, San Diego, California, USA; [d]Department of Secondary Education, San Francisco State University, San Francisco, California, USA

ABSTRACT

The adoption and implementation of the Next Generation Science Standards (NGSS) require significant shifts in how K-12 science teachers implement instruction and in the ways that science teacher educators prepare future science teachers. The use of anchoring phenomena to drive instruction is one of these significant shifts. However, identifying phenomena that anchor K-12 student learning and support students in developing conceptual understanding while aligning with the NGSS Performance Expectations can be challenging for teachers, especially for preservice teachers (PSTs). This paper outlines the development and implementation of the ASET Phenomenon Tool (Phenomenon Tool) by a group of science education faculty in a networked improvement community (NIC). The Phenomenon Tool aims to help PSTs identify and evaluate student-centered NGSS phenomena. Based on data collected over five academic years, we have found that more PSTs were able to identify a phenomenon after the NIC faculty implemented the Phenomenon Tool in their science methods courses. In this paper, we also present the PSTs' alternative concepts about phenomena and their weaknesses in describing phenomena. The strategies and possible activities for the use of the phenomenon tool with teachers are discussed at the end.

KEYWORDS

Instructional tools; Networked Improvement Community (NIC); NGSS; phenomena; preservice teachers

Introduction

The adoption and implementation of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) require significant shifts in how K-12 science teachers implement instruction and in how science teacher educators prepare future science teachers (Lederman & Lederman, 2014; National Research Council [NRC], 2012; Windschitl et al., 2014). One of the significant shifts is the use of phenomena to drive science instruction and learning. The NGSS propose that a phenomenon should not be merely used as a "hook" but, instead, should be used for eliciting questions from students and engaging students in relevant science practices to build the necessary knowledge to explain, model, or make predictions

CONTACT Lin Xiang lin.xiang@uky.edu Department of Science, Technology, Engineering, & Mathematics, University of Kentucky, 113 Taylor Education Building, 597 S Upper St, Lexington, KY 40508, USA

*Both authors contributed equally as the first authors of this paper.

from the phenomenon at the end of a lesson or a unit. Students should not just learn about a phenomenon or use it to confirm certain scientific concepts but focus on figuring out why and how the phenomenon happens (NGSS Achieve, 2016).

To align with this vision, Lowell et al. (2021) identify *phenomenon-based* as the first of four key elements to evaluate curriculum and instruction for alignment to the NGSS. They define a more NGSS-aligned curriculum as one with its goals, activities, and lessons "focused on figuring out a conceptually rich phenomenon" (p. 13). Reiser et al. (2021) propose a phenomenon-based conceptual storyline unit as an instructional model to design and implement NGSS-aligned instruction. The storyline typically starts with presenting a phenomenon that anchors students' learning throughout the unit and then engages students in conducting three-dimensional learning to explain the phenomenon by the end of the unit. This type of phenomenon is known as *anchoring phenomena* as they may be used to drive science instruction and learning.

However, identifying phenomena that anchor K-12 student learning and support students' development and conceptual understanding that align with the NGSS Performance Expectations can be challenging (Lo et al., 2014; Lowell et al., 2021), and this may be especially true for preservice teachers (PSTs) given that PSTs have a novice understanding of NGSS and a limited experience with phenomenon-based teaching. This paper presents the development of the ASET Phenomenon Tool (Phenomenon Tool) by a group of faculty members in a Networked Improvement Community (NIC) to support PSTs in identifying phenomena that can anchor three-dimensional science instruction. We describe the development process of the Phenomenon Tool over three iterations by presenting the changes in PSTs' phenomenon responses in nine science methods courses after the tool was implemented, identifying PSTs' alternative concepts about phenomena, summarizing the challenges to develop and implement the tool among the NIC faculty, and describing the refinement of the tool over time. As a result, our audience, especially science teacher educators, may gain a deep understanding of the tool and be able to implement this tool in their science methods courses effectively.

Literature review and theoretical framework

Phenomena in science education documents and standards

Science education literature defines phenomena as "observable events that occur in the universe and that we can use our science knowledge to explain or predict (NGSS Achieve, 2016, p. 1)." Three features of phenomena are derived from this definition. First, phenomena are events that humans can directly (i.e., using senses) or indirectly (i.e., using instruments) detect and examine. Second, phenomena take place in the physical world, which may include various natural settings and human-made settings, such as labs and testing sites. Third, phenomena can be explained or predicted using underlying scientific concepts. These features distinguish phenomena from a range of relevant conceptual entities, such as questions, concepts, and models. For example, "Why is the sky blue?" is not a phenomenon but a question elicited from an observed event (i.e., a phenomenon) that the sky is blue. A phenomenon is a *specific* scenario occurring in a certain situation, whereas a concept is a *general* idea that may help explain one or multiple phenomena (Inouye et al., 2020). In addition, phenomena vary in complexity. A relatively simple phenomenon, such as the oscillatory motion of a simple pendulum, can be studied through a few simple investigations and explained by a small number of concepts. In contrast, making sense of more complex phenomena, such as population fluctuation, diseases, and ecological change, requires more extensive investigations and involves more scientific concepts.

Focusing science education on explaining phenomena has been a core theme in the US science education documents since the last century (American Association for the Advancement of Science [AAAS], 1993, 2009; NRC, 1996). NGSS and *the Framework for K-12 Science Education* (the Framework) (NRC, 2012) take a step further to explicitly require engaging students in authentic science and engineering practices to develop an understanding of disciplinary ideas within the context of scientific phenomena (Bybee, 2014; NRC, 2015). The Framework states, "[the] goal for students is to construct logically coherent explanations of phenomena that incorporate their current understanding of science, or a model that represents it, and are consistent with the available evidence" (NRC, 2012, p. 52). The vision of NGSS on the explicit use of phenomena in science instruction is rooted in the following perspectives: 1) phenomena have been traditionally downplayed in science education despite their central role in science, 2) engaging students in explaining phenomena creates opportunities for students to develop deeper and transferable knowledge by figuring out why something happens, and 3) engaging students in explaining real-life phenomena allows students to recognize the importance of scientific ideas in the real world and appreciate the social relevance of science (NGSS Achieve, 2016).

The challenges of using phenomena to drive science instruction

It became evident from teacher professional development efforts that teachers needed to learn how to identify phenomena to drive the learning of core ideas while connecting to diverse learners (NGSS Achieve, 2017). Lo et al. (2014) described multiple challenges in teachers' use of phenomena during instruction, including 1) confusing phenomena with investigations, 2) having difficulties in presenting phenomena in a way that elicits targeted explanations, and 3) having difficulties in using phenomena to promote micro-level understanding. Lowell et al. (2021) also reported that teachers often used phenomena as a "hook" or an example of a scientific idea, even when the curriculum was intended for students to explore and explain phenomena.

Unfortunately, there is currently no consensus on how to engage and support teachers in selecting phenomena that drive NGSS-aligned science instruction. So far, very few attempts exist to help teachers choose proper anchoring phenomena for their instruction. Penuel and Bell (2016) proposed seven qualities for a good anchoring phenomenon, including 1) relating to students' experience, 2) supporting the understanding of disciplinary core ideas (DCIs) and performing various practices, 3) being complex enough to involve a series of investigations, 4) being observable, 5) calling for an explanation, 6) having some existing learning resources, such as data or text, and 7) having public significance. Willard (2017) suggested that teachers first identify the target DCIs and then go through a flowchart containing five questions to select proper anchoring phenomena, including 1) whether the phenomenon addresses the entire DCI element, 2) whether the phenomenon is observable to students, 3) whether the phenomenon is comprehensible and investigable to students, 4) whether the phenomenon is relevant to students and may engage students in exploring the explanation, and 5) whether the phenomenon is efficient to use in term of the financial costs and time investment. These criteria ask teachers to consider observability, connections to target DCIs, supportiveness to reasoning and learning practices, and relevance to students when selecting an effective anchoring phenomenon. While we agree these currently published criteria provide valuable guidelines, we argue they lack explicit language to ask teachers to distinguish a phenomenon from the relevant conceptual constructs, such as questions, concepts, investigations, etc. From our observations in science methods courses, PSTs' challenges in selecting anchoring phenomena are associated with a lack of understanding about what phenomena are, how to identify the scope of a phenomenon to determine whether it suits the targeted performance expectation, and how to facilitate students in exploring and explaining phenomena. This calls for more studies on the development and implementation of tools to support teachers' ability to identify and use anchoring phenomena for science instruction.

Improvement science (IS) and networked improvement communities (NIC)

Science methods courses play a crucial role in preparing PSTs to be ready to take on the challenges of NGSS (NRC, 2012; Windschitl et al., 2014), including the need to guide the selection of scientifically sound and instructionally viable phenomena, because they are often the only course(s) in teacher preparation that solely focus on science teaching (NRC, 2001). However, currently, there is virtually no documented information about the readiness of science education faculty or existing supports available to them for teaching about NGSS, including phenomena. In addition, university education departments often have only one or two science education faculty members, leaving them to learn about NGSS on their own. Even at those sites with multiple faculty responsible for science teacher preparation, many lack time for professional development or collaboration (Sunal et al., 2001).

One strategy that has been used to facilitate communication and cooperation among individuals across institutions working to solve complex problems, such as fostering PST understanding of NGSS, is to incorporate the Improvement Science (IS) Framework (Berwick, 2008; Bryk et al., 2015; Lewis, 2015) to develop Networked Improvement Communities (NICs). The IS framework was selected for this project because it is committed to (a) a joint definition of problems of teaching and learning practice by researchers and practitioners, (b) consideration of variation among contexts, (c) an iterative design process that includes collection and sharing of data regularly across stakeholders in the group, and (d) development of capacity for scaling and sustaining change in systems (Bryk et al., 2015). Guided by these principles, a group of individuals across multiple levels and institutions, especially those who are most directly influenced by innovations and potential solutions to problems, are brought together to form a NIC to develop and test innovations aimed at solving the same problems (Bryk et al., 2011; LeMahieu et al., 2017). NIC members collaboratively define the problems, the improvement goals, and the changes made to achieve the goals, and then they implement iterative inquiry cycles, typically the plan-do-study-act (PDSA) cycle, to generate solutions. During the process, the developed knowledge and solutions are rapidly spread across the networked institutes (Cobb & Virella, 2019). Unlike the traditional research design, IS and NICs do not view variation as problematic nor stress the fidelity of implementing innovations at new sites. Recognizing the existence of variation in different sites, IS and NICs view variation as a potential source of ideas for what works and with whom, and expect modifications on the innovation when it is implemented at the new site (Lewis, 2015). The current study reflects the efforts to develop a supporting tool to enhance PST's understanding of phenomena and their ability to design phenomenon-based instruction through our NIC. Details about the formation of the NIC are described in the study context below.

Research questions

In this study, we developed and implemented the ASET Phenomenon Tool to foster PSTs' understanding of phenomena through three PDSA iterations. The following research questions were used to guide our data analyses and reflect on the tool developments:

(1) What did PSTs identify as phenomena while developing a three-dimensional science unit plan for their science methods courses?
(2) What were the challenges and weaknesses that NIC faculty identified while developing and implementing the Phenomenon Tool?
(3) What should be included in the Phenomenon Tool to support PSTs in identifying NGSS-aligned anchoring phenomena?
(4) To what extent were PSTs able to identify a phenomenon after using the Phenomenon Tool in their science methods courses?

Context of the study

The NIC

The work reported in this paper was done by a group of 15 university faculty members across eight universities working together as a NIC. The NIC was formed within the scope of the ASET and A-STEP projects to accomplish two goals: 1) facilitating communication and sharing expertise among science education faculty members working toward a common goal of improving PST's understanding of NGSS within science methods courses, and 2) disseminating, getting feedback about, and training science education faculty members on the use of tools designed to facilitate PST's understanding of NGSS.

The 15 NIC members were selected because they each taught the science methods course for future teachers at their university and they were all working in states that were adopting NGSS or standards closely aligned with these. These faculty members were also known to the research team and indicated a desire to improve instruction to better prepare teachers to teach science lessons that aligned with the vision of NGSS. Initially, faculty members involved with teaching the science methods courses for secondary education were selected, and then it was decided to include their elementary science methods counterparts to allow for the inclusion of two faculty members from each university. This inclusion of a second faculty member from most campuses was intentional to ensure accountability locally within the university and not just with the NIC members who were spread across multiple states. At the beginning of the study, the faculty members varied in their experience of teaching science methods courses, ranging from a new instructor to 17 years of teaching experience. They also varied in their awareness of NGSS with some having been involved with development at the state level, others having supported early implementation efforts in local school districts and the remaining having only awareness of the published documents and website. None of the NIC members had specific experience with phenomena as described in the NGSS as the NIC was forming.

The NIC members met for monthly videoconferences and an annual in-person multi-day meeting from 2016–2022. During these meetings, NIC members shared ideas and goals for their science methods courses, presented curricular ideas related to NGSS, and discussed successes and failures around NGSS teaching in their courses. They also shared curricular and NGSS-related resources over the years via the NIC website. While the overarching goal was to improve instruction in our science methods courses to align with the vision of NGSS, within the NIC, smaller and more specific problems were defined and explored by sub-groups, such as the phenomenon-subgroup that focused on developing the Phenomenon Tool.

Science methods course instruction

As part of the larger efforts of the NIC, faculty members each implemented the ASET Toolkit to support PSTs' understanding of how to align science teaching to the vision of NGSS. This included the use of the ASET 3-Dimensional Mapping Tool (3D Map) during class to identify dimensions of the NGSS in exemplar lessons and to discuss how these dimensions could be woven together when enacting the lesson (Sinapuelas et al., 2018, 2019). They also included the use of the ASET Science and Engineering Practice Tools (SEP Tools) to support PSTs in understanding the depth and complexity of these SEPs and consideration of what aspects of a given SEP were included in these exemplar lessons. While faculty members implemented these tools in a way that best fit their unique classroom setting, they each required that students complete a 3D Map (Figure 1) as part of their summative course assignment to develop a multi-day science lesson sequence. The lesson

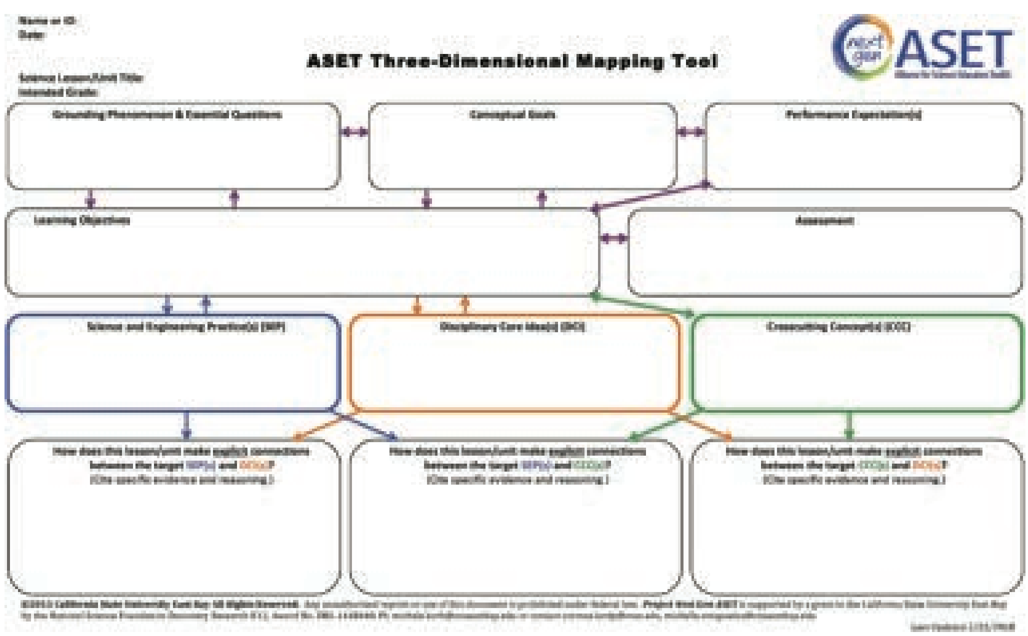


Figure 1. The ASET 3-dimensional mapping tool.

sequence unit topic was selected by the PSTs. The 3D Map was included as part of this assignment at each site in an effort to prompt students to consider how each of these NGSS dimensions and larger lesson planning components such as assessment were being enacted through their lesson sequence (Sinapuelas et al., 2018, 2019).

Phenomenon-subgroup

This study began during the in-person meeting at the end of the 2016–2017 academic year. During this meeting, the NIC faculty worked in pairs to characterize the phenomena identified by PSTs in the 2016–2017 academic year as part of the science unit planning assignment completed for their secondary science methods courses. These efforts revealed a lack of understanding of phenomena among these PSTs.

Reflecting on the need to make an improvement around Phenomena instruction, the NIC members set enhancing PSTs' understanding of phenomena and their abilities to identify anchoring phenomena as an improvement goal and proposed to develop a supporting tool to assist PSTs in understanding and identifying anchoring phenomena. It was decided to create a phenomena-focused working group (hereafter referred to as "phenomenon subgroup") to meet this improvement goal. The phenomenon subgroup consisted of one ASET project researcher and four faculty members from three universities, focused on addressing the specific problem of supporting our PSTs in identifying effective anchoring phenomena for use in their classrooms.

The phenomenon subgroup carried out a series of three Plan-Do-Study-Act (PDSA) cycles (Bryk et al., 2015; Deming, 1994) to develop and refine the Phenomenon Tool during the 2016–2019, 2021–2022, and 2022–2023 academic years. During each PDSA cycle, the phenomena identified by PSTs as part of their science unit planning assignment were reviewed by the phenomenon subgroup with the aim of determining how to create, implement, or modify the phenomenon tool (*Plan*). The phenomenon subgroup then created or modified the phenomenon tool as per the discussion and shared it with NIC members to collect new phenomenon responses from PSTs the following semester (*Do*). Next, the newly collected phenomenon responses were analyzed, and instructors' tool implementation experiences were discussed (*Study*) to determine how well the tool supported PSTs in understanding and identifying anchoring phenomena and how the tool could be improved (*Act*). Table 1 provides a detailed summary of the three iterations, including 1) the frequency at which phenomena were discussed during monthly meetings with the entire NIC, 2) the specific topics related to phenomena that emerged from these discussions, 3) the notes on the work that the phenomenon subgroup engaged in to bring new ideas and understanding to the larger group, and 4) a timeline of when the three versions of the phenomenon tool were released to the larger NIC.

Methods

Participants

This study included the PSTs who enrolled in nine science methods courses focused on secondary instruction taught by NIC members across six universities in five academic years (AYs) and consented to include their work as research data for this study. PSTs in these

Table 1. Timeline of NIC discussion related to phenomena and phenomenon subgroup activities.

Academic Year	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22
NIC meetings related to phenomena	• An in-person multi-day NIC meeting	• Six monthly NIC videoconferences	• Two monthly NIC videoconferences	• One monthly NIC videoconferences	• No meeting due to COVID-19 pandemic	• Three monthly NIC videoconferences
Subgroup meetings related to phenomena	• Subgroup formed during Summer 2017	• Five meetings	• Five meetings	• No meetings	• One meeting	• Seven meetings
Activities related to phenomena	• NIC members shared their general instructional approaches related to phenomena and identified the need to provide PSTs with more support in their identification and implementation of phenomena	• NIC members shared their instructional approaches related to phenomena in methods courses at the eight institutions • Subgroup shared initial data coding to characterize phenomena and a draft of phenomenon tool • NIC members started to use the phenomenon tool in methods courses	• Subgroup shared data coding of phenomenon from 2017–18 • NIC members shared further instructional shifts being made to support identification of NGSS phenomenon • Subgroup continued coding phenomenon responses from PSTs	• NIC members discussed the tool to support elementary teachers' understanding of NGSS phenomenon	• Subgroup created new version of phenomenon tool in summer 2021	• NIC members used the new tool version in methods courses • Subgroup received feedback and made improvements to phenomenon tool
Phenomenon Tool Development		Version 1			Version 2	Version 3

courses were enrolled to partially fulfill the requirements for a teaching credential. Some of them sought to be certified in one science content area, such as biology, chemistry, earth science, or physics; some others were certified in middle school science, which integrated all science content areas. Given that these PSTs were entering a teacher credentialing program, none had significant teaching experience, and they graduated from high school before the implementation of NGSS, it was assumed they began the science methods courses with a novice understanding of NGSS and a limited vision for phenomenon-based teaching. In the science methods courses, PSTs worked in small groups or individually to develop the lesson sequence unit and complete the 3D Map.

Materials and data collection

Two types of data were collected to assist in the development of the Phenomenon Tool: PSTs' phenomenon responses in the 3D Maps and the field notes of NIC videoconferences and phenomenon subgroup videoconferences. For this study, 3D Maps completed by PSTs as part of the summative lesson sequence development assignment in each science methods course were collected since they included the phenomenon identified for each science lesson sequence, and so were used to represent the PSTs ability to identify phenomena for use in a classroom lesson at the end of semester. A total of 220 maps were collected over three PDSA iterations, and the phenomenon responses in these maps were used as the research data.

All of the monthly NIC videoconferences and phenomenon subgroup videoconferences were video recorded, and field notes were generated based on the recordings. The discussions of phenomena in these field notes were reviewed by the phenomenon-subgroup to identify the themes emerging from the development and use of the current phenomenon tool versions and document the processes of improvements.

Data analysis

Our data analysis was guided by the NGSS view of phenomena (NGSS Achieve, 2016) and the identification of emerging themes from the gathered data (Corbin & Strauss, 1990; Crabtree & Miller, 1999). During the initial stages of data analysis, a set of 56 phenomenon responses from PSTs were sorted by the NIC members into three categories: phenomenon, maybe a phenomenon, not a phenomenon, during our annual NIC in-person meeting. After sorting the responses, the NIC as a whole discussed what they noticed in these PST-identified phenomena and created a list of initial themes. Starting with these initial themes identified from the larger NIC, the phenomenon subgroup continued the analysis and further coded the phenomena to determine emerging themes in the data. From these efforts, more specific criteria to sort phenomena were created (Table 2). Then, PST-identified phenomena were coded based on these criteria by each member of the phenomenon subgroup to confirm agreement.

We viewed these criteria as sequential, and they led to a three-step coding of PST-identified phenomena. First, we coded whether a response was a phenomenon based on criteria 1–3. If it did not meet all three, we did not count it as a phenomenon and did not continue to code the response. Once we determined if a given response was a phenomenon, consideration was given for criteria 4–7 to measure how well it aligned with the vision of

Table 2. Coding criteria for PST phenomena responses.

It is a phenomenon if:
(1) It is an event or process that is observable directly or indirectly, through human senses or instrumentation
(a) Should relate to one coherent phenomenon if written as multiple questions or statements
(2) It is grounded in the natural world
(3) Linking multiple scientific concepts is required to generate a complete explanation
It is an anchoring phenomenon if it:
(4) Elicits explanations that are aligned to NGSS DCI learning goals
(5) Is specific or contextualized enough so that the explanations can address a particular situation
(6) Is large enough for students to explore various aspects related to the phenomenon in multiple modalities that encompass more than one lesson/activity
(7) Has an explanation that can reasonably be developed from a series of investigations that utilize the SEPs
It is presented well to students if it:
(8) Is relevant and interesting, ideally relates directly to the students' life
(9) Is presented in a way that clearly provides or elicits an image to students (picture or mental imagery) of an event or process that is observable, either directly or indirectly.

NGSS because these four criteria define what is necessary to determine if the identified phenomenon could be used to anchor a unit or subset of lessons aligned with the NGSS. Separating criteria 1–3 for the larger set of *phenomena* from criteria 4–7 for *anchoring phenomena* helped to clarify the contextual specificity of these terms. Again, a response had to be coded as an anchoring phenomenon (criteria 1–7) to be considered if it is well-presented (criteria 8–9). Criteria 8–9 reflect the personal and cultural relevance to the K-12 students' lives and the planned presentation of the phenomenon. A phenomenon response that satisfied all nine criteria was regarded as a well-presented anchoring phenomenon.

The phenomenon subgroup applied the coding scheme to analyze the PSTs' phenomenon responses gathered during 2016–2019, 2021, and 2022. In this article, we present our coding for the first three criteria, which classified the responses into "phenomenon" and "not-a-phenomenon" groups, to identify the extent to which PSTs could identify a phenomenon before the creation of the phenomenon tool and after implementing the phenomenon tool. At this point, we had not formally coded the gathered phenomenon responses for the second category (i.e., anchoring phenomenon) and the third category (i.e., how well the phenomenon would be presented in PST's classroom) as these analyses require consideration of the entire lesson plan and related materials. In other words, without reading the lesson plans, we could not confidently say if it was an anchoring phenomenon or was presented well to students. In the first PSDA cycle, all five phenomenon-subgroup members participated in coding. During the process, they first coded the phenomenon responses independently, and then compared the coding results. Any discrepancies were solved through discussions. Three of the five phenomenon-subgroup members coded the phenomenon responses in the rest of the two PDSA cycles following the same procedure.

After coding each year, we specifically examined the "not-a-phenomenon" group and summarized what PSTs mistakenly identified as phenomena in these responses. Trends were identified within this to characterize patterns of confusion in identifying a phenomenon. From this, we characterized the further improvements we hoped to make in terms of supporting students' identification of the phenomenon. When analyzing the field notes generated from the review of NIC videoconferences during the same PDSA cycle, we summarized the challenges NIC members mentioned when they engaged in activities to support their PSTs in identifying anchoring phenomena, their reflection on the phenomenon tool implementation, and their feedback on the phenomenon tool. We then overlayed these trends with those identified from the PSTs "not-a-phenomenon" items to identify any correlations or related themes that emerged. Next, we used the analysis results from both PST phenomenon responses and NIC videoconference field notes as the rationale for improving the Phenomenon Tool.

Findings

In this section, we present the development of the Phenomenon Tool over three PDSA cycles. For each PDSA cycle, we organize the findings based on the four research questions.

Development of the phenomenon tool: version 1

The development of the Phenomenon Tool was initiated by the NIC faculty members sorting 56 phenomena sampled from PSTs' 3D maps into categories of "phenomenon," "maybe a phenomenon," and "not a phenomenon." We anticipated that most of the PSTs' phenomenon responses in the science unit assignments would be coded as "a phenomenon" or "maybe a phenomenon." However, out of the 56 phenomenon responses, only 8 (14%) were coded as phenomena, 13 (23%) were coded as "maybe a phenomenon," and 35 (63%) were coded as "not a phenomenon." Out of the 60 phenomenon responses gathered in the 2016–2017 AY, only 16 (27%) satisfied criteria 1–3 and, therefore, were coded as phenomena (Figure 2). Further evaluation of "not-a-phenomenon" responses revealed that PSTs confused phenomena with questions and concepts because many PSTs proposed questions, often focused on defining a concept, as phenomena (Table 3). For example, questions such as "What are genes? What does it mean if a gene is dominant or recessive?" "What is the structure of matter?" and "Why do some things react together" were identified by PSTs as

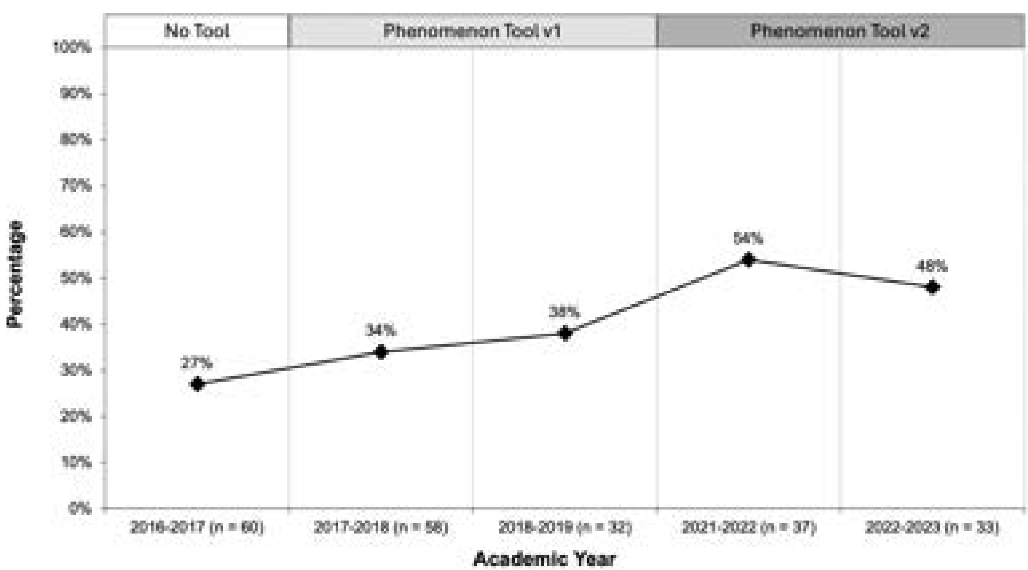


Figure 2. Percentages of PST phenomenon responses coded as a phenomenon over five academic years.

Table 3. Alternative concepts and weaknesses of PSTs' "not-a-phenomenon" responses.

Alternative concept/Weakness	Example
Propose questions that focus on defining concepts	• How do solid, liquid, and gas molecules behave, interact, and change with changes of thermal energy?
Regard concepts as phenomena	• Static electricity • Life Changes Over Time
Regard learning objectives as phenomena	• Students will construct an explanation for why the molecules listed under inputs are not identical to the molecules that are listed under outputs using the structure of macromolecules as evidence that rearrangement must occur in a one paragraph response.
No observations are specified	• Salt shakers and a cup of water for our phenomenon • Mantis Shrimps Punch • Ponds • A picture of the Grand Canyon with the Colorado River at the bottom.
Regard student learning activities as phenomena	• Students are encouraged to think about questions and answer those questions based on how all living life is made of specialized cells that have DNA.
Regard a scientific conclusion or claim as a phenomenon	• Homeostasis is essential for an organism to accommodate changes in the surrounding environment and to sustain life • Ocean Acidification Due to Increase in Carbon Dioxide

phenomena. Two types of challenges around how to support PSTs in identifying a phenomenon to anchor an NGSS lesson were uncovered during the process of sorting and characterizing the PST-identified phenomena.

The first challenge recognized by the phenomenon subgroup was that, although the inclusion of a phenomenon box at the top left of the 3D Mapping Tool prompted the identification of the anchoring phenomenon for a given lesson sequence or unit, the 3D Mapping Tool alone did not provide sufficient support because of a lack of understanding of phenomena among PSTs. It was decided that clarity around what defines a phenomenon to anchor an NGSS lesson was needed to support shifting PSTs' identification of anchoring phenomenon. It also suggested PSTs required additional support in evaluating their own choice of phenomenon.

Second, we found that NIC faculty members' definitions of phenomenon and what is needed for a phenomenon to anchor science instruction were not as clear and consistent as we had previously assumed. Some of the NIC faculty did not realize the need to differentiate *phenomena* from *anchoring phenomena*. In making their sorting decision, a majority of NIC faculty considered not only if it was an observable event in the natural world but also how it was informing the PSTs' teaching. It was then decided that this second aspect is critical to consider for an anchoring phenomenon, but faculty must first identify if a given response from a PST is simply a phenomenon. Moreover, some of the NIC members did not define large, complex scientific events as anchoring phenomena because they were too large to explain in a science classroom, while others were adamant that they were indeed scientific phenomena and should, therefore, be included as anchoring phenomena. Simultaneously, some faculty did not regard an event that could easily be explained within a single class period as an anchoring phenomenon, arguing that the scope was too small to be a phenomenon in an NGSS-aligned class.

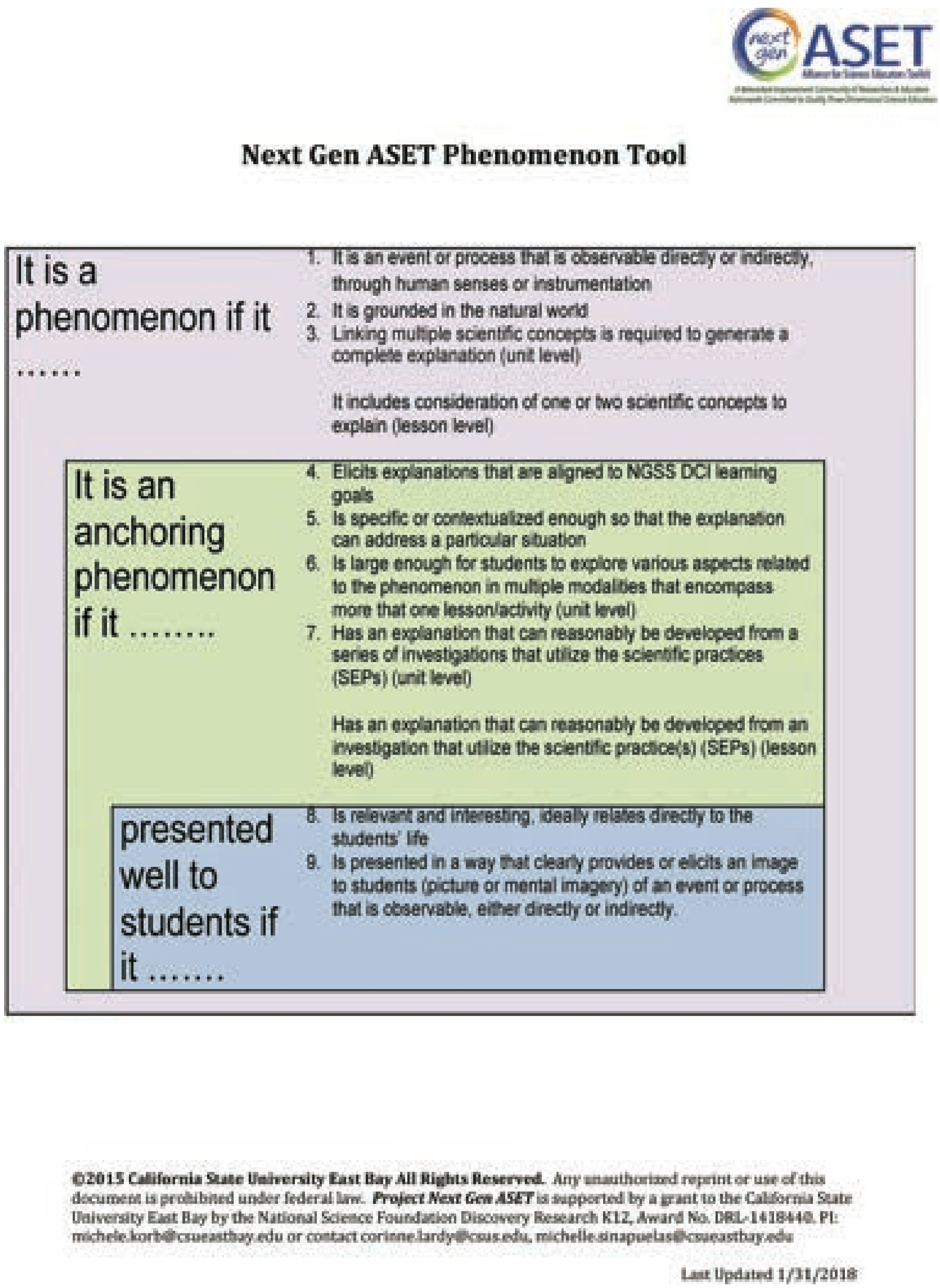
These discussions between our NIC faculty illustrated that supporting PSTs in understanding how to identify, evaluate, and implement phenomena would not be as simple as previously expected. The discussions led to an insight that instruction for PSTs needed to support their ability to distinguish phenomena from concepts and questions, as well as distinguish among a larger set of phenomena in the natural world, a smaller set that could be used to anchor a set of lessons aligned to NGSS (i.e., anchoring phenomena), and a very small set of phenomena that could be easily answered with simple investigations (i.e., investigative phenomena). Therefore, the phenomenon subgroup recommended modifying the 3D Mapping Tool slightly to provide a place for PSTs to include their phenomenon separately from the essential questions that might be asked during instruction to guide the exploration of the phenomenon. This separation is evident by the use of "&" instead of the original "/" in the Phenomenon Box in Figure 1 and was done to help PSTs distinguish between phenomena and questions. More importantly, they recommended creating an additional tool that would support the identification of an anchoring phenomenon, divided into three general categories: a) phenomenon, b) anchoring phenomenon, and c) anchoring phenomenon presented well for a classroom. From these recommendations, in the summer of 2017, the phenomenon subgroup adopted the criteria created by the NIC faculty while coding the PSTs' phenomenon responses to develop the first version of the Phenomenon Tool (Figure 3).

The Phenomenon Tool V1.0, alongside initial results from coding, was shared with the larger NIC, and NIC members integrated using the tool in their science methods classes during the 2017–2018 AY and 2018–2019 AY. To integrate the tool as part of our larger science methods courses, PSTs explored and discussed the role of phenomena in science education and selected possible phenomena for classroom lessons; they used the Phenomenon Tool V1.0 to evaluate and refine their selections. This identification of the initial problem, the challenges to supporting PSTs to identify anchoring phenomenon, and the creation of the Phenomenon Tool as a result of evaluation around this problem completed the first PDSA cycle in our work.

Development of the phenomenon tool: version 2

Coding the PST phenomenon responses gathered from the 3D Mapping Tool during the 2017–2018 AY and 2018–2019 AY, we observed a small but noticeable increase in the percentage of PSTs' phenomenon responses that fit the three criteria of phenomena, an increase from 27% to 38% (Figure 2) and fewer PSTs directly posted questions as phenomena. The alternative concepts revealed by the "not-a-phenomenon" responses included 1) regarding a concept as a phenomenon, 2) regarding a learning objective as a phenomenon, 3) regarding a learning activity as phenomenon, 4) lack of the observational specification of a phenomenon, and 5) regarding a scientific conclusion or claim as a phenomenon (Table 3).

During 2017–2018 AY and 2018–2019 AY, our NIC faculty continued to discuss the phenomena identified by the PSTs enrolled in their science methods courses and reflect on their implementation of the Phenomenon Tool. The NIC faculty realized that it was not enough to simply present the phenomenon criteria outlined on the tool to PSTs. A certain scaffold was needed to engage the PSTs in active reflection and discussion of the phenomena they identified based on the criteria. Consequently, during the summer of 2021, as the university shutdowns from the COVID-19 pandemic lessened, the phenomenon subgroup acted on the above realization to create the second version of the Phenomena Tool (Figure 4). Three improvements were made to support the PSTs in engaging in structured reflection and discussion of phenomena. Table 4 outlines the improvements made and the corresponding rationale based on the feedback from the NIC members.


Next Gen ASET Phenomenon Tool

It is a phenomenon if it ......

1. It is an event or process that is observable directly or indirectly, through human senses or instrumentation
2. It is grounded in the natural world
3. Linking multiple scientific concepts is required to generate a complete explanation (unit level)

   It includes consideration of one or two scientific concepts to explain (lesson level)

It is an anchoring phenomenon if it ....

4. Elicits explanations that are aligned to NGSS DCI learning goals
5. Is specific or contextualized enough so that the explanation can address a particular situation
6. Is large enough for students to explore various aspects related to the phenomenon in multiple modalities that encompass more that one lesson/activity (unit level)
7. Has an explanation that can reasonably be developed from a series of investigations that utilize the scientific practices (SEPs) (unit level)

   Has an explanation that can reasonably be developed from an investigation that utilize the scientific practice(s) (SEPs) (lesson level)

presented well to students if it ....

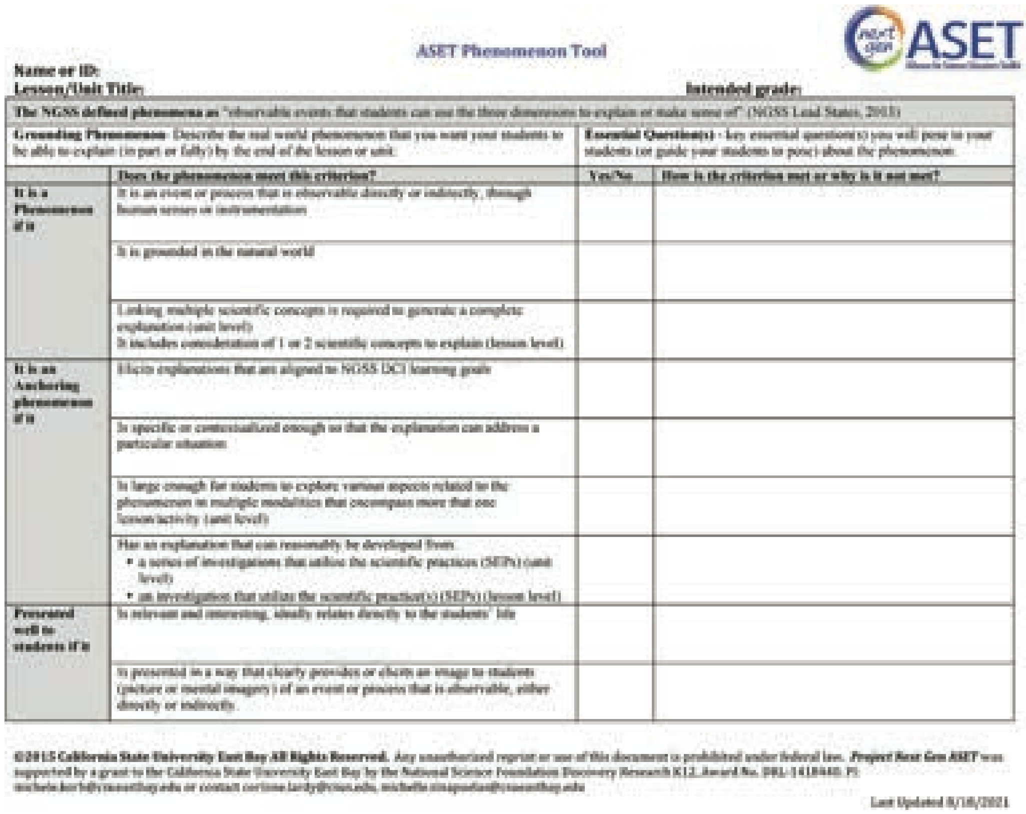
8. Is relevant and interesting, ideally relates directly to the students' life
9. Is presented in a way that clearly provides or elicits an image to students (picture or mental imagery) of an event or process that is observable, either directly or indirectly.

©2015 California State University East Bay All Rights Reserved. Any unauthorized reprint or use of this document is prohibited under federal law. *Project Next Gen ASET* is supported by a grant to the California State University East Bay by the National Science Foundation Discovery Research K12, Award No. DRL-1418440. PI: michele.korb@csueastbay.edu or contact corinne.lardy@csus.edu, michelle.sinapuelas@csueastbay.edu

Last Updated 1/31/2018

Figure 3. The phenomenon tool V 1.0.

The Phenomenon Tool V2.0 was shared with the larger NIC and used in NIC members' science methods courses during the 2021–2022 AY and 2022–2023 AY. In these courses,


ASET Phenomenon Tool

Name or ID:
Lesson/Unit Title:
Intended grade:

The NGSS defined phenomena as "observable events that students can use the three dimensions to explain or make sense of" (NGSS Lead States, 2013)			
Grounding Phenomenon: Describe the real world phenomenon that you want your students to be able to explain (in part or fully) by the end of the lesson or unit		Essential Question(s) - key essential question(s) you will pose to your students (or guide your students to pose) about the phenomenon	
	Does the phenomenon meet this criterion?	Yes/No	How is the criterion met or why is it not met?
It is a Phenomenon if it	It is an event or process that is observable directly or indirectly, through human senses or instrumentation		
	It is grounded in the natural world		
	Linking multiple scientific concepts is required to generate a complete explanation (unit level) It includes consideration of 1 or 2 scientific concepts to explain (lesson level)		
It is an Anchoring phenomenon if it	Elicits explanations that are aligned to NGSS DCI learning goals		
	Is specific or contextualized enough so that the explanation can address a particular situation		
	Is large enough for students to explore various aspects related to the phenomenon in multiple modalities that encompass more than one lesson/activity (unit level)		
	Has an explanation that can reasonably be developed from: • a series of investigations that utilize the scientific practices (SEPs) (unit level) • an investigation that utilizes the scientific practice(s) (SEPs) (lesson level)		
Presented well to students if it	Is relevant and interesting, ideally relates directly to the students' life		
	Is presented in a way that clearly provides or elicits an image to students (picture or mental imagery) of an event or process that is observable, either directly or indirectly		

©2015 California State University East Bay All Rights Reserved. Any unauthorized reprint or use of this document is prohibited under federal law. Project Next Gen ASET was supported by a grant to the California State University East Bay by the National Science Foundation Discovery Research K12, Award No. DRL-1418440.

Last Updated 8/18/2021

Figure 4. The phenomenon tool V 2.0.

Table 4. Improvements and rationale considered in creating the phenomenon tool V 2.0.

Improvements	Rationale
• Reformatted to provide criteria from Version 1 in the left column. A column on the right provides space for PSTs to write their justification of how the criterion was met or not.	• Provides PSTs a space and structure to reflect on the phenomenon based on each criterion
• Provided a middle column for PSTs to indicate Yes/No for if the criterion had been met.	• Forces PSTs to assess whether a phenomenon meets a particular criterion
• Included boxes at the top of the table to write down identified anchoring phenomena and relevant essential questions	• Provides PSTs a place on the tool to articulate the phenomenon and essential questions so they may discuss the phenomenon independently of the entire lesson plan. Namely, PSTs can clearly articulate just the phenomenon

PSTs either used the Phenomenon Tool to evaluate phenomenon examples provided by the instructors or the phenomena generated themselves. In either case, they needed to assess the phenomenon based on each criterion and justify their opinions. Then, the instructors could use the student artifacts (i.e., the Phenomenon Tool sheets filled out by PSTs) to assess PSTs' understanding and hold class discussions on PSTs' alternative concepts about phenomena. This identification of further improvements and action to modify the original Phenomenon Tool in response completed the second PDSA cycle in our work.

Development of the phenomenon tool: version 3

Coding the PST phenomenon responses gathered as part of completing their 3D Mapping Tool during the 2021–2022 AY and 2022–2023 AY, we observed a clear increase in the percentage of PSTs' phenomenon responses that fit the criteria of phenomena, from 38% to 54% (Figure 2). No new alternative concepts were revealed among the "not-a-phenomenon" responses from the two academic years.

During the 2021–22 AY and 2022–23 AY, the phenomenon subgroup identified six weaknesses of the Phenomenon Tool v2.0 from the feedback provided by the larger NIC during monthly meetings. First, the NIC members suggested revising and reorganizing some criteria to better capture the essence of anchoring phenomena. For example, at this point, NIC members reached the agreement that developing an explanation for the phenomena is essential in NGSS-aligned learning and an anchoring phenomenon should be able to connect multiple scientific concepts. Therefore, they suggested moving the criterion, "linking multiple scientific concepts is required to generate a complete explanation," from the "phenomenon" category into the "anchoring phenomenon" category. Meanwhile, they pointed out that the criterion "Is large enough for students to explore various aspects related to the phenomenon in multiple modalities that encompass more than one lesson/activity" appeared to overlap with the criterion mentioned above. Second, no criteria in the phenomenon tool V2.0 may be applied to evaluate the PSTs' phenomenon responses related to human activities or human-made artifacts, such as a bridge or a car. Third, the phenomenon tool V2.0 did not involve students in considering crosscutting concepts when identifying anchoring phenomena. Fourth, the name of the third category, "presented well to students," did not adequately prompt a student-centered instructional view. The two criteria, criteria 8 and 9, were also not phrased in a way that encouraged PSTs to make clear connections to students' funds of knowledge and social justice issues. Fifth, NIC members suggested adjusting the order of some criteria to prompt a coherent and independent thinking process of anchoring phenomena among PSTs. Sixth, an additional scaffold was needed to enable PSTs or other end users to use the tool more independently.

From these, and in consultation with an expert in the field of phenomenon-based NGSS-aligned science teaching who also served as an external evaluator on the project, further improvements were made that resulted in the third version of the Phenomenon Tool (Figure 5). This version kept the same format as V2.0, but improvements in the language were made to address the weaknesses identified. The criteria were refined to highlight the key features of effective anchoring phenomena. The phrase *human-affected world* was used along with the natural world to include the phenomena related to human activity and engineering design. The criterion order was adjusted to streamline PST's thinking process. The criterion language was improved to further message the refined criteria. For example, action verbs such as "describes" instead of "it is" were used to message instructors' expectations. Also, users were asked to consider all three dimensions when identifying or evaluating a phenomenon. Finally, prompting questions were added as a second page in reference to each criterion to provide an alternative way to think of these criteria and enable PSTs to use the tool more independently. Table 5 outlines the improvements made and the rationale. This identification of further improvements and the

ASET Phenomenon Tool

Name or ID:
Lesson/Unit Title: **Intended grade:**

Statement of Phenomenon:
Essential Questions you would use to prompt your students:

The NGSS defined phenomena as "observable events that students can use the three dimensions to explain or make sense of" (NGSS Lead States, 2013)			
Grounding Phenomenon- Describe the real world phenomenon that you want your students to be able to explain (in part or fully) by the end of the lesson or unit		**Essential Question(s)** - key essential question(s) you will pose to your students (or guide your students to pose) about the phenomenon	
	Does the phenomenon meet this criterion?	**Yes/No**	**How is the criterion met or why is it not met?**
It is a Phenomenon if it	Is grounded in the natural and/or human-affected world (including agriculture, engineering, medicine)		
	Describes an event or process that is observable directly or indirectly, through human senses or instrumentation		
It is an Anchoring phenomenon if it	Describes a specific or contextualized event or process so that the students' explanation addresses a particular situation		
	Linking multiple scientific concepts is required to generate a complete explanation (segment/unit level)		
	Elicits explanations that are aligned to NGSS DCI learning goals		
	Has an explanation that can reasonably be developed from: • a series of investigations that utilize the scientific practices (SEPs) and crosscutting concepts (CCCs) (unit level) • an investigation that utilizes the scientific practice(s) (SEPs) and crosscutting concepts (CCCs) (lesson level)		
Implementation is student centered if it	Is relevant and interesting, building on students' funds of knowledge		
	Is presented in a way that clearly provides or elicits an image to students (picture or mental imagery) of an event or process that is observable, either directly or indirectly		

Last Updated 6/23/2022

ASET Phenomenon Tool

The NGSS defined phenomena as "observable events that students can use the three dimensions to explain or make sense of" (NGSS Lead States, 2013)		
Grounding Phenomenon- Describe the real world phenomenon that you want your students to be able to explain (in part or fully) by the end of the lesson or unit		**Essential Question(s)** - key essential question(s) you will pose to your students (or guide your students to pose) about the phenomenon
	Criterion	**Suggested questions to ask yourself in evaluating phenomenon**
It is a Phenomenon if it	Is grounded in the natural and/or human-affected world (including agriculture, engineering, medicine)	Where can it be observed in the natural world?
	Describes an event or process that is observable directly or indirectly, through human senses or instrumentation	How will students observe it (picture, video clip, real thing, etc.)?
It is an Anchoring phenomenon if it	Describes a specific or contextualized event or process so that the students' explanation addresses a particular situation	What is the specific example of a general process?
	Linking multiple scientific concepts is required to generate a complete explanation (segment/unit level)	List the scientific concepts necessary for students to explain the phenomenon.
	Elicits explanations that are aligned to NGSS DCI learning goals	What are the DCI(s) that align with this phenomenon?
	Has an explanation that can reasonably be developed from: • a series of investigations that utilize the scientific practices (SEPs) and crosscutting concepts (CCCs) (unit level) • an investigation that utilizes the scientific practice(s) (SEPs) and crosscutting concepts (CCCs) (lesson level)	How will students explore this phenomenon?
Implementation is student centered if it	Is relevant and interesting, building on students' funds of knowledge	How does it build upon every day or family experiences? Why will students find it relevant and interesting?
	Is presented in a way that clearly provides or elicits an image to students (picture or mental imagery) of an event or process that is observable, either directly or indirectly	How will it be presented to students?

©2015 California State University East Bay All Rights Reserved. Any unauthorized reprint or use of this document is prohibited under federal law. ***Project Next Gen ASET*** was supported by a grant to the California State University East Bay by the National Science Foundation Discovery Research K12, Award No. DRL-1418440. PI: michele.korb@csueastbay.edu or contact corinne.lardy@csus.edu, michelle.sinapuelas@csueastbay.edu

Last Updated 6/23/2022

Figure 5. The phenomenon tool V 3.0.

Table 5. Improvements and rationale considered in creating the phenomenon tool V 3.0.

Improvement	Rationale
• Modified criterion #1 from Version 2 to say "Describes . . ." instead of simply "It is . . ." to clearly message the expectation that articulation of the phenomena should include a description of what is being considered.	• NIC members realized the need to clearly message their expectation that the phenomena should be observable, and PSTs are expected to describe this process or event.
• Modified criterion #2 from Version 2 to include the *human-affected world* along with the natural world	• NIC members realized that simply saying "natural world" may exclude all phenomena related to human activity or results of human engineering
• Switched the order of criteria #1 and #2 for "it is a phenomenon if it"	• NIC members realized it is more natural to encourage PSTs to first consider where an event occurs and then whether it is observable.
• Moved criterion #3 down to be a criterion for "it is an anchoring phenomenon if it"	• NIC members realized that linking multiple concepts is a requirement for an anchoring phenomenon.
• Modified Criterion #5 from Version 2 to prompt for evaluation of the phenomenon provided	• This change was made to further message and evaluate the PSTs ability to describe the observable event that was now the second criteria in Version 3. It highlights that a phenomenon is a specific example of a general process.
• Moved criterion #4 from Version 2 down to criterion # 5 in Version 3 and determined the current order of criteria #3, #4, and #5 in version 3 for "it is an anchoring phenomenon if it"	• This change was made to provide a coherent thinking process that encourages PSTs to realize an anchoring phenomenon being a specific example of a general process and it needs to link multiple scientific concepts and its explanation is aligned with NGSS DCI learning goals.
• Deleted Criterion #6 from Version 2	• This criterion became redundant since criteria # 4 in Version 3 prompted for the need to link multiple concepts.
• Modified criterion #7 from Version 2 to include both SEPs and CCCs	• This change was made to include all three dimensions for identifying anchoring phenomena.
• Modified criterion #8 from Version 2 to say "building on students funds of knowledge" in place of "ideally relates directly to the student's life"	• This change was made to more specifically link with language used in many of our science methods courses and current literature to specify students' funds of knowledge rather than the originally more general phrase of students' lives
• Change made to third criterion category to say "Implementation is student-centered if it" instead of "Presented well to students if it"	• This change was made to prompt a student-centered teaching view that considers the relevance of the phenomena to students and possibility for students to observe or explore the phenomena.
• Added a second page with refined criteria listed on the left column and suggested questions to ask users in evaluating phenomenon on the right column	• This change provides an alternative way to think of the criteria and enables PSTs to use the tool more independently

actions to modify the Phenomenon Tool in response completed the third PDSA Cycle in our work.

Discussion

Guided by the IS framework, the current study presents a process in which a group of NIC faculty developed and refined a phenomenon tool through three PDSA cycles for supporting PSTs to identify and evaluate phenomena that may anchor NGSS-aligned science instruction. During the iterations, we identified PSTs' alternative concepts about phenomena and explored strategies to design and implement the ASET Phenomenon Tool effectively in science methods courses. By the time we wrote up this work, we had found that using the Phenomenon Tool led to more PSTs being able to identify a phenomenon to anchor their science units.

One consistent theme that arose through NIC faculty discussions around the PST-identified phenomena was the explicit recognition of PSTs' weak understanding of anchoring phenomena, suggested by 46 ~ 73% of phenomenon responses proposed by PSTs as anchoring phenomena in their 3D Maps that were not even phenomena (Figure 2). Lo et al. (2014) found that some teachers confused phenomena with investigations. Our results expand their findings by revealing that PSTs may also regard questions, concepts, learning objectives, learning activities, or scientific conclusions as phenomena. These findings clearly suggest a low understanding of phenomena among PSTs. We propose that the previously existing tools, such as those from Penuel and Bell (2016) and Willard (2017), do not fully support PSTs in identifying anchoring phenomena because PSTs are still struggling to simply identify a phenomenon. This finding makes clear the need to include phenomenon criteria as the first category in the phenomenon tool presented in this paper to prompt users first to determine whether the selected item is a phenomenon.

Another important finding is that some PSTs' phenomenon responses lack specification on the observable aspect(s) of a phenomenon. Although these responses appear to provide students with some objects to work with or consider, such as "Salt shakers and [a] cup of water" and "Ponds," these responses do not describe any specific processes or events. Therefore, they are so broad and open-ended that students do not know what to observe. This type of phenomenon response is an indicator of a low understanding of phenomena. These PSTs might fail to understand that a phenomenon is a *specific* scenario occurring in a certain situation (Inouye et al., 2020). Or alternatively, it could indicate the PST's low understanding of the particular phenomenon or the relevant content ideas because they might not know which aspect should be specified. In either case, the PSTs are likely to struggle with focusing students on exploring or explaining a certain phenomenon because they are unclear about what students should do with the phenomenon. This finding reinforces another finding from Lo et al. (2014) that teachers had difficulties in presenting phenomena in a way that elicits target explanations. Therefore, more studies should be conducted to learn the underlying reasons and how to assist PSTs in articulating phenomena.

The increasing percentage of PSTs' phenomenon responses that meet the criteria of a phenomenon over five academic years demonstrates the positive impact of the Phenomenon Tool being integrated into science methods courses for PSTs. Meanwhile, we believe two other factors contribute to the positive results—the increased understanding of phenomena and anchoring phenomena and increased experience in implementing the phenomenon tool among NIC faculty. In other words, the NIC faculty members developed their knowledge of the discipline of education on phenomena. The IS framework contends that two different types of knowledge are needed for achieving an improvement: the basic knowledge of the discipline of education and the system of profound knowledge for enacting the basic discipline knowledge in education settings (Deming, 1994; LeMahieu et al., 2017; Lewis, 2015). Taking the example of improving students' capacity to make sense of math problems, Lewis (2015) referred to the basic knowledge from the discipline of education as the knowledge about effective math tasks and instructional strategies, and she regarded the system of profound knowledge as the knowledge of the math teaching systems, the knowledge of motivating educators, and knowledge of organizational routines. In this study, none of the NIC members had specific experience with phenomena as described in the NGSS as the NIC was forming. By working as a NIC, they were able to discuss their understanding of phenomena, communicate challenges and ideas to support PSTs in identifying NGSS phenomena on a regular basis, and cooperate with one another to create, test, and improve the Phenomenon Tool over multiple PSDA cycles. Regular communication and cooperation continue to provide the NIC faculty with opportunities to develop a more coherent and consistent view of phenomena. Meanwhile, the NIC faculty have become more experienced in designing phenomenon-identifying tasks and using the phenomenon tool over time. For example, the field notes have revealed NIC members' recognition of the need to make more explicit criteria for the PSTs to use as they select and evaluate their own phenomena within the context of our science methods courses. NIC members' knowledge increase was also suggested by their productive feedback on the tool during the NIC videoconferences and evolved strategies in their science methods courses. Therefore, the NIC functioned as a vehicle to meet our shared improvement goal of enhancing PSTs' understanding of phenomena and their abilities to identify phenomena, along with deepening our faculty members' ideas around phenomena and how to support their PSTs on this topic.

Implications and limitations

Figure 6 summarizes the evolution of supporting components and implementation strategies across the three versions of the Phenomenon Tool. We identified three main ideas to help support instruction on phenomena with PSTs. Throughout the course, we suggest methods instructors 1) consider their own definitions and examples of phenomena, using the latest version of the Phenomenon Tool to identify any areas of weakness, 2) explicitly discuss phenomena related to example lessons throughout the course (even when the focus is on something other than phenomena), and 3) consider social justice standards to think about "relevant for students" criteria and include connections to social justice (e.g., identifying the harmful influence of bias). Additionally, when explicitly teaching about

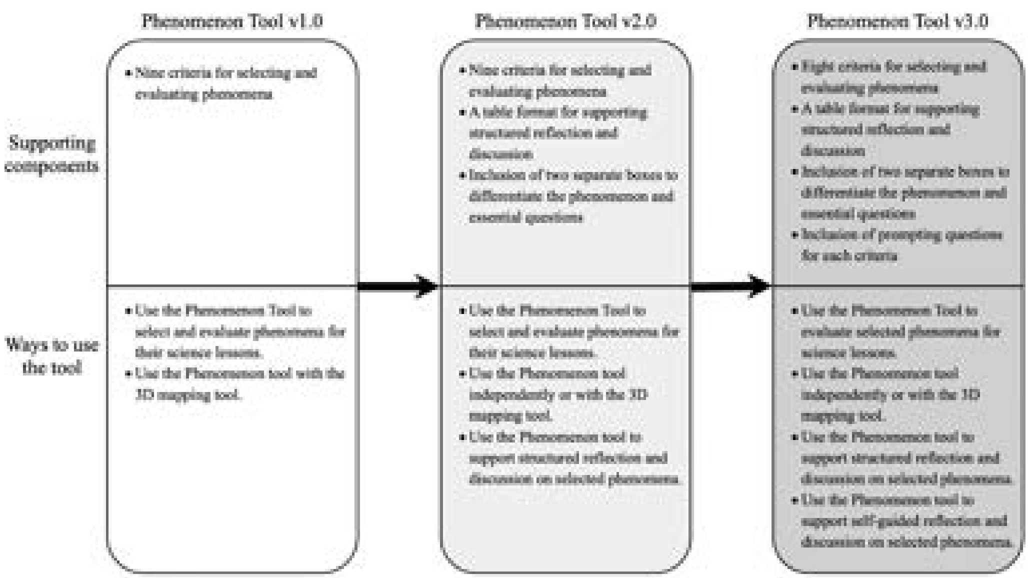


Figure 6. The supporting components in three versions of the phenomenon tool and the ways to use the tool in a science methods course.

phenomena, we found a few activities helpful in pushing on students' understanding. Similar to our own initial analysis of phenomena, one productive activity was to have PSTs sort and discuss a set of examples that include non-phenomena, phenomena but not anchoring phenomena, anchoring phenomena, and student-centered anchoring phenomena. PSTs should be encouraged to evaluate and revise the phenomena they select as they begin to plan lessons and units. The Phenomenon Tool V3.0 can be useful for evaluating existing phenomenon examples in pre-made curricula as well as evaluating phenomena generated by PSTs for novel lessons or units.

We acknowledge certain limitations with this work, particularly if viewed through the lens of traditional experimental science paradigms. The ASET Phenomenon Tool was used across various university sites each with their own unique context of how the science methods course functioned within their larger credential program. Variations in contexts are often viewed as problematic. However, allowing this variability provided the opportunity to study how the Phenomenon Tool worked and for whom within these various contexts. Another factor that is sometimes considered a limitation from the lens of the experimental science paradigm was the absence of formal instruments to assess PSTs' ability to identify phenomena before using the Phenomenon Tool in all PDSA cycles. Based on the data from our coding of PSTs' responses in the first PDSA cycle, only 27% of the responses were coded as phenomena, suggesting PSTs across all NIC sites lacked understanding on this topic. Therefore, in the following PDSA cycles we operated under the assumption that PSTs' understanding was low at the start of the course, given the PSTs entering our science methods course had little to no prior experience specific to NGSS. It is important to clarify that this study did not fall into the experimental science paradigm; instead, it was guided by the IS framework. In terms of measurement, Lewis (2015) noted that IS-guided studies may utilize practical measurement tools to test improvement indicators during PDSA cycles. In this study, we evaluated PSTs' abilities to identify phenomena based on their ongoing in-class performances. For example, prior to introducing the Phenomenon Tool, some NIC faculty members asked PSTs to identify phenomena from a collection of items that include phenomena and non-phenomena (such as questions, concepts, activities, etc.) and observed that most PSTs performed poorly on the task. Given these, when implementing the Phenomenon Tool within a new context it must be considered what specific needs this new context has and how to best implement the tool to address these needs. It is important to emphasize that the Phenomenon Tool cannot simply be handed to a group of educators or to PSTs for use. The Phenomenon Tool is intended to support active learning as part of a course, providing criteria to consider and discuss in evaluating phenomena, guided by the course instructor.

Overall, this study contributes to our understanding of science teacher education by providing much-needed information about how PSTs envision phenomena within the context of NGSS during their science methods courses. This is important, as it informs us about what resources may be needed to help science teacher educators more effectively teach PSTs to align instruction to the vision of the NGSS in their own planning and teaching. This study also offers an example of a support tool to accomplish this goal of supporting PSTs' understanding of phenomena. In addition, this study contributes to the field of improvement science by documenting a concrete example of how our NIC functioned as a vehicle to meet our shared improvement goal to enhance PSTs' understanding of phenomena and their abilities to identify phenomena. In the future, we will continue this work to refine the tool and implement it with other populations of teachers. We encourage science teacher educators to utilize this tool for their science methods courses and in-service teacher professional development.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The research reported here was supported by the National Science Foundation Discovery Research K12 under Award No. DRL-1418440 and DRL-1908900.

ORCID

Lin Xiang http://orcid.org/0000-0003-0470-143X

References

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. Oxford University Press.

American Association for the Advancement of Science. (2009). *Benchmarks for science literacy*. Oxford University Press.

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

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

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*. Harvard Education Press.

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

Cobb, C. D., & Virella, P. (2019). The legitimization of improvement science in academe. *Journal of System and Cybernet Information*, *17*(1), 287–296.

Corbin, J., & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. *Zeitschrift für Soziologie*, *19*(6), 418–427. https://doi.org/10.1515/zfsoz-1990-0602

Crabtree, B. F., & Miller, W. L. (Eds.). (1999). *Doing qualitative research*. Sage publications.

Deming, W. E. (1994). *The new economics: For industry, government, education*. The MIT Press.

Inouye, M., Houseal, A., & Gunshenan, C. (2020). Beyond the hook. *The Science Teacher*, *87*(9), 59–63. https://doi.org/10.1080/00368555.2020.12293545

Lederman, N. G., & Lederman, J. S. (2014). The next generation science standards: Implications for inservice and preservice teacher education. *Journal of Science Teacher Education*, *25*(2), 141–143. https://doi.org/10.1007/s10972-014-9382-3

LeMahieu, P. G., Grunow, A., Baker, L., Nordstrum, L. E., & Gomez, L. M. (2017). Networked improvement communities: The discipline of improvement science meets the power of networks. *Quality Assurance in Education*, *25*(1), 5–25. https://doi.org/10.1108/QAE-12-2016-0084

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

Lo, A. S., Krist, C., Reiser, B. J., Novak, M., & Lo, A. (2014). Examining shifts in teachers' understanding of NGSS and their impact on planned instruction. In *annual meeting of NARST*, Pittsburgh, PA.

Lowell, B. R., Cherbow, K., & McNeill, K. L. (2021). Redesign or relabel? How a commercial curriculum and its implementation oversimplify key features of the NGSS. *Science Education*, *105*(1), 5–32. https://doi.org/10.1002/sce.21604

National Research Council. (1996). *National science education standards*. National Academies Press.

National Research Council. (2001). *Educating teachers of science, mathematics, and technology: New practices for the new millenium*. The National Academies Press.

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

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

NGSS Achieve, I. (2016). *Using phenomena in NGSS-designed lessons and units*. https://www.nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf

NGSS Achieve, I. (2017). *Lessons learned from the NGSS early implementer districts*. Professional Learning.

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

Penuel, W. R., & Bell, P. (2016). *Qualities of a good anchor phenomenon for a coherent sequence of science lessons*. STEM Teaching Tools Initiative, Institute for Science + Math Education. University of Washington. https://stemteachingtools.org/brief/28

Reiser, B. J., Novak, M., McGill, T. A., & Penuel, W. R. (2021). Storyline units: An instructional model to support coherence from the students' perspective. *Journal of Science Teacher Education*, *32*(7), 805–829. https://doi.org/10.1080/1046560X.2021.1884784

Sinapuelas, M. L., Lardy, C., Korb, M. A., Bae-Lee, C., & DiStefano, R. (2019). Developing a three-dimensional view of science teaching: A tool to support preservice Teacher discourse. *Journal of Science Teacher Education*, *30*(2), 101–121. https://doi.org/10.1080/1046560X.2018.1537059

Sinapuelas, M. L. S., Lardy, C., Korb, M. A., & DiStefano, R. (2018). A toolkit to support preservice teacher dialogue for planning NGSS three-dimensional lessons. *Innovations in Science Teacher Education*, *3*(4). https://innovations.theaste.org/a-toolkit-to-support-preservice-teacher-dialogue-for-planning-ngss-three-dimensional-lessons/

Sunal, D. W., Hodges, J., Sunal, C. S., Whitaker, K. W., Freeman, L. M., Edwards, L., Johnston, R. A., & Odell, M. (2001). Teaching science in higher education: Faculty professional development and barriers to change. *School Science and Mathematics*, *101*(5), 246–257. https://doi.org/10.1111/j.1949-8594.2001.tb18027.x

Willard, T. (2017). *Criteria for evaluating phenomena*. NGSS@NSTA STEM Starts Here, National Science Teaching Association. https://static.nsta.org/ngss/docs/Criteria%20for%20Evaluating%20a%20Phenomenon.pdf

Windschitl, M., Schwarz, C., & Passmore, C. (2014). *Supporting the implementation of the next generation science standards (NGSS) through research: Pre-service teacher education*. National Association for Research in Science Teaching (NARST) Position Paper. https://narst.org/ngsspapers/preservice.cfm