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From Standards to Objectives: Using the ASET Three-dimensional Mapping Tool to Support and Assess Pre-Service Elementary Teachers' Development of Three-Dimensional Science Learning Objectives

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ABSTRACT

Learning objectives occupy a foundational role in educational practice by communicating the purpose of instruction to students, guiding the development of assessment, and informing the design of instructional activities. Since the release of the Next Generation Science Standards (NGSS), considerable efforts have been made to improve preservice teachers' ability to plan and implement NGSS-aligned science instruction. However, research on how preservice teachers (PSTs) construct NGSS-aligned science learning objectives remains limited. This study examined how elementary PSTs identified the three NGSS dimensions—science and engineering practices (SEPs), crosscutting concepts (CCCs), and disciplinary core ideas (DCIs)—from performance expectations and translated them into learning objectives with support from a three-dimensional (3D) mapping tool. By analyzing 132 maps and 242 learning objectives, our findings offer insights into both the progress and challenges PSTs face when constructing three-dimensional science learning objectives. Key findings include: 1) most PSTs were able to create two- or three-dimensional learning objectives using the 3D mapping tool; 2) the three NGSS dimensions appeared in PSTs' learning objectives to varying degrees, with DCIs included in most objectives, SEPs in about three-quarters of them, and CCCs in only one-third of the objectives; 3) most PSTs successfully identify relevant SEPs, DCIs, and CCCs from the performance expectations selected for their lesson sequences; and 4) while PSTs could often incorporate intended DCIs into their learning objectives, they struggled to properly integrate SEPs and CCCs. We discuss possible reasons for these findings and the implications for preparing future elementary teachers to plan NGSS-aligned science instruction.

KEYWORDS
Elementary preservice teachers; learning objectives; NGSS; science education; teacher education; three-dimensional

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Introduction

The Framework for K–12 Science Education (National Research Council [NRC], 2012) and the Next Generation Science Standards (NGSS) (NGSS Lead States [NGSS], 2013) mark a substantial shift from the dominant instructional approaches in most U.S. K–12 science classrooms. The new vision requires a transformative rethinking of both teaching and learning practices, moving far beyond traditional content delivery toward deeper, integrated learning experiences (Reiser, 2014). At the core of the NGSS is the purposeful integration of three dimensions—Science and Engineering Practices (SEPs), Crosscutting Concepts (CCCs), and Disciplinary Core Ideas (DCIs)—so that students learn core scientific ideas in the context of engaging in authentic scientific and engineering practices, while recognizing unifying concepts that connect across domains (NRC, 2012). The standards explicitly encourage teachers to weave these three dimensions together into coherent, instructionally rich learning experiences in their instructional design (Kang et al., 2019; Merritt et al., 2018).

However, translating the three dimensions into manageable, coherent classroom instruction is complex and requires substantial pedagogical adaptation (Bybee, 2013). Teachers must navigate the complexities of translating multidimensional standards into actionable and assessable learning objectives that guide both instruction and assessment. In the NGSS, Performance Expectations (PEs) are concise statements that specify what students should know and be able to do to demonstrate their understanding of science concepts by the end of a particular grade level or course. Each PE integrates SEPs, CCCs, and DCIs into a coherent statement, thereby signaling to teachers the intended learning outcomes for students and providing clear guidance for end-of-instruction expectations and a frame for assessments (Krajcik et al., 2014). The challenge for science teachers lies in interpreting PEs to develop clear, measurable, and instructionally useful learning objectives that translate the NGSS vision into day-to-day teaching practice.

Currently, studies on NGSS implementation predominantly examine teachers' general understanding of NGSS or their interpretations and enactment of specific dimensions—especially SEPs, while research on how preservice teachers (PST) or inservice teachers effectively write science learning objectives based on PEs and the relevant NGSS's three dimensions is notably absent. In this study, we examined the learning objectives constructed by elementary PSTs when using a Three-dimensional Mapping Tool (3D Map) (Figure 1, Sinapuelas et al., 2019) in planning an NGSS-aligned learning sequence. Specifically, we identified the extent to which elementary PSTs may construct multidimensional learning objectives with the support of the 3D map and the characteristics of representations of three dimensions in these learning objectives. This work may inform teacher educators in using the 3D maps to scaffold effective learning experiences for their elementary PSTs to construct NGSS-aligned, clear, multidimensional day-to-day learning objectives, as well as assess the quality of those objectives.

Literature review

Learning objectives in teaching and lesson planning

Learning objectives can be best understood as descriptions of what the learner will know and be able to do after completing specific educational activities. They occupy

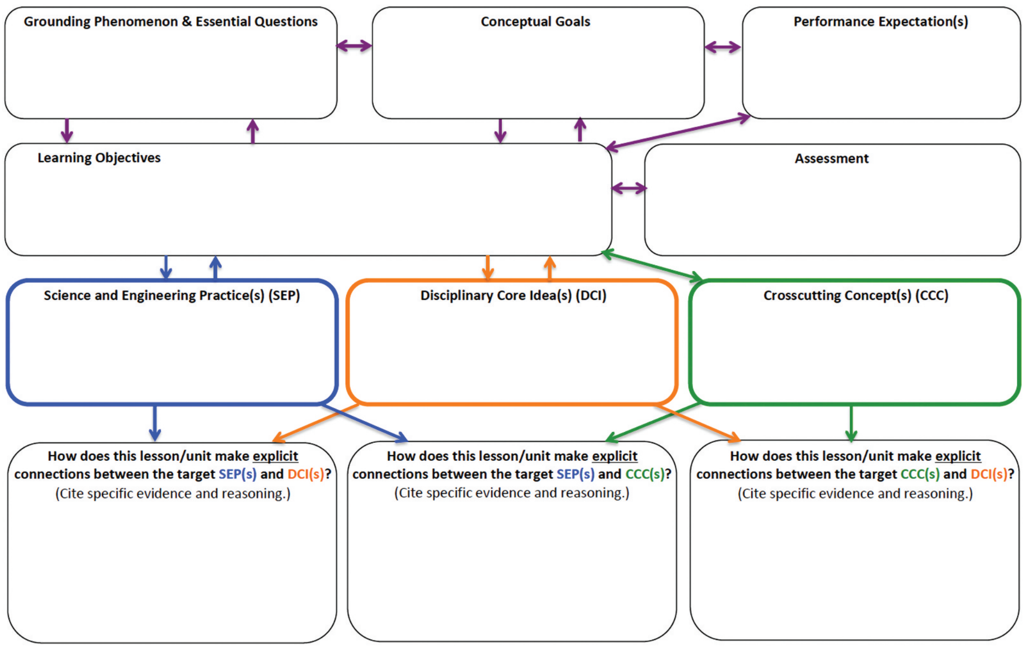


Figure 1. The ASET three-dimensional mapping tool (3D map).

a foundational role in educational practice, serving as the stated intentions that communicate the purpose of instruction to students, colleagues, and broader academic communities (Mager, 1997; Rodriguez & Albano, 2017). Well-written learning objectives clearly delineate knowledge, skills, or attitudes to be gained in measurable terms and thoroughly describe the expected performance and the conditions for its demonstration (Chatterjee & Corral, 2017; Orr et al., 2022). Therefore, when thoughtfully constructed, learning objectives are the bedrock for developing both formative and summative assessments and inform the design of instructional activities that enable students to master essential content and skills. A learning objective articulates instructional purpose by including an action verb, thoroughly describing the expected performance, and specifying the conditions for its demonstration (Orr et al., 2022). Learning objectives can be constructed at various scopes, such as course-level, section/unit-level, and individual lesson-level. Regardless of the type and scope, educators commonly agree that clarity, observability, and measurability are three important criteria for a strong learning objective (Felder & Brent, 2024; Tullu et al., 2015).

Extensive research supports the central role of clear learning objectives in guiding teaching practices and enhancing student outcomes. Well-defined objectives direct instructional focus by establishing explicit expectations for both teachers and students (Chatterjee & Corral, 2017; Orr et al., 2022). This clarity of learning objectives is critical to alignment—ensuring coherence between planned activities, assessments, and desired learning outcomes, thereby supporting meaningful measurement of student progress (Sewagegn, 2020). Such clarity fostered constructive alignment, as curriculum, pedagogy, and assessment were seamlessly woven together. Studies have shown that explicit use of numbered learning objectives on lecture slides enhanced student focus, reduced stress, and increased preparedness for assessment (Boyatzis et al., 2022). Relevant literature further highlights that teachers proficient in formulating and utilizing learning objectives design more effective and cohesive lessons, and are better positioned to engage in reflective practice (Alles et al., 2018).

Challenges in articulating learning objectives for PSTs

Despite consensus on their importance, articulating clear, specific, and measurable learning objectives remains a persistent challenge, particularly among PSTs. We found that studies on constructing science learning objectives among PSTs are surprisingly scarce. Kaya and Nafiz Kaya (2023) found PSTs' learning objectives "focused on conceptual science, not NOS aspects, science practices, and affective dispositions in science" (p. 17), based on the analysis of the lesson plans of 631 undergraduates in a middle school science teacher preparation program in Turkey. Several relevant studies have been identified in other subject areas. Amelia et al. (2024) found that preservice English teachers often failed to explicitly link learning activities to well-defined objectives, struggling to write objectives that were observable, learner-focused, and aligned with assessment. Similarly, Coggins and Colburn (2018) observed that preservice elementary teachers had difficulty leveraging assessment data to adjust instruction according to established objectives. While targeted interventions improved these skills, ongoing challenges with specifying what students should know and do after instruction remained prevalent. Finnish research also indicates that preservice teachers frequently compose objectives that are vague or teacher-centered, hindering their potential as tools for guiding formative assessment and instruction (Atjonen et al., 2024). These findings point to the need for comprehensive mentorship, exemplars, and deliberate practice in teacher preparation programs to ensure that learning objectives genuinely support teaching and learning.

Learning objectives within the NGSS Framework

The Framework for K–12 Science Education and the NGSS highlight the integration of three dimensions into the curriculum development, instruction, learning, and assessment (NGSS, 2013; NRC, 2012). The NGSS PEs can largely be viewed as unit-level learning objectives, as they specify what students should know and be able to do to demonstrate their understanding of science concepts by the end of a particular grade level or course. When teachers break down and translate PEs into their day-to-day individual learning objectives, they need to determine the relevant and proper three dimensions at a small scope to develop clear, measurable, and instructionally useful learning objectives. Bybee (2013) noted, "One of the most significant challenges has been that of integration. It's easy to recommend that the three dimensions be integrated, but much more complex to actually realize this integration in classroom instruction" (p. 56). Teachers must navigate the complexities of translating multidimensional standards into actionable and assessable learning objectives that guide both instruction and assessment.

Despite growing research on NGSS implementation, little is known about how preservice and inservice teachers construct science learning objectives that embody all three NGSS dimensions. A recent review of 10 years of three-dimensional science research in secondary classrooms documents a broad and expanding literature on NGSS-aligned instruction, including work on teacher learning, professional development, assessment, and systemic support (Smith et al., 2025). This review indicates that research has focused primarily on the implementation of three-dimensional instruction rather than on the specific processes by which teachers translate performance expectations into lesson- and unit-level learning objectives. Most existing empirical studies examine teachers' overall understanding of NGSS or their enactment of individual dimensions, particularly SEPs. For example, Hanuscin and Zangori (2016) reported that elementary PSTs viewed NGSS as "a useful guide for the planning and design of instruction" (p. 809), "a benchmark by which to evaluate themselves and students" (p. 811), and "an achievable vision for elementary science" (p. 812) rather than as concrete tools for objective-writing. Ricketts (2014) and Dalvi et al. (2021) identified broad variability in elementary PSTs' interpretations of SEPs, noting that problematic or fragmented understanding frequently impeded deeper integration. Research with secondary science teachers also reveals that sophisticated understandings of the epistemic nature of SEPs are comparatively rare (Kite et al., 2021). Studies of elementary teacher enactment demonstrate considerable variation in the depth and authenticity with which SEPs are integrated into instruction, with many instances characterized by procedural rather than conceptual engagement (Kang et al., 2019). Merritt et al. (2018) found that while elementary teachers incorporated some SEPs, engineering practices were less frequently enacted, and integration across the three dimensions was often partial and fragmented.

Studies have also revealed limited knowledge among PSTs and inservice teachers and implicit implementation of CCC in the classroom. For example, Lee and Arias (2024) found that elementary PSTs held useful initial knowledge of CCCs, but this knowledge varied and appeared to be parsimonious. Marckwordt et al. (2022) reported that many teachers viewed CCCs as the most challenging dimension in NGSS. In classroom practice, elementary teachers were found to most frequently use patterns and cause and effect (Kang et al., 2019). By observing elementary teachers' instruction, Fick et al. (2022) found that teachers implement nearly all CCCs implicitly, with patterns being the primary exception. Building on these empirical findings, Fick and Arias (2022) reviewed studies from 2012–2019 using CCCs as an analytic lens and underscored that most CCC research has concentrated on how CCCs function in instruction, curriculum, student learning, and research framing, with comparatively less attention to how teachers plan for CCCs at the level of learning goals, tasks, or assessments. This review clarifies both what is known and what remains underexplored about CCCs in three-dimensional teaching and learning, revealing the gap that aligns with the broader lack of empirical work on how teachers articulate CCCs, and the three dimensions more generally, in written learning objectives for lessons or unit plans.

Collectively, these studies, including the recent syntheses of CCC-focused and three-dimensional science research, highlight that teachers still face substantial challenges in integrating the three NGSS dimensions in ways that support the intended vision of three-dimensional learning. Notably, even within this expanded and up-to-date literature base, empirical work that directly examines how pre- and inservice teachers write three-dimensional learning objectives aligned with NGSS performance expectations remains scarce. In addition, relatively few tools have been developed to support teachers in integrating the three NGSS dimensions into learning objectives. As a first step toward addressing this challenge and gap, this exploratory study analyzes the learning objectives written by elementary PSTs in science methods courses scaffolded by the ASET Three-Dimensional

Mapping Tool, with the aim of illuminating and supporting the translation of the NGSS three-dimensional vision into instructional practice.

Three-dimensional mapping tool

In response to the need to support PSTs' understanding and implementation/enactment of NGSS, the ASET Toolkit (Toolkit from here onward) was created as part of a National Science Foundation-funded grant. The Toolkit comprises several tools, including the Three-Dimensional Mapping Tool (3D Map) (Figure 1, Sinapuelas et al., 2019). The 3D Map was designed to meet the needs of PSTs in the context of science methods courses by providing a visual scaffold of the components of NGSS-aligned instruction and how those components interact with one another. One of the goals of the 3D Map is to illustrate the complexity of interactions among NGSS components as they relate to learning objectives, and in turn, prompt PSTs to write learning objectives that incorporate all three dimensions. The tool does this by prompting PSTs to, when using the 3D Map as a planning tool, determine each of the three specific dimensions for the PE(s) they plan to focus on during instruction in the "Science & Engineering Practice(s) (SEP)," "Crosscutting Concept(s) (CCC)," and "Disciplinary Core Idea(s) (DCI)," boxes (3D-box). These three boxes are connected to the "Learning Objective(s)" box (LO-box) with arrows, which, along with course instructor modeling, serve as visual prompts to integrate the three specified dimensions into instructional learning goals.

Since its inception in 2016, the 3D Map has been used in elementary methods courses on eight university campuses in the U.S., including those of the authors. While the tool is designed to prompt PSTs to write three-dimensional learning objectives (Ross & Lardy, 2025), we sought to examine how effectively it supported students in achieving this goal. Specifically, our research questions are:

(1) Which dimensions (SEP, CCC, and DCI) of NGSS were represented in elementary PSTs' learning objectives? What were the common characteristics of the learning objectives that lacked a certain dimension?
(2) To what extent were the individual learning objectives three-dimensional? To what extent were the 3D maps three-dimensional based on all learning objectives in the map?
(3) To what extent were PSTs able to identify the three dimensions of the selected performance expectation and translate them into three-dimensional learning objectives?

Methods

Context of study

This study is situated within a larger NSF-funded initiative, Aligning the Science Teacher Education Pathway (A-STEP) project (DRL-1908900), which engages a Networked Improvement Community (NIC) comprising six campuses in the western United States, a mountain region university, and a midwestern university. NICs are organizations that include individuals across multiple levels, especially those who are most directly influenced by innovations and potential solutions to problems, who are all focused on working together to develop and test innovations to solve the same problem (Bryk et al., 2011). A goal of the A-STEP project is to examine four key steps along the teacher education pathway where the Next Generation Standards (NGSS) are enacted (i.e., moving beyond awareness of the NGSS). These four steps occur during: 1) PSTs' enrollment in science teaching methods courses at each university that participates, 2) PSTs' fieldwork experiences and training for inservice participating cooperating teachers, 3) induction program experiences for early career teachers, and 4) school district professional development for inservice teachers. These steps follow the traditional trajectory for a teacher from a credential program through their career in a school district. During the previous NSF project, Next Gen Alliance for Science Educators Toolkit (ASET) (DRL-1418440), the NIC designed, implemented, and improved the ASET Toolkit (https://www.nextgenaset.org/) that allowed NIC members to integrate instruction to support PSTs' understanding of the NGSS in their courses while studying their own pedagogical shifts, as well as their progress in planning NGSS-based lessons and units for K-12 teaching. This same Toolkit continued to be used and studied in the current project as a common source of vernacular and concepts to drive dialogue around curriculum and pedagogical strategies for the NGSS. The NIC has continued to refine its strategies for engaging stakeholders across different steps of the teacher education pathway. It has also expanded its nationwide dissemination efforts and collaborated with teacher educators and science education practitioners to support the enactment of the NGSS, using the ASET Toolkit to scaffold ongoing discourse around these refinements.

One of the goals of this project was to investigate how the ASET Toolkit was used to facilitate discourse to enact NGSS-aligned curriculum and instruction within and across different steps of the science teacher education pathway. One of those pathway steps includes the preparation of new teachers (i.e., PSTs). In this study, we focused on those PSTs at the elementary level. The current research team is composed of a subset of faculty in this NIC who have used the 3D map to scaffold the creation of new or the unpacking of existing NGSS-aligned curriculum in elementary science teaching methods courses for PSTs.

Participants

This study included PSTs enrolled in 13 elementary science methods courses taught by NIC members across six universities from 2019 to 2023, all of whom consented to have their work used as research data. PSTs in these science methods courses were enrolled to partially fulfill the requirements for an elementary teaching credential. None of these PSTs had significant teaching experience, and they graduated from high school before the implementation of NGSS. Therefore, it was assumed they began the elementary science methods courses with a novice understanding of NGSS and the three dimensions.

Materials and data collection

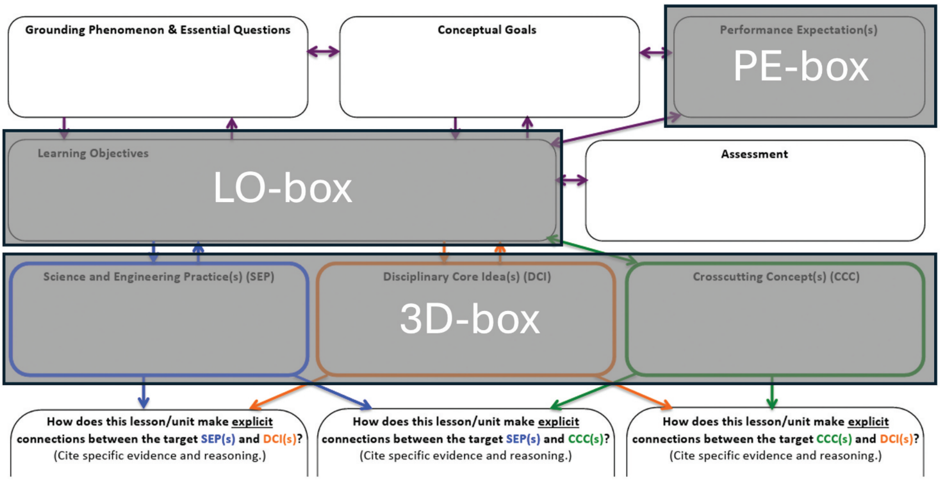
All PSTs enrolled in the 13 elementary science methods courses across the six universities completed a common course assignment that asked them to develop a lesson or lesson sequence aligned with the NGSS. These science methods courses typically included an integrated field-based practicum where PSTs were placed at a specific elementary grade level. To align the course assignment with the practicum placement, PSTs were asked to focus on the PEs for the corresponding grade level. Although PSTs' selections were limited to their assigned grade level, they retained the flexibility to choose which PE to focus on within that grade. While designing the lesson or lesson sequence, PSTs worked in small groups using the 3D map to outline the key components, including the PE, the three dimensions, learning objectives, the anchoring phenomenon, essential questions, and assessments (Figure 1). Prior to planning, PSTs were provided with examples of how to use the map. A total of 132 lessons/lesson sequences were collected from the participants during the Summer, Fall, and Spring semesters from 2019 to 2023. The 3D maps from these lessons/lesson sequences served as the data source for this study. A total of 242 learning objective entries were analyzed from the 132 maps, as approximately 50% of the maps contained more than one learning objective entry.

Data analysis

Our analysis proceeded in three stages, utilizing both qualitative and quantitative analysis approaches, to answer the research questions. Figure 2 illustrates the overall process used to analyze PSTs' learning objectives (hereafter referred to as LOs). The three gray boxes at the top highlight the components of the 3D Map that are included for analysis. The LO-box includes the LOs written by PSTs, which were coded for the presence of the three NGSS dimensions. The PE-box displays the NGSS Performance Expectation (PE) that PSTs chose to guide their lessons/lesson sequences and, therefore, provides the reference point for identifying the three NGSS dimensions. The 3D-box contains the dimensions, i.e., SEP(s), CCC(s), and DCI(s), that PSTs selected when constructing their lessons/lesson sequences based on the PE. The lower half of the figure illustrates the analysis that proceeded through three main steps. Step 1 involved coding each LO to identify its dimensional components, resulting in the presence of dimensions for each LO (LO-box dimensions). Step 2 determined the dimensionality of individual LOs and the entire maps (e.g., one-, two-, or three-dimensional). Step 3 compared the dimensions among PE-box, 3D-box, and LO-box. Specifically, Step 3a identified the dimensions present in the PE-box and 3D-box, while Steps 3b and 3c compared these sets of dimensions (PE-box vs. 3D-box; 3D-box vs. LO-box) to evaluate the degree of alignment.

Stage 1: coding learning objectives

Each LO written by PSTs on the 3D Map was examined for evidence of the representation of the three NGSS dimensions: SEP, CCC, and DCI. Five authors participated in the coding process. Each coder independently analyzed the learning objectives before meeting regularly to compare results, discuss discrepancies, and reach consensus by referencing *the Framework* (NRC, 2012). For SEPs, coders identified the specific practice included in the LO, using the eight NGSS practices (SEPs 1–8, such as 1 as Asking Questions and Defining Problems or 7 as Engaging in Argument from Evidence). For CCCs, coders applied a three-point scale, where "0" indicated that no CCC was present, "1" indicated an unclear or ambiguous reference, and "2" indicated clear evidence of a CCC. When a CCC was coded as "2," coders also identified which specific CCC (e.g., Patterns, Cause and Effect, or



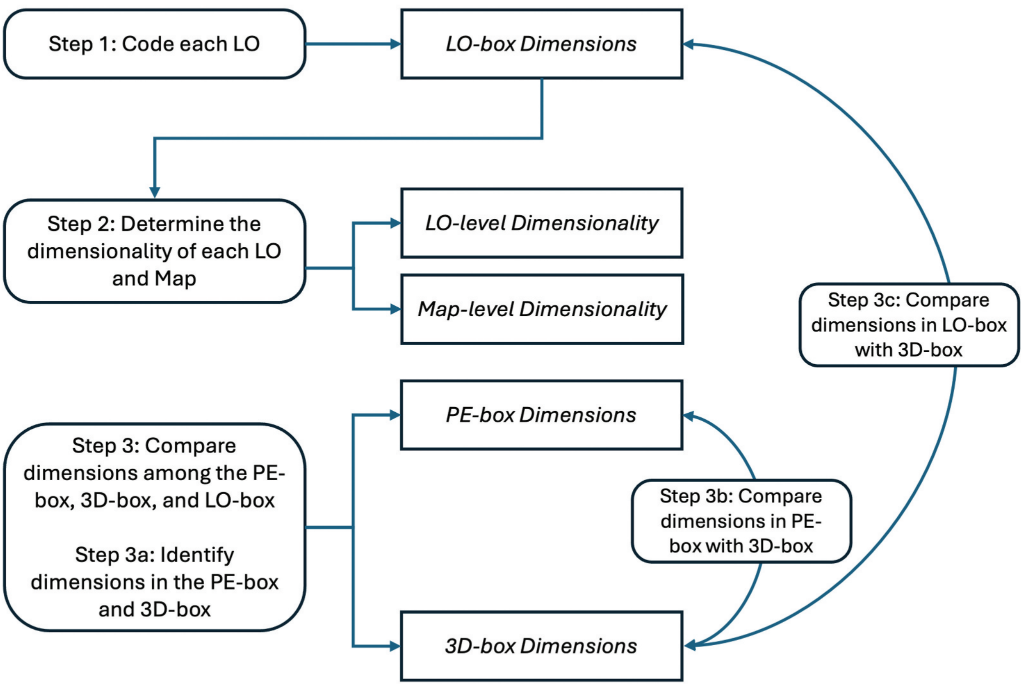


Figure 2. Three stages of the data analysis procedure.

Systems and System Models) was represented. For DCIs, coders used a simple yes/no scheme, marking “yes” when a DCI was explicitly present and “no” when no DCI was evident. This coding process produced a dimensional profile for every LO, which we refer to as the LO-box dimensions, and served as the foundation for subsequent classification and comparison. This analysis allowed us to answer the first research question by revealing which NGSS dimensions were presented in elementary PSTs' LOs and what features characterized objectives missing one or more dimensions.

Stage 2: determining dimensionality of LOs and maps

After coding, each LO was classified according to its dimensionality. LOs that included evidence of all three dimensions were considered three-dimensional (3D); objectives that included any two of the three dimensions were considered two-dimensional (2D); objectives that included only one dimension were considered one-dimensional (1D). Once all LOs were classified, we determined the overall dimensionality of each 3D map. A map was coded as 3D if at least one of its LOs included all three dimensions; a map was coded as 2D if none of its LOs were three-dimensional but at least one included two dimensions. A map was coded as 1D if all of its LOs included only one dimension. This analysis addressed the second research question by examining the extent to which individual LOs were three-dimensional and how three-dimensionality was reflected in the overall 3D Maps.

Stage 3: comparing dimensions among the PE-box, 3D-box, and LO-box

We next identified the dimensions of the Performance Expectation (PE) selected for each 3D Map using the NGSS document; these dimensions were referred to as the PE-box dimensions. We also identified the dimensions that PSTs themselves selected and filled in the three separate boxes of the 3D Map (the SEP box, CCC box, and DCI box). These dimensions were collectively referred to as the 3D-box dimension. Next, we conducted two sets of comparisons to examine dimension alignment by first comparing the dimensions in the PE-box to the 3D-box and then the dimensions in the 3D-box to the LO-box. In other words, we examined whether the SEP, CCC, and DCI of the PE-box, 3D-box, and LO-box within the same map corresponded with one another. These comparisons were essential for determining how effectively PSTs translated the three dimensions identified in the NGSS Performance Expectation into their own instructional planning and LOs.

In either set of comparison, our comparison results generally fell into four categories: inclusive, overlapping, distinct, or missing/inaccurate (Table 1). Comparisons were coded as *inclusive* when the content of the compared boxes was identical (e.g., both the PE-box and 3D-box identified the same SEP/CCC/DCI) or when one box encompassed the other (e.g., the SEP/CCC/DCI identified in the 3D-box represented a subset of that in the PE-box, or vice versa). Comparisons were coded as *overlapping* when the compared boxes shared

Table 1. Categories of alignment comparisons.

Category	Description	Examples
		(PE-box) ←→(3D-box)
Inclusive	The compared dimension contents are the same, or one is a subset of the other.	Patterns ←→ Patterns Patterns, cause and effect ←→ Patterns Patterns ←→ Patterns, cause and effect
Overlapping	The compared dimension contents have both the same and different items.	Patterns, Cause and Effect ←→ Cause and effect, Energy and Matter
Distinct	The compared dimension contents are completely different.	Patterns, cause and effect ←→ Energy and Matter Cause and Effect ←→ no CCC identified in learning objective
Missing/ Inaccurate	PSTs missed or included incorrect content in the 3D boxes	PSTs included DCI or SEP in the CCC box or irrelevant information

one or several common items, but they both contained additional different elements (e.g., both the PE-box and 3D-box included the same CCC of patterns, but the PE-box and 3D-box also included one or more additional CCCs). Comparisons were considered *distinct* when the compared boxes contained entirely different dimensions (e.g., the PE-box and 3D-box identified different CCCs). Note, when PSTs included certain SEP/CCC/DCI in the 3D-box but their LOs were coded as no DCI, no SEP, or no CCCs, we classified the comparison results as *distinct*, because the LOs themselves did not provide sufficient evidence to determine whether PSTs purposefully omitted the dimension. Finally, cases were specifically coded as *missing/inaccurate* when PSTs misplaced SEP/CCC/DCI into incorrect 3D-boxes or left a 3D-box blank. Table 1 presents examples of the CCC comparisons to illustrate these four categories. This classification method was used for both comparison sets, i.e., PE-box versus 3D-box and 3D-box versus LO-box, across all three dimensions.

We also analyzed the dimension alignment at the map level. For maps only containing one LO, the dimension alignment of the maps was identical to that of the LOs. For maps containing more than one LO, their dimension alignments were collectively determined based on all LOs within the map. Detailed coding rules for this process are provided in Supplementary Table 1. Together, these comparisons allowed us to evaluate the extent to which PSTs selected three dimensions based on the NGSS PE they chose and integrated these dimensions into LOs, thereby addressing the third research question.

Results

Which dimensions (SEP, CCC, and DCI) of NGSS were represented in elementary PSTs' LOs? What were the common characteristics of the LOs that lacked a certain dimension?

All three dimensions, i.e., SEP, CCC, and DCI, were identified in the coded LOs, but largely varied in frequency, providing insight into which NGSS dimensions PSTs tend to emphasize or overlook when designing NGSS-aligned instruction. Specifically, 76.0% of the LOs contained at least one SEP, 32.3% of the LOs explicitly referenced a CCC, and 95.9% of the LOs included a science topic related to a DCI. Further findings of each dimension are detailed below.

Science and engineering practices (SEPs)

We found that 76.0% of the LOs contained at least one SEP. Specifically, 66.5% of the objectives contained one SEP, 8.7% contained two SEPs, and 0.8% contained three or more SEPs. Obtaining, evaluating, and communicating information (SEP 8) was the most identified SEP (21.1%), followed by modeling (SEP 2) (17.8%), investigations (SEP 3) (13.2%), and data analysis and interpretations (SEP 4) (12.8%), while mathematical and computational thinking (SEP 5) was the least identified (0.4%) (Figure 3).

When coding LOs for the SEP dimension, we relied on the presence of keywords that suggested particular practices. For instance, the practice of *developing and using models* (SEP 2) was typically indicated by words such as model or modeling, while the practice of *analyzing and interpreting data* (SEP 4) was suggested by phrases such as analyze data, compare and contrast, or identify differences. However, some keywords were more difficult to interpret. The verb *explain* was particularly challenging because

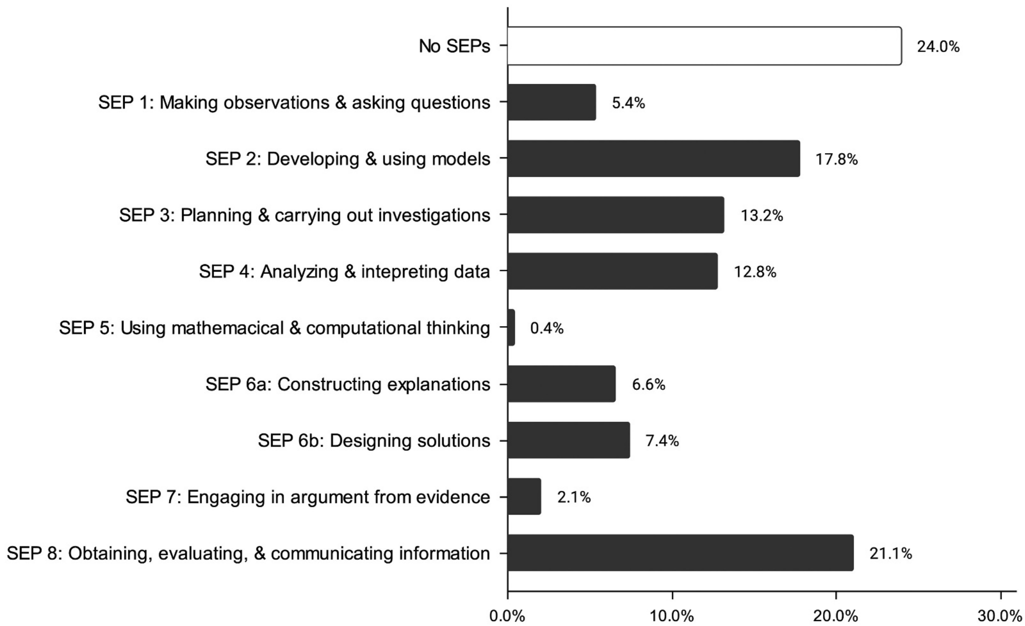


Figure 3. Frequencies of no SEPs and SEPs in 242 learning objectives.

it might initially appear to signal the practice of *constructing explanations* (SEP 6). In many cases, though, PSTs used *explain* in ways that did not involve justification supported by evidence but instead called for description or summary. We found 15 such LOs, for example, "Students will be able to explain echolocation and its relationship to whales." These objectives asked students to simply communicate or describe scientific ideas rather than to construct evidence-based explanations. According to the NGSS, *constructing explanations* requires students to use evidence and reasoning to justify a claim about a scientific phenomenon (NGSS, 2013). However, in the above example, the verb *explain* reflected a descriptive task rather than an evidence-based practice, so we coded it as *obtaining, evaluating, and communicating information* (SEP 8). In contrast, we coded LOs as *constructing explanations* (SEP 6) when they explicitly required the use of evidence, as in "Students will construct a scientific explanation, with evidence, about how water resources can affect the living things that depend on it" (Table 2).

We coded 58 LOs (24.0%) as lacking an SEP and identified three characteristics among these LOs, including that 1) using non-measurable action words, such as learn, understand, and demonstrate, that do not represent a clear SEP (42 LOs), 2) asking students to complete a worksheet or quiz (15 LOs), and 3) asking for the definition of concepts (1 LO) (Table 2).

Crosscutting concepts (CCCs)

CCCs were the least identified dimension in PSTs' LOs because PSTs either did not include a CCC in their LOs or only implied a CCC in their LOs (Figure 4). Overall, only 32.3% of LOs explicitly represented a CCC, approximately 44.6% implied a certain CCC, and around 23.1% did not contain a CCC. *Cause and effect* was the most frequently identified CCC,

Table 2. SEP codes, examples, and characteristics.

SEP Code	Example	Characteristics
No SEPs	*Students will understand that dark materials absorb more heat energy than light materials.*	Use of non-measurable verbs
	SWBAT distinguish between the four different types of weathering by correctly answering 7 of 10 questions correctly.	Complete a worksheet or a quiz
	Students will be able to define condensation as a gas changing to a liquid due to the removal of thermal energy.	Ask for a definition
SEP 1: Making observations and asking questions	*Students will describe and notice the types of damage earthquakes cause. Students will also create questions to fulfill their initial wonder inquiry.*	Keywords: *notice, create questions*
SEP 2: Developing and using models	*Students will be able to explain how cooling water vapor causes condensation through models.* *They will use a model to represent and describe relationships between the components of the model and the model itself.*	Keywords: *models, use a model*
SEP 3: Planning and carrying out investigations	*Students will investigate the interaction of magnets with various materials.* *I can experiment with materials to distinguish between reversible and non-reversible changes.*	Keywords: *investigate, experiment*
SEP 4: Analyzing and interpreting data	*Students will identify patterns displayed by various materials (i.e., plastic, wood, metals).* *Students will use evidence to identify and categorize different seasons.*	Keywords: *identify patterns, categorize*
SEP 5: Using mathematical and computational thinking	*Students will be able to investigate the scale of microorganisms that live on and in the human body (scale, proportion, and quantity) and ask questions about these microorganisms, by using quantitative thinking and evidence from a digital scale tool to sort a set of tiny objects by relative size and recording the results in their microbiome investigation notebook and organizing a set of cards of organisms from smallest and largest*	Keywords: *using quantitative thinking*
SEP 6a: Constructing explanations	*I can use logical reasoning to explain how their observations of fossils provide evidence to support what the fossils can tell them about the past.* *Students will construct a scientific explanation, with evidence, about how water resources can affect the living things that depend on it.*	Keywords: explain, reason, evidence, *construct a scientific explanation*
SEP 6b: Designing solutions	*Students will also be able to design a solution for communication over a long distance.*	Keywords: *design a solution*
SEP 7: Engaging in argument from evidence	*Students will explore the human impact on Earth's environment. They will develop an oral or written argument to explain how human activities have a cause and effect on the environment.*	Keywords: *develop an oral or written argument*
SEP 8: Obtaining, evaluating, and communicating information	*I can evaluate the concepts presented in the video in class and develop explanations through small/whole group discussions.*	Keywords: evaluate, explanation*
	Students will be able to explain echolocation and its relationship to whales.	Keywords: *explain**
	**The word "explain" is used to ask for a description rather than an evidence-based explanation.*	

found in 13.6% of LOs, followed by *patterns* (5.0%). *Stability and change* was the least identified CCC (1.7%) (Figure 4).

Similar to identifying SEPs, we could identify an explicit CCC based on the relevant keywords (Table 3). One example of LO containing an implicit CCC looked like this: "Students will be able to describe by drawing and labeling the Earth's layers and the resources we get from each." This LO semantically implied CCC of *systems*

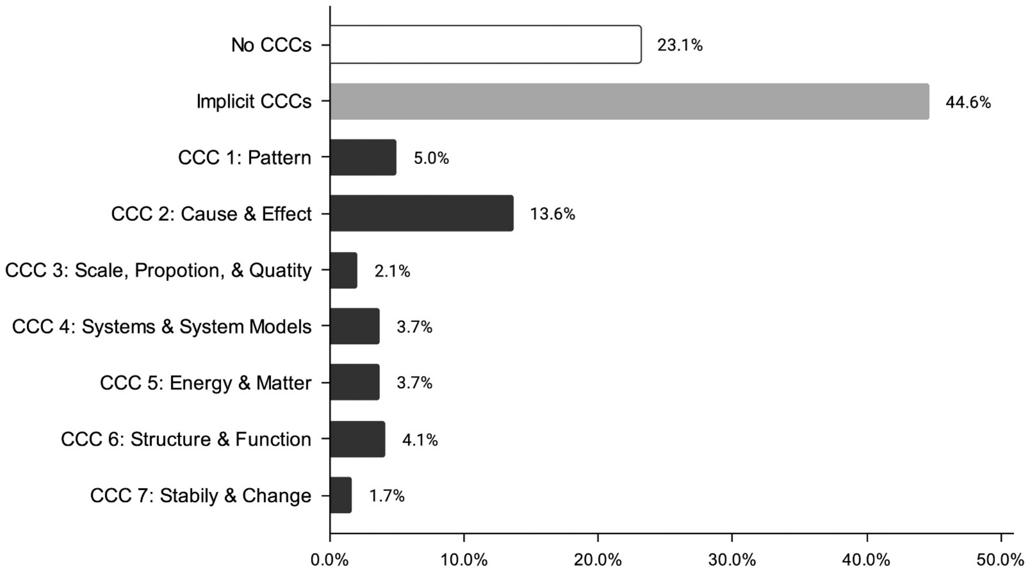


Figure 4. Percentages of no CCCs, implicit CCCs, and explicit CCCs in 242 objectives.

and system models, but it was not explicit enough to make the CCC evident. In comparison, in the objective "I can explain how the body has different systems that work together to keep us alive," the phrase "system" and "work together" explicitly present the CCC of *systems and system models*.

We coded 56 LOs (23.1%) as lacking a CCC and identified three characteristics among these LOs, including that 1) emphasizing defining concepts (28 LOs), 2) only focusing on SEP (s) (23 LOs), and 3) only stating a general question (5 LOs) (Table 3).

Disciplinary core ideas (DCIs)

We determined that 95.9% of the LOs represented the dimension of DCI, as these LOs typically included a specific topic or concept related to a DCI (Table 4). Ten LOs (4.1%) were found not to contain any DCI. When examining these LOs closely, we found that all of them contained a SEP, while two also contained a CCC. Two examples are provided in row "No DCIs" in Table 4. The first example explicitly described the modeling practice (SEP) but lacked an explicit DCI or a CCC. In the second example, "innovate a way" represented *designing solutions* (SEP 6B), and "impact on" suggested the CCC of *cause and effect*.

To what extent were the individual LOs three-dimensional? To what extent were the 3D maps three-dimensional based on all LOs in the map?

Using the dimension profile of each LO, we determined the dimensionality for individual LOs and the 3D maps. Since LOs could include an implicit CCC or an explicit CCC, we determined the dimensionality of each LO using two different criteria. In the first criterion, dimensionality was determined by considering both

Table 3. CCC codes, examples, and characteristics.

CCC Code	Example	Characteristics
No CCCs	*By the end of this lesson, students will be able to describe what weathering and water erosion are.*	Primarily focus on defining concepts
	Students will be able to plan and carry out an investigation of the different types of organisms in the schoolyard.	Highly focused on SEP(s)
	Students will reflect on what animals need to grow in an environment by journaling.	Only state a general question
Implicit CCCs	*Students will be able to describe by drawing and labeling the Earth's layers and the resources we get from each.*	Imply systems and system models
	Students will be able to analyze the relationship between an animal and its habitat.	Imply cause and effect or structure and function
	I can distinguish between what living things need to survive versus non-living things which do not need anything to survive.	Imply pattern
CCC 1: Patterns	*Students will identify patterns displayed by various materials (i.e., plastic, wood, metals).* *Students will be able to investigate the moon patterns to identify the patterns of daily changes day and night.*	Keywords: *Patterns*
CCC 2: Cause and effect	*Students will be able to explain how cooling water vapor causes condensation through models.* *I can talk about how pushing or pulling an object softer or harder changes the way that it moves.*	Keywords: *cause, (A) change (B)*
CCC 3: Scale, proportion, and quantity	*Students will be able to investigate the scale of microorganisms that live on and in the human body (scale, proportion, and quantity) and ask questions about these microorganisms, by using quantitative thinking and evidence from a digital scale tool to sort a set of tiny objects by relative size and recording the results in their microbiome investigation notebook and organizing a set of cards of organisms from smallest and largest.* *Students would be able to test and collect data (distance and time based on investigation of the five flights.*	Keywords: *scale, (measure) time, (measure) distance*
CCC4: Systems and system models	*Students will be able to apply the knowledge of the relationship of producers and consumers within an ecosystem by sketching and labeling a model of an ecosystem.* *I can explain how the body has different systems that work together to keep us alive.*	Keywords: *system, model, work together*
CCC 5: Energy and matter	*SWBAT explain how electricity is a form of energy and is transferred by electric currents by creating their own flashlights.* *Construct an apparatus to investigate energy and how it is transformed into other types.*	Keywords: (*energy) transfer, energy transform, heat*
CCC 6: Structure and function	*Students will demonstrate comprehension of the scientific concept by creating a camouflaged chameleon in order to explain how reptiles can use their physical structure to survive in their environment.* *Students will be able to create a simple model that mimics the function of a butterfly pollinating plants.*	Keywords: *structure, function*
CCC 7: Stability and change	*Students will be able to use fossils and rock formations as evidence to construct explanations of changes in landscapes over time.*	Keywords: *change over time*

Table 4. DCI codes, examples, and characteristics.

DCI Code	Example	Characteristics
No DCIs	*They will use a model to represent and describe relationships between the components of the model and the model itself.*	Included the SEP of modeling but lacked an explicit DCI or a CCC
	I can innovate a way to make a positive impact on the environment.	Included the SEP of designing solutions, and the CCC of cause and effect.
Contain a DCI	*I can use observations of the sun, moon, and stars to describe patterns in the sky.*	Include a specific topic or concept that relates to a DCI (ESS1.A)

explicit and implicit CCCs, while in the second, it was based only on explicit CCCs. When implicit CCCs were included, more than half of the LOs (56.6%) were three-dimensional (3D), 33.1% were two-dimensional (2D), and 10.3% were one-

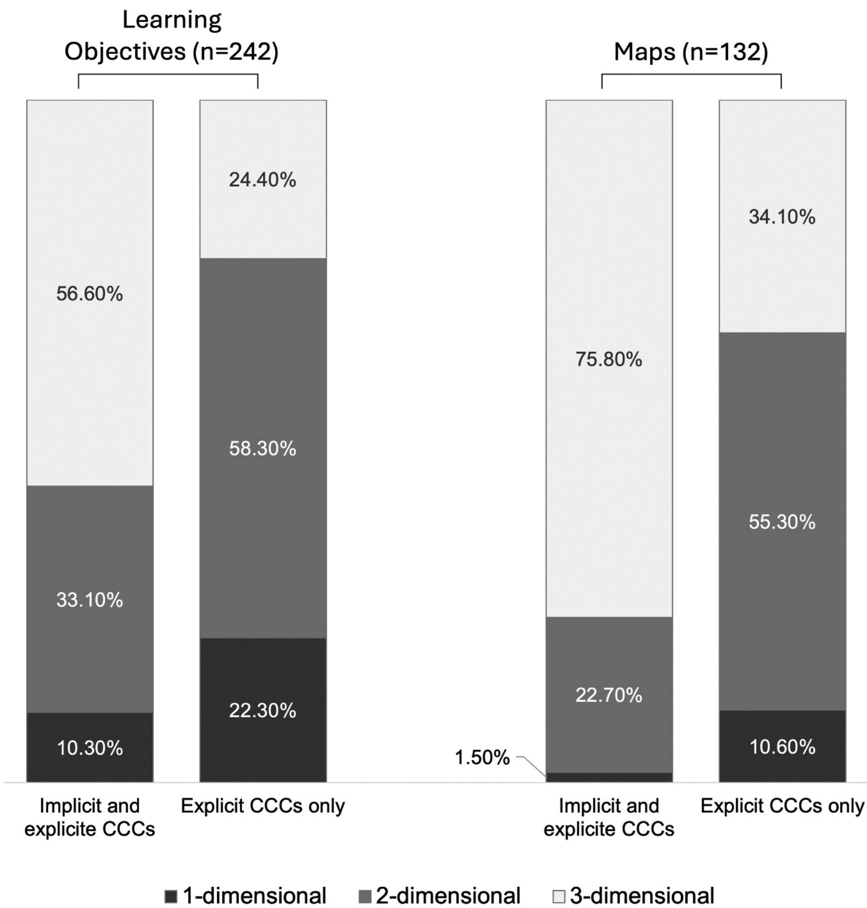


Figure 5. Distribution of dimensionality of learning objectives ($n = 242$) and maps ($n = 132$).

dimensional (1D). When only explicit CCCs were considered, the proportion of 3D LOs decreased substantially to 22.3%, while 58.3% were 2D and 24.4% were 1D (Figure 5).

The dimensionality of a 3D map was collectively determined by the dimensionality of the LOs on the map. Analyzing dimensionality at the map level allowed us to assess whether PSTs' integration of the three NGSS dimensions extended beyond individual LOs to the overall structure of their planned lessons. When counting both implicit and explicit CCCs, we found that 75.8% of maps were three-dimensional (3D) as they contained at least one 3D LO. Up to 22.7% of maps were two-dimensional (2D) as they did not contain any 3D LOs but had at least one 2D LO, and 1.5% of the maps were one-dimensional (1D). However, when considering only explicit CCCs, we found that only 34.1% of maps were 3D, 55.3% were 2D, and 10.6% were 1D (Figure 5).

The patterns at both LO- and Map-levels suggested that most of the LOs and maps were two-dimensional (2D) or three-dimensional (3D), while only a small portion of them were one-dimensional (1D). The perceived three-dimensionality of LOs and maps was strongly influenced by whether implicit CCCs were considered in the analysis.

To what extent were PSTs able to identify the three dimensions of the selected performance expectation and translate them into three-dimensional LOs?

To address this question, we compared the dimensions identified in the PE-box, 3D-box, and LO-box for every learning objective and each 3D map. This comparison provided a way to examine how effectively PSTs moved from recognizing the three dimensions within a standard (the PE) to selecting them in the 3D Map and finally embedding them in their written LOs. The comparisons were categorized as inclusive, overlapping, distinct, or missing/inaccurate, with additional codes for CCC comparison. Results revealed important differences across the three NGSS dimensions (Figure 6).

Alignment of three NGSS dimensions at the LO level

For SEPs, the alignment between the PE-box and 3D-box showed that 64.5% of comparisons were coded as inclusive, indicating that many PSTs recognized the SEP embedded in the PE. However, 23.1% were distinct, suggesting that some PSTs selected SEPs in their 3D-box that did not align with the SEP associated with the corresponding NGSS PE. The proportion of inclusive alignments decreased in the 3D-box versus LO-box comparisons, with 62.8% distinct and only 31% inclusive (Figure 6a).

For CCCs, alignment was more complicated. Between the PE-box and 3D-box, 76.0% of comparisons were inclusive and only 12.8% were distinct, indicating that PSTs typically identified CCCs consistent with the PE. This alignment decreased when comparing the 3D-box and LO-box, where only 23.1% were inclusive and 31.0% were distinct. Comparisons could not be conducted for 44.6% of LOs for CCCs because CCCs were implied rather than explicitly stated in the LOs, suggesting that PSTs often recognized CCCs but did not make them explicit in writing. Thus, instead of excluding these LOs, we applied a new category, *implicit CCC*, when comparing the 3D-box with the LO-box to avoid information loss. In a few cases, PSTs selected a PE to which the NGSS does not specify a CCC. Rather than excluding these cases, we coded them as *no CCC in PE*, since PSTs could still determine a CCC in writing a LO for their lesson sequence (Figure 6a).

For DCIs, alignment between the PE-box and 3D-box was notably higher than for the other dimensions: 74.8% of comparisons were inclusive, although 17.8% showed inaccurate connections. This suggests that PSTs were generally able to identify the DCI embedded in the PE and include a corresponding DCI in the 3D-box. The proportion of alignments between the 3D-box and LO-box increased, with 83.1% inclusive and only 12.8% distinct, which implies that PSTs carried the DCIs identified from the PE forward consistently into their LOs (Figure 6a).

Alignment of three NGSS dimensions at the map level

In addition to analyzing individual LOs, we compared the dimensions identified in the PE-box, 3D-box, and LO-box for each 3D Map. According to the NGSS Framework (NRC, 2012), PEs are "not intended to be taught or assessed one at a time or in isolation" but serve as grade-level or -band endpoints toward which instruction progresses. Because units and lessons are designed to develop all three dimensions of learning over time, PSTs may have included SEPs or CCCs in their daily LOs that were not explicitly linked to the selected PE. Therefore, we examined the alignment of the three dimensions across the PE-box, 3D-box, and LO-box at the map level to capture how PSTs translated and integrated NGSS

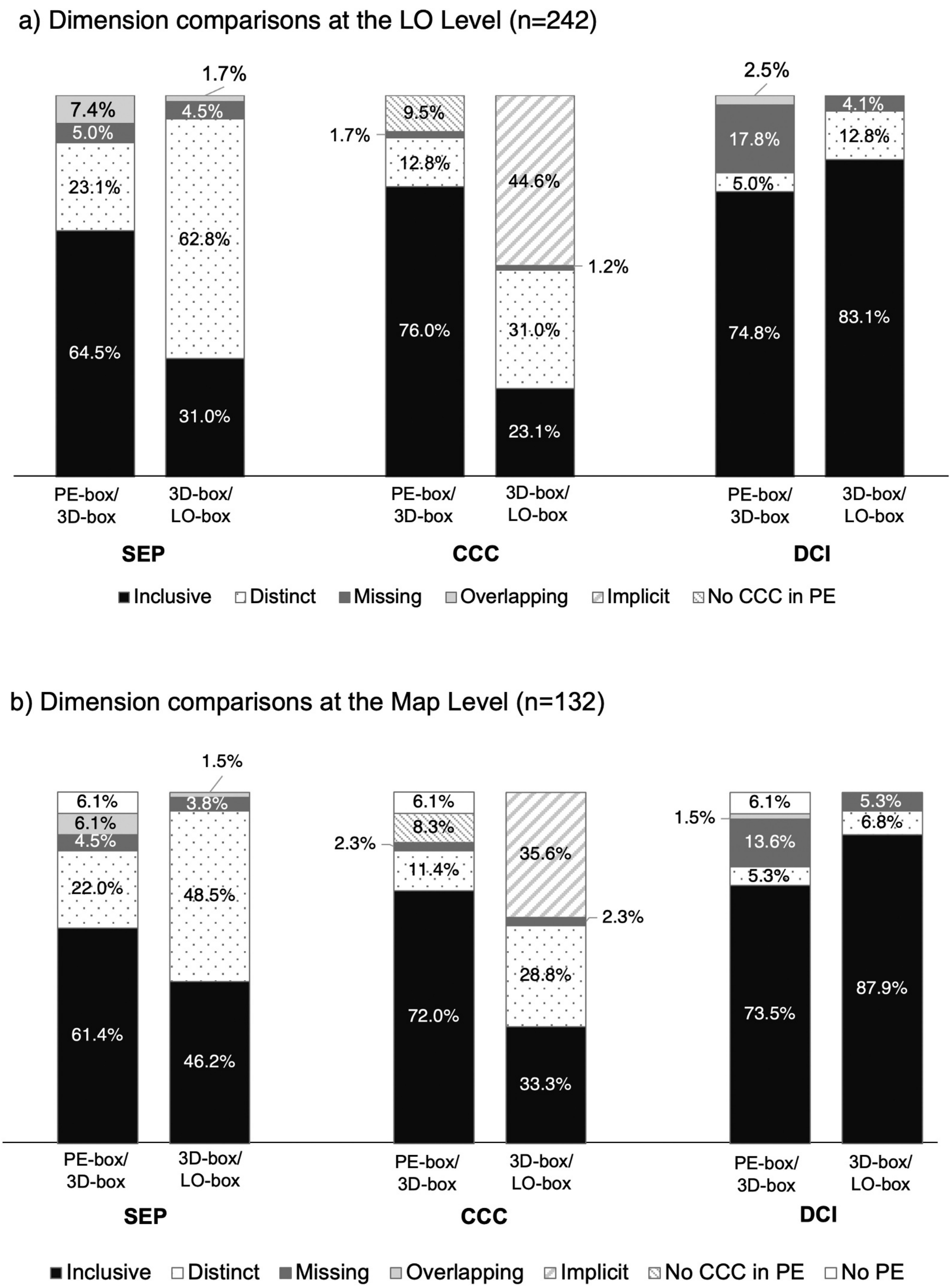


Figure 6. Comparisons of three NGSS dimensions between PE box and 3D-box and between 3D-box and LO-box for learning objectives ($n = 242$) and maps ($n = 132$).

dimensions beyond a single LO. Overall, the trends at the map level were consistent with the LO level findings.

For SEPs, PE-box to 3D-box comparisons showed 61.4% inclusive and 22.0% distinct. However, alignment again dropped in 3D-box to LO-box comparisons, with less than half (46.2%) inclusive and nearly half (48.5%) distinct. For CCCs, 72.0% of PE-box to 3D-box comparisons were inclusive, indicating that most PSTs selected CCCs consistent with their chosen PE. However, when comparing the 3D-box and LO-box, inclusive alignment dropped to 33.3%, while 28.8% were distinct and 35.6% were implicit. These results mirror those at the LO level, showing that CCCs were often left implicit even when initially selected accurately in the 3D-box. For DCIs, PE-box to 3D-box alignment was 73.5% inclusive, and 3D-box to LO-box alignment was even higher at 87.9% inclusive (Figure 6b).

Discussion

Smith et al. (2025) scoping review demonstrates that research on three-dimensional science implementation now spans multiple levels of the system, from individual teachers to institutional structures. Our findings complement this system-level view by zooming in on a critical yet underexamined mechanism in classroom planning: the formulation of NGSS-aligned LOs from PEs. Despite the widespread adoption of NGSS, supporting PSTs in developing three-dimensional LOs remains challenging. Our study contributes to this area by examining the extent to which PSTs identified and translated the three NGSS dimensions into LOs with support from a 3D Map. Our findings show that the 3D map serves as 1) a supporting tool that explicitly focused the elementary PSTs on identifying dimensions from their selected PE and explicitly tasked them to integrate the three NGSS dimensions into the LOs for their instructional sequences, and 2) an effective assessment tool that reveals PSTs' understanding of the three dimensions of a PE and their ability to design day-to-day three-dimensional learning experiences based on it. Our findings also indicate that while most elementary PSTs could identify the three dimensions within a PE, they struggled to integrate relevant SEPs and CCCs into LOs for their instructional sequences.

Our results indicate that many PSTs were able to construct multidimensional learning objectives using the 3D map. Specifically, approximately 78% of learning objectives were two- or three-dimensional when only explicit CCCs were counted, and this proportion increased to about 90% when both explicit and implicit CCCs were included. We do not claim a direct causal relationship between the use of the 3D map and the construction of multi-dimensional LOs, but we believe the 3D map played an important role in engaging our PSTs in a productive mapping process. This process involved collaboratively examining target PEs, determining SEPs, DCIs, and CCCs for their lessons/lesson sequences, and constructing relevant three-dimensional science LOs. In our study, this type of integrative planning is less likely to occur without the structured scaffolding provided by the map.

The 3D map enabled us to analyze PSTs' LO construction process by examining two stages: identifying the three dimensions and integrating them into LOs. Overall, the high alignment between the PE-box and 3D-box demonstrated PSTs' ability to identify the three dimensions of a PE. In this study, our PSTs had some flexibility in selecting a PE at the assigned grade level. As a result, they were likely to choose PEs they knew better, which might have helped them identify the three dimensions more accurately. Meanwhile, we found relatively low discrepancies in SEPs (23.1%) and CCCs (12.8%) between the PE-box and the 3D-box. While this pattern could suggest PSTs' developing understanding of a PE, variations in the specific SEPs/CCCs emphasized at the lesson level may reflect appropriate instructional adaptation rather than misalignment. According to *the Framework* (NRC, 2012), PEs serve as unit-level or grade-band endpoints toward which instruction progresses over time. Given that the PSTs only designed a lesson/lesson sequence, rather than a complete unit, the differences in SEPs/CCCs between the PE-box and the 3D-box also likely reflect the inherent flexibility in translating PEs into lesson-level LOs.

Our analysis of the alignment between 3D-box and LO-box suggests that elementary PSTs struggled to translate SEPs and CCCs into their LOs. We observed low alignment between the 3D-box and LO-box for SEPs and CCCs at the LO level: 31% and 23.1%, respectively. As mentioned above, PSTs could select SEPs/CCCs that differ from those in the PEs when designing daily learning experiences. If PSTs successfully integrated the selected SEPs/CCCs into their LOs, we would expect to observe high alignment between the 3D-box and LO-box. Compared with the dimension alignment between the PE-box and 3D-box, the low alignment between the 3D-box and LO-box is more likely to reflect PSTs' developing understanding of SEPs or CCCs. Previous studies have shown that many PSTs lacked understanding of SEPs and CCCs (Dalvi et al., 2021; Lee & Arias, 2024; Ricketts, 2014). Marckwordt et al. (2022) reported that science teachers regarded CCCs as the most challenging dimension because they were unfamiliar with many CCCs and considered some CCCs abstract. In this sense, our findings not only corroborate previous research but also suggest that teachers' LOs may serve as an indicator of their understanding of NGSS dimensions. Overall, these comparisons suggest that, in addition to scaffolding PSTs in breaking down a PE and constructing learning objectives, the 3D map served as a useful analytical tool for us, teacher educators, to identify the challenges PSTs faced during the process.

Our study further contributes to the literature by quantifying the extent of PSTs' difficulties and characterizing LOs that lack one or more dimensions. These results provide strong empirical evidence that teacher educators can use to identify PSTs' areas for growth and diagnose existing challenges. We highlight three examples below. First, we found that 23% to 24% of LOs lacked either a SEP or a CCC, while only 4.1% lacked a DCI. These results suggest that PSTs may need additional time or support to understand SEPs and CCCs. They also help explain prior research showing teachers tend to emphasize content knowledge over practices and crosscutting ideas (Kang et al., 2019; Merritt et al., 2018). From our perspective, when teachers fail to include appropriate SEPs or CCCs when articulating intended learning outcomes (i.e., constructing the LOs), they are more likely to prioritize content knowledge during instruction. Second, earlier research showed that PSTs frequently use general verbs or descriptive statements rather than measurable, evidence-based objectives (Amelia et al., 2024; Coggins & Colburn, 2018). We found that our PSTs often used unmeasurable verbs (e.g., *understand, learn*) in LOs lacking an SEP. Additionally, we observed that many PSTs misused the verb *explain* to mean *describe* rather than to mean justify claims with evidence, indicating both confusion between everyday and scientific language and a developing understanding of the key components of a scientific explanation. Third, Fick et al. (2022) found that, except for *patterns*, elementary science teachers implement all CCCs in the classroom implicitly. In another study, Arias et al. (2024) found that elementary teachers most frequently use *patterns* and *cause and effect* in science instruction, as they regarded these CCCs as most accessible for their students. Our results show that CCCs were not only the least present in PSTs' learning objectives, but the most cited CCCs were also *cause and effect* and *patterns*. Building on the studies from Fick et al. (2022) and Arias et al. (2024), we speculate that the absence and implicitness of CCCs in PSTs' LOs may stem from the limited experience to learn about CCCs as students or from a lack of opportunities to observe explicit CCC implementation in classrooms during field observations.

In a few maps, we found PSTs copied NGSS PEs directly into their LOs rather than adapting them for classroom use. Studies of teacher practice and lesson planning show that instead of writing LOs tailored to student outcomes, some teachers frequently "mirror" the language of standards. For example, analysis of classroom and lesson planning practices in research on project-based learning found "the alignment between teaching objectives and classroom assessments and between teaching objectives and instructional activities was lacking" (Zhao et al., 2023, p. 10). The researchers attributed this lack of alignment between LOs, instructional activities, and assessments to teachers' limited curriculum knowledge. Connecting to our findings, we believe that while the 3D Map tool supports recognition of NGSS dimensions, teacher educators' guidance remains essential for helping PSTs articulate and integrate them coherently. Without explicit instructor modeling and feedback, PSTs may treat the boxes as separate checklists rather than as parts of a coherent framework for 3D learning.

Implications

Two primary sets of implications arise from this study. The first set of implications is in regard to what was learned about how science teacher educators may better support PSTs in constructing three-dimensional LOs, both in general and through the use of the 3D Map. In general, we recommend that teacher educators be explicit about the language that they use when engaging PSTs in the SEPs and CCCs, in particular, drawing on the language of the SEPs and CCCs to create LOs. Verbs related to the SEPs and CCCs used by PSTs in their LOs suggest that PSTs may confuse the scientific use of words like "explain" and "model," for example, with the everyday use of these words, leading to an LO that does not include the intended SEP and CCC. This study suggests that the 3D Map may be helpful in supporting PSTs in creating three-dimensional LOs by providing a visual scaffold that explicitly prompts students to consider all three dimensions, especially CCCs, which teachers often do not explicitly include in their instruction (Fick et al., 2022). Meanwhile, PSTs still need support from their instructor to make sense of the components of the tool and to provide repeated, structured opportunities for them to practice using it both collaboratively and individually.

The second set of implications of this work is in regard to the process of analysis for this study and the insights that it provided to the authors as a group of science teacher educators. While we found the 3D Map to be a helpful tool to elicit our PSTs' thinking about three-dimensional LOs, the true power of this as an assessment tool lies in the collaborative discussions of the authors while working to interpret patterns in PSTs' thinking. Through these discussions we developed a clearer understanding of what our own teaching objectives are in our methods courses in regards to three-dimensional LOs and, as an extension, the components of NGSS. Questions such as, "What should a CCC look like in PSTs' LOs?" "Do all LOs really need to be three-dimensional?" and "What am I doing in my course to influence my PSTs' understanding of the SEPs?" dominated our analysis discussions and, in turn, led us to critically reflect on our own teaching practices and goals. We recommend that more groups of educators from different contexts engage in such analysis and report on what they have learned to our greater community of science teacher educators, so that we may all learn from such extended collaborative discussions about the best ways to support PSTs in understanding and applying three-dimensional teaching.

The current study illustrates the value of systematically coding LOs to reveal patterns in how PSTs conceptualize NGSS integration. By comparing the dimensions (i.e., SEP, CCC, DCI) present in targeted PE, dimensions selected by PSTs, and the dimensions coded in PSTs' LOs, this study contributes to expanding our understanding of elementary PSTs' ability and challenges in constructing three-dimensional LOs. Taken together, these results demonstrate that while PSTs can identify NGSS dimensions and begin to incorporate them within their planning, explicit support and guided mediation are necessary for them to move from recognition to transformation. The ASET Three-dimensional Mapping Tool offers a valuable framework for making this reasoning visible and for advancing both research and practice in the preparation of teachers capable of designing coherent, multidimensional science instruction. Future research could extend this framework by analyzing longitudinal development of objective-writing skills across the teacher preparation pathway and exploring how PSTs' written LOs translate into enacted classroom lessons during practicum or induction phases.

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