

COMMENTARY

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Planning and carrying out investigations: an entry to learning and to teacher professional development around NGSS science and engineering practices

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Abstract

The shift from science inquiry to science practices as recommended in the US reports *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* and the *Next Generation Science Standards* has implications for classroom/school level instruction and assessment practices and, therefore, for teacher's professional development. We explore some of these implications and the nuances of adopting a practice orientation for science education through the lens of one NGSS practice 'Planning and Carrying Out Investigations' (PCOI). We argue that a focus on any one practice must necessarily consider embracing a 'suite of practices' approach to guide in the design of the curriculum, instruction, assessment, and evaluation. We introduce the 5D model as a curriculum and instruction framework (1) to examine how unpacking PCOI can help teachers bridge to other less-familiar-to-teachers NGSS practices and (2) to help capture the 'struggle' of doing science by problematizing and unpacking for students the 5D component elements of measurement and observation.

1. Deciding what and how to measure, observe, and sample;
2. Developing or selecting procedures/tools to measure and collect data;
3. Documenting and systematically recording results and observations;
4. Devising representations for structuring data and patterns of observations; and
5. Determining if (1) the data are good (valid and reliable) and can be used as evidence, (2) additional or new data are needed, or (3) a new investigation design or set of measurements are needed.

Our hypothesis is that the 5D model provides struggle type experiences for students to acquire not only conceptual, procedural and epistemic knowledge but also to attain desired 'knowledge problematic' images of the nature of science. Additionally, we further contend that PCOI is a more familiar professional development context for teachers wherein the 5D approach can help bridge the gap between the less familiar and the more complex practices such as building and refining models and explanations.

Background

For scientists and engineers, PCOI has many steps involving numerous decisions and frequently requiring repeated attempts. It takes time to sort things out in the natural world, to ask the right questions, and to make the appropriate measurements and observations. The *Framework*

(NRC 2012) points out, however, that such sense-making enactments are missing in our current K-12 science programs. Currently, we find in many science programs, online websites, and curriculum materials streamlined 'cookbook' investigations and out-of-date activities for K-12 students. Such cookbook and dated investigations tend to strip out the sense-making complexities of doing science and thereby omit the practices and using knowledge orientation of the NGSS (NGSS Lead States, 2013). If students only

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encounter preplanned confirmatory investigations following step-by-step procedures that ensure the desired outcome occurs, then important and relevant thinking and designing practices and struggles that are part of doing science and engineering get stripped away. When the struggle of doing science is eliminated or simplified, learners get the wrong perceptions of what is involved when obtaining scientific knowledge and evidence. Thus, a principal goal of the *Framework* (NRC 2012) is to ensure learners' experiences with doing science emphasizes practices and reflects a bit of the struggle.

The *Framework* (2012) "stresses the importance of developing students' knowledge of how science and engineering achieve their ends while also strengthening their competency with related practices." (p 41) so as to "help students become more critical consumers of scientific information." (p 41). Engaging in investigations that are designed for making choices and decisions during planning and implementation, provides students opportunities for finding what works out and what does not. Setting up groups so that students use different ways of measuring, recording, and/or representing creates 'coming together making sense' opportunities in a classroom for sharing and comparing. Each group then presents on how they tackled the investigation. Such sharing often leads to refinements to the investigation plans, alterations in how to take measurements or perhaps a decision to start over. These are important 'doing science' experiences that develop students' insights into the nature of science and the dynamics of how scientific knowledge is generated, refined, and justified.

We hypothesize that a reconsideration of planning and carrying out investigations (PCOI) as a suite of component practices to be unpacked will help reveal to students the scientific struggles involved with building knowledge about the natural world. This unpacking position is different from the 'fused practices' stance, outlined in the next section, which combines several science and engineering practice. Unpacking the suite of practices embedded in PCOI will aid and challenge teachers, too, as they engage in the monitoring and mediation of students reasoning and knowledge building. Through measurements and observations of the material world and of the designed world, scientists as well as students test claims, questions, conjectures, hypotheses and models; e.g., about nature, life on Earth, and the material composition and structure of matter and energy. Good science and engineering investigations put theories, explanations, designs and solutions to severe tests. Such severe tests are the goal of planning and carrying out investigations. Wellington and Osborne (2001) argue though that a major shortcoming of our educational programs is that we offer little to justify the current lack of focus on how science builds and refines theories, models, and explanations; e.g., epistemic practices in classrooms. Osborne and Wellington are speaking to the misplaced priorities we find

in most science curriculum. That is, the persistent and dominant focus on teaching what we know. How we come to know and why we believe what we know are marginalized aspects of science learning. The long-term effect, discussed in the next section, leads to learners' acquiring incorrect images of science.

A critical step forward for changing this 'what we know' condition is engaging learners in doing science and examining the relationships between evidence and explanation. In classrooms, such opportunities typically occur when planning and carrying out investigations (PCOI) that are designed to engage learners in the nuanced decision making steps of moving from questions, to measures, to data, to evidence, and to explanation. PCOI is a complex process and frequently an iterative one, too. It takes time when designing and implementing investigations to sort things out about measuring and structuring data. If students and teachers only encounter preplanned confirmatory investigations based on tried and true step-by-step procedures always ensuring the anticipated outcome(s), then an undesirable outcome for students is that important and relevant cognitive and materials struggles of doing science get stripped away. A negative outcome for teachers is that important formative assessment and feedback-on-learning opportunities get omitted, too.

The learning sciences literature (Sawyer, 2014) informs us that the structure of knowledge and the processes of knowing and learning are much more nuanced. That is, context and content matter. We now understand how cognitive, social, and cultural dynamics of learning are mutually supportive of one another and intertwined. "[Y]ou cannot strip learning of its content, nor study it in a 'neutral' context. It is always situated, always related to some ongoing enterprise" (Bruner, 2004; p20). Thus, learning goals are not just knowing about things but also using knowledge to build and refine claims. In the STEM disciplines, knowledge use is situated in or coupled to disciplinary practices that focus on building and refining designs, solutions, models and theories.

When we synthesize the learning sciences research (c.f., Duschl, 2008) we learn:

- (1) The incorporation and assessment of science learning in educational contexts should focus on three integrated domains:
 - The conceptual structures and cognitive processes used when reasoning scientifically,
 - The epistemic frameworks used when developing and evaluating scientific knowledge, and,
 - The social processes and contexts that shape how knowledge is communicated, represented, argued and debated.
- (2) The conditions for science learning and assessment improve through the establishment of:

- Learning environments that promote active productive student learning,
- Instructional sequences that promote integrating science learning across each of the 3 domains in (1),
- Activities and tasks that make students' thinking visible in each of the 3 domains in (1), and
- Teacher designed assessment practices that monitor learning and provide feedback on thinking and learning in each of the three domains.

This learning sciences research focus has contributed to new views about how to engage students in school science. The *Taking Science To School* (NRC, 2007) report interprets the learning science perspectives by stating science education in grades K-8 needs to emphasize three practices:

1. Building and refining theories and models,
2. Constructing arguments and explanations,
3. Using specialized ways of talking, writing and representing phenomena.

However, if we are going to raise the learning performance bar for students, then there are implications for teachers as well. The orientation to coupling the learning of content with engagement with practices (i.e., using knowledge) and doing so within coherent sequences of instruction both within and across grade levels is a new challenge for STEM teachers. A promising perspective for beginning teacher education is the recommendation that the education of early career teachers should focus on a core set of pedagogical routines.

A core challenge for all teacher preparation programs is to identify the knowledge and skills that are both essential for new teachers and within teachers' reach. These skills should be defined broadly enough to fit with different instructional approaches that are commonly used in teaching, readily mastered by novices, and that provide novices with a professional foundation to equip them to learn more about students and about teaching. (National Academy of Education, 2009, p 4).

These core practices and skills have come to be known as High Level or Ambitious Teaching Practices. Mark Windschitl and Jessica Thompson have a research program that is pursuing development of core practices for ambitious science teaching (Windschitl et al, 2012; Windschitl et al 2011). For them the approach is to focus on 4 discourse tools as core practices:

1. Selecting big ideas – identifying inquiry-worthy ideas
2. Eliciting students' hypotheses – attending to students' initial and unfolding ideas

3. Making sense of activity – Making meaning of science phenomena
4. Pressing for evidence-based explanation – Reasoning with explanatory models through phenomena.

Practices 3 and 4 are situated in PCOI activities. For teachers, the practices challenge is developing formative assessment routines that mediate student learning and reasoning. The 5D model suite of practices unpacks for teachers as well the critical epistemic practices that need to be monitored. Such teacher monitoring and mediation practices are labeled 'Assessment for Learning' and is distinct from evaluation practices (e.g., quizzes and tests) associated with 'Assessment of Learning' (Gitomer and Duschl, 2007). The teaching routines and assessment practices associated with PCOI lessons are indeed complex. However, as Windschitl et al (2012) argue accomplished and ambitious science teaching (i) examines and identifies the diversity of students knowledge and reasoning and (ii) mediates student learning by providing experiences and discourse opportunities that enable students to develop understandings of conceptual structures, to employ criteria for evaluating the status of knowledge claims, and to participate in communicating evidence and knowledge claims to others. Ambitious teaching involves creating classroom learning environments that promote the sharing and display of students ideas and thereby making learners' thinking visible that, in turn, make possible teachers' assessment for learning practices. The crux of the matter is simple to state but complex to implement and manage. Not unlike the 5E model, discussed in the next section, which research shows has been a very effective instructional framework for science teachers to coordinate inquiry learning, the 5D suite of practices model we hypothesize will aide teachers in successful implementation of the three *Taking Science to School* practices listed above.

Knowledge problematic and the 5D component elements

The *Framework* (NRC 2012) recommends that within 3-year grade bands (e.g., K-2 3 to 5, 6 to 8, 9 to 12), students' engagements with PCOIs should increasingly lead them to broaden and deepen the complexity of investigations, both in terms of the questions and problems being posed as well as the measures and methods being employed. The *Framework's* stance is to avoid students only doing investigations that present science knowledge and scientific inquiry in ways that are viewed as non-problematic. Non-problematic in the sense that science would be seen as a straightforward path to answers and explanations where there is no struggle: ask a question, you always get the answer; make measurements, you always selected the right

tool and procedure; make observations, you always obtain the correct information knowing when and where to look.

Carey and Smith (1993), Smith et al. (2000), and Smith and Wenk (2006) report research examining K-16 students' images of science and found evidence that indeed many learners do the attainment of scientific knowledge as non-problematic. Employing the same structured interview protocols, they assigned students to one of the three levels of views about images of science

Level 1 Students view scientific knowledge as a collection of true beliefs about how to do something correctly or as basic facts. Scientific knowledge accumulates piecemeal through telling and observation which is certain and true. Students view scientific knowledge as unproblematic.

Level 2 Students view science knowledge as a set of tested ideas. Notions of explanation and testing hypotheses appear at this level. Here, students view science as figuring out how and why things work and absolute knowledge comes about through diligence and effort. Level 2 is a transitional level.

Level 3 Students see scientific knowledge consisting of well-tested theories and models that are used to explain and predict natural events. Theories are seen as guiding inquiry and evidence from experiments is not only used for/against hypotheses but theories as well. Theories and models are also seen as more or less useful rather than strictly right or wrong, and that knowledge of world is fundamentally elusive and uncertain. Students view scientific knowledge as problematic.

Carey et al. (1989) asked seventh graders a series of questions about the goals and practices of science and about the relationships between scientists' ideas, experiments, and data. Here, too, they found the same global perspectives about the nature of science.

- Level 1 in which scientists were regarded simply as collecting facts about the world: knowledge unproblematic
- Level 2 transitional
- Level 3 in which scientists were seen as concerned with building ever more powerful and explanatorily adequate theories about the world: knowledge problematic

Another interview study (Grosslight et al. 1991) probed middle school students' understanding of models and modeling and achieved similar results.

- Level 1 Many children regarded models merely as copies of the world.
- Level 2 Children understood that models involve both the selection and omission of features, but

emphasis remained on the models themselves rather than on the scientists' ideas behind the model.

- Level 3 Models were regarded as tools developed for the purpose of testing theories.

Driver et al. (1996) report similar results. Researching students' images of science, they found that students who complete too many investigations, year in and year out, that are designed to follow a set of procedures thus ensuring sound results, fail to recognize that the results of investigations are used in science to engage in model building and revision activities. In other words, the impression students acquire is that science investigations typically work and the anticipated outcomes are usually achieved. Absent are the struggles that scientists encounter when trying to decide how, what, where, and when to measure or observe what some researchers (Lehrer et al. 2008; Ford, 2008; Duschl, 2008) refer to as 'getting a grip on nature.' A steady diet of such investigations-without-struggles seems to lead students to leave school with the level 1 naïve notions: obtaining results from investigations and developing scientific knowledge are non-problematic.

A National Research Council study, *America's Lab Report* (NRC, 2006), provides a possible explanation for the results described in the aforementioned studies. The study found that the sequence of instruction and role of laboratory activities often are experienced as separate. The NRC report recommended greater use of integrated instructional units.

Integrated instructional units have two key features. First, laboratory experiences and other educational experiences are carefully designed to help students attain learning goals. Second, the laboratory experience is explicitly connected to and integrated with other learning experiences. Our proposal of a 5D framework is intended to address the need for an integrated instructional approach to Planning and Carrying Out Investigations.

PCOI can instead reveal how obtaining, building, and refining scientific knowledge through scientific inquiries involves working through a variety of complexities or what we introduce in the 5D framework as a suite of practices embedded in five component elements of measurement and observation. Our position is that a focus on any one practice must necessarily embrace a suite of practices approach to guide in the design of curriculum, instruction, assessment, and evaluation. Songer has advanced the notion of 'fused' practices as a strategy for bundling together *NGSS* core ideas, crosscutting concepts, and science and engineering practices. In Songer et al. (2009) and Gotwals and Songer (2013), the core idea *biodiversity* is blended with the crosscutting concept *patterns* and three fused practices: *planning and carrying out investigations, analyzing and interpreting data, and constructing explanations*. Rather than bundling practices, we advocate a practice

unpacking stance. The 5D model takes up a suite of practices orientation that captures the struggle of doing science by problematizing and unpacking component PCOI elements of measurement and observation. Once problems have been posed, questions asked, or hypotheses stated, scientists and engineers turn to a set of component elements that typically include the following:

1. Deciding what and how to measure, observe, and sample;
2. Developing or selecting procedures/tools to measure and collect data;
3. Documenting and systematically recording results and observations;
4. Devising representations for structuring data and patterns of observations; and
5. Determining if (1) the data are good (valid and reliable) and can be used as evidence, (2) additional or new data are needed, or (3) a new investigation design or set of measurements are needed.

Our hypothesis is that the component elements deciding, developing, documenting, devising, and determining in the 5D provides struggle type experiences for students that will lead (1) to acquiring conceptual, procedural, and epistemic knowledge and (2) to attaining desired knowledge problematic images of the nature of science.

The proposed 5D model has general connections to the BSCS 5E Instructional Model (Bybee, 2015). The 5D model is specific to the challenge of Planning and Conducting Investigations while the BSCS 5E model has wider or more general applicability. Beyond the parallel of the two models, we also note research supporting the positive learning outcomes and use of the 5E model (Scott et al., 2014; Wilson et al., 2010; Taylor et al., 2015).

Discussion

Complexities in school science investigations

Taking Science to School (NRC, 2007), the synthesis study report of K-8 science learning, takes up the review of PCOI issues in chapter 5 - 'Generating and Evaluating Scientific Evidence and Explanations.' It is beyond the scope of the article to present a full synthesis of the research from chapter 5. However, a reading of the chapter's section and subsection headings offers up important insights about the landscape of school science investigations that teachers will need to become proficient:

- Generating Evidence
 - Asking questions and formulating hypotheses
 - Designing experiments
 - Observing and recording
- Evaluating Evidence
 - Co-variation evidence
 - Evidence in the contexts of investigations
- Beliefs about causal mechanisms and plausibility
- Evaluating evidence that contradicts prior beliefs
- The importance of experience and instruction
- Representational systems that support modeling
 - Mathematics
 - Data
 - Scale models, diagrams, and maps

In order to get a better sense of the complexities that exist in PCOI, consider the two general statements in the *Framework* (2012; p 50) that distinguish science and engineering investigations. The general goal is designing experiences where students are using prior knowledge and evidence to build and refine models, designs, and explanations.

Scientific investigation may be conducted in the field or the laboratory. A major practice of scientists is planning and carrying out a systematic investigation, which requires the identification of what is to be recorded and, if applicable, what are to be treated as the dependent and independent variables (control of variables). Observations and data collected from such work are used to test existing theories and explanations or to revise and develop new ones.

Engineers use investigation both to gain data essential for specifying design criteria or parameters and to test their designs. Like scientists, engineers must identify relevant variables, decide how they will be measured, and collect data for analysis. Their investigations help them to identify how effective, efficient, and durable their designs may be under a range of conditions.

In classrooms and out-of-school learning environments that engage learners in conducting experiments and investigations, there exist some general distinctions for PCOI. One important distinction brought out in the 'Designing Experiments' section that reviews the literature on children designing experiments is the differences between knowledge lean and knowledge rich activities. Domain-general experiments and demonstrations typically stress the learning of a strategy (e.g., control of variables) in simplified stripped down conceptual knowledge contexts. The experiments and investigations are typically completed in one or two lesson periods and minimize the need to consider relevant domain-specific prior knowledge. Thus, the design of domain-general investigations is viewed as having knowledge lean requirements. An example is doing a control of variable (COV) experiment to find the law of the pendulum. The experimenter isolates three variables (length of string, size of weight, height from which weight is released) to determine which variable(s) influences the period/time of swing. In this case,

only the length of the string changes the period of the pendulum.

Engaging learners in the design of domain-specific experiments/investigations that are knowledge rich and less constrained reveal very different patterns of engagement by children. Such experiences typically require a sequence of lessons over days and perhaps weeks to complete and, importantly, also require the use of prior knowledge. An example, building on the domain general COV activity, is posing a challenge to students to construct a pendulum that can be used as 1 s/period counter or second timer. Here, time measurements from an array of different length pendulums are used to develop a data set. The data set, in turn, is used to build a data structure representation to find which pendulum length has a 1-s period. Extensions of the lesson could predict and then investigate if different materials (e.g., wooden dowels, metal pipes, and chains) as the same length of the string would produce a 1-s swinger/pendulum. Domain-specific investigation researches were found to have knowledge rich requirements and demands.

Another important distinction for PCOI is adopting a learning progression or perspective for engaging in PCOI. The *NGSS Science and Engineering Practices Grade Band Matrix* suggests the following 'end of grade band goal statements' that appear in the PCOI:

- Investigations based on fair tests to support explanations or design solutions (K-2).
- Investigations that control variables and provide evidence to support explanations or design solutions (3 to 5).
- Investigations that use multiple variables and provide evidence to support explanations or design solutions (6 to 8).
- Investigations that build, test, and revise conceptual, mathematical, physical, and empirical models (9 to 12).

The 5D model component elements deciding, developing, documenting, devising, and determining frame the kind and type of problematic processes that the students of K-12 might consider or encounter when engaging in PCOI activities. The intent is to allow such PCOI experiences to unfold and enable rich opportunities for discussions and engagements to take place. The basic idea is to problematize the data and evidence generated in an investigation and get students to represent and talk about the data and evidence. Hence, the recommendation we are making with the 5D model is to unpack PCOI in terms of problems of measurement and measuring. What measurements should be taken? What is the sample and size of sample for taking the measures?

Is the sample size sufficient and well constructed to address issues of chance outcomes? What level of accuracy and precision do you want? What instruments or tools should be used to make such measurements? Precision is very important and opens up many other problems to achieve the goal to measure and record as accurately as possible so as to try and eliminate as many sources of error as possible. Then there are the precision issues when doing field studies such as conducting observation, conducting counts, gathering samples, and generating representations and drawings. Once again, we see how obtaining, building, and refining scientific knowledge becomes problematic.

Another relevant distinction is the types of hypothesis-based investigations scientists and engineers develop. Scientists and engineers have two fundamental goals when investigating and observing the world: (1) systematically describe the world; and (2) develop and test models, mechanisms, theories, and explanations for how the world works. The three broad categories for such investigations are the following:

- Generate observations/measurements that induce a hypothesis to account for a pattern - (discovery context)
- Test existing hypotheses under consideration against one another - (confirmation/verification context)
- Isolating variables or controlling variable investigations that allow for valid inferences and also to put constraints on the number of possible experiments to consider.

Planning investigations begins with designing experimental or observational inquiries that align to the question(s) being asked or the hypothesis being put forth. One begins this process by considering the relevant properties, attributes, and variables and then determining how they may be observed, measured, isolated, or controlled. Isolating and controlling variables are important for determining patterns, establishing cause and effect relationships, and building mechanisms to explain or describe events and systems. In laboratory experiments, students need to decide the following:

- which variable(s) will be treated as results, the outcomes of the experiment that are allowed to be different and vary, and
- which variable(s) are to be treated as the inputs and thus must be held constant, that is controlled.

Another distinction is between lab and field investigations. In field observations, planning investigations are very different and begin with finding out what can and cannot be controlled and then deciding when to do measurements

or how to collect different samples of data under different conditions. A model-based approach is needed. The range of choices, the complexities with obtaining and setting up materials, and the wide variety of sources of error are what makes scientific knowledge problematic - it is complex work and involves planning and thinking that can frequently be inaccurate or misdirected, yet another important aspect of the scientific struggle that makes science knowledge problematic and difficult to attain.

Forms of knowledge, ways of knowing

The *Framework* (NRC, 2012) 'stresses the importance of developing students' knowledge of how science and engineering achieve their ends while also strengthening their competency with related practices' (p 41) so as to 'help students become more critical consumers of scientific information' (p 41). Engaging in the 5D component elements for PCOI pushes students into making choices and making decisions, some that might work out and some that might not. Setting up groups so that students use different ways of measuring, recording, and/or representing creates 'coming together making sense' opportunities in a classroom (Duschl, 2003). A teacher can ask at the end of the lessons, 'So, what did we find out, what did we learn about the design and procedures of the investigation?' Each group then presents on how they tackled the investigation. Such sharing often leads to refinements to the investigation plans, alterations in how to take measurements, or perhaps a decision to start over (Duschl and Gitomer 1997). These are important 'doing science' experiences that develop students' insights into the workings of science and understandings of how scientific knowledge is generated and justified.

Engaging students in coming together events for considering, reviewing, and critiquing the design of experiments and investigations, the data gathering and measurement plans, and the quality of data and evidence obtained are important conversations to have before, during, and/or after carrying out investigations (Engels & Contant, 2002). As stated in the *Framework*, (NRC, 2012) '[u]nderstanding how science functions requires a synthesis of content knowledge, procedural knowledge, and epistemic knowledge' (p 78). Both procedural and epistemic knowledge are strongly located in PCOI.

Procedural knowledge as used in the *Framework* (NRC, 2012) represents the suite of methods scientists and engineers use to ensure findings are valid and reliable. Again, scientists and engineers make many decisions to ensure that data are accurate and that the evidence obtained is valid (true measures or observations) and reliable (obtained using procedures that can be repeated). Procedures such as using control groups to test the effect of treatments, sampling procedures to make sure what you are measuring/observing is representative of the larger population,

double-blind studies to eliminate any chance of bias, and establishing the precision of measurement are examples of how scientists go about studying nature.

Epistemic knowledge is knowledge of the various sets of criteria, rules, and values held in the sciences and in engineering disciplines for deciding 'what counts' or 'what is best.' Examples of epistemic knowledge include deciding what is a fair test, a precise and accurate measurement, systematic observations, testable hypotheses, etc. Epistemic knowledge is more often than not developed and decided by communities and not by individuals. Scientists and engineers develop epistemic knowledge when writing papers or presenting to research groups and at conferences. The goal is being able to explain how we have come to know what we know and why we believe this explanation over alternatives. Each of the 5Ds can be seen as a knowledge-building component of PCOI and thus constitutes epistemic knowledge.

Considering the 5D components presented above, PCOI lesson sequences may stress one or more of these elements. Engaging students with inventing measures or selecting measures from a set of options opens up important dynamics about the nature of scientific inquiry. So, does allowing students to invent representations or choose among options for graphically presenting results enhance scientific inquiry learning experiences? (Lehrer and Schauble, 2000, 2002).

Our position is that unpacking the component elements for students is a critically important goal for instruction over the course of the school year as well as over a grade band (e.g., K-2 3 to 5, 6 to 8, 9 to 12), and we would maintain that the unpacking of PCOI is also a viable and powerful initial context for designing K-12 NGSS teacher professional development programs addressing the instructional coordination of the Frameworks 3 Dimensions. Even more so, it provides students with 'doing' opportunities with these component practice elements. It is worthwhile then to consider the long-term end of K-12 goals the *Framework* puts forth for the third S and E practice - planning and carrying out investigations.

By grade 12, students should be able to do the following:

- Formulate a question that can be investigated within the scope of the classroom, school laboratory, or field with available resources and, when appropriate, frame a hypothesis (that is, a possible explanation that predicts a particular and stable outcome) based on a model or theory.
- Decide what data are to be gathered, what tools are needed to do the gathering, and how measurements will be recorded.
- Decide how much data are needed to produce reliable measurements and consider any limitations on the precision of the data.

- Plan experimental or field-research procedures, identifying relevant independent and dependent variables and, when appropriate, the need for controls.
- Consider possible confounding variables or effects and ensure that the investigation's design has controlled for them.

Conclusions

The *Framework* (NRC, 2012) rightfully stresses that the science and engineering practices should begin in the very earliest grades and then progress through middle school to high school engaging students in ever more complex sophisticated levels of performances. Here, we have focused on unpacking PCOI to demonstrate how an emphasis on measurement and observation using the 5D framework invokes a suite of practices that occur when designing and conducting such inquiries. We have discussed the importance of opportunities to design investigations so students can learn the importance of decisions surrounding what and when to measure, how and where to sample or observe, what to keep constant, and how to select or construct data collection tools and instruments that are appropriate to the needs of an inquiry. Students also need experiences that are outside the laboratory so they learn it is not the sole domain for scientific inquiry. For many scientists (e.g., geographers, geologists, oceanographers, field biologists, psychologists, ecologists), the 'laboratory' is the natural world where experiments are conducted and data are collected in the field. In the elementary years, students' experiences should be structured to help them learn to plan investigations and define the features to be investigated such as looking for patterns and interactions that suggest causal relationships. 'From the earliest grades, students should have opportunities to carry out careful and systematic investigations, with appropriately supported prior experiences that develop their ability to observe and measure and to record data using appropriate tools and instruments' (NRC, 2012, p 60-61).

At all grade levels, there is a need for balance between investigations structured by the teacher and those that emerge from students' own questions or from authentic investigations of agreed upon problems; e.g., the source of a classroom's fruit flies (Lehrer and Schabule, 2002). Students should have several opportunities to engage in practices where they decide what data are to be gathered, what variables should be controlled, and what tools or instruments are needed to gather and to record data with precision. Recall, that a *Framework* goal is to avoid students developing 'knowledge unproblematic' views of science knowledge and scientific inquiry. Planning and carrying out investigations employing the 5D unpacked practices are important experiences that help students

engage with conceptual knowledge, procedural knowledge, and epistemic knowledge and encounter struggle experiences that can help develop a knowledge problematic view of scientific inquiry.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

The authors have contributed equally to the manuscript. Both authors read and approved the final manuscript.

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