# Chapter 9
# The Use of Metacognitive Prompts to Foster Nature of Science Learning

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Building students' knowledge of the nature of science (NOS) has potential to improve important elements of science literacy as students learn both a body of scientific knowledge and develop understanding of how that body of knowledge has come to be (Duschl 1990; Peters and Kitsantas 2010a). Over 20 years of evidence has demonstrated that a person's epistemology plays a role in developing reasoning, connecting evidence and claims, and setting the foundation for learning approaches (Hofer and Pintrich 1997; King and Kitchener 1994). Therefore, an emphasis on teaching NOS in science class is important in developing scientifically literate students. However, teaching a sophisticated understanding of NOS to students has been difficult in part due to unfocused pedagogical approaches offered to teachers. The incorporation of NOS teaching into inquiry-based lessons can be focused by a learning theory, and self-regulated learning theory (SRL) has potential as a helpful tool for incorporation of NOS because the theory explains learning as a goal-directed process whereby a person is required to identify a problem, examine relevant data to inform a solution, develop a solution, and evaluate the solution (Zimmerman 2008). The approach offered in this chapter presents new opportunities to reach students supported by a well-document learning theory.

SRL describes how learners react to their learning environment with their currently held beliefs, values, knowledge, motivation, and metacognitive strategies. According to SRL theory, individuals are not merely passive players in the learning process; rather, they have the potential to exert personal agency and control over their learning goals. Self-regulated learners enter three phases of a learning cycle: forethought, performance, and self-reflection (Zimmerman 2000) as illustrated in

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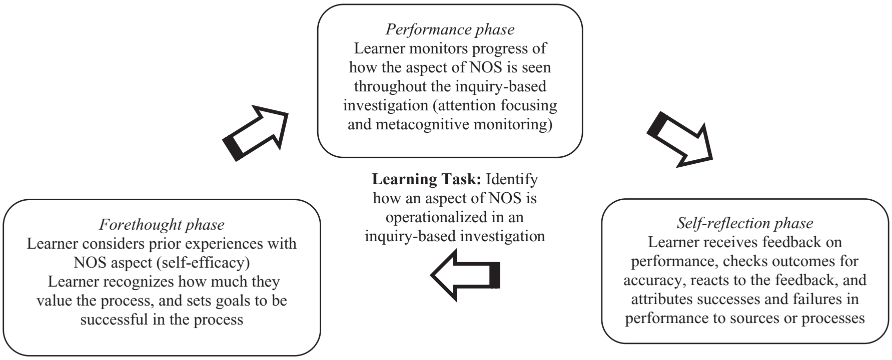


**Fig. 9.1** Self-regulated learning (SRL) in an aspect of NOS during an inquiry-based activity. (Adapted from Zimmerman 2000)

an NOS teaching context in Fig. 9.1. The forethought phase refers to influential processes that precede efforts to act and set the stage for action such as analyzing tasks and setting process-oriented goals. The performance phase includes processes that occur during the action, such as implementation of the task and metacognitive monitoring. The self-reflection phase refers to the processes that occur after the performance efforts which influence a person's response to the action, such as the use of standards to make self-judgments about the performance. Students continue to cycle through the self-regulation feedback loops each time they encounter a learning task, and if they have helpful learning strategies, such as setting a learning goal that is accurate and achievable and monitoring their performance against that goal throughout a cycle, they develop more sophisticated forethought, performance, and self-reflection processes. If learners use detrimental learning processes, such as having low self-efficacy or setting vague goals that are not aligned with the teacher's learning goals, they can develop bad habits in terms of learning strategies and decline in their academic performance (Zimmerman 2008). Although self-regulatory processes are internally driven, they can be encouraged by mentors or an appropriately constructed learning environment (Zimmerman 2000), thus allowing a teacher to serve as a model to teach how NOS is present in scientific investigations in a directed way. Across most academic skill areas and content domains, such as reading, mathematics, writing, and science, the literature shows that SRL processes (e.g., planning, strategy use, monitoring, and evaluation) are key determinants of students' achievement (Butler et al. 2005; Cleary and Platten 2013; De Corte et al. 2011; Graham and Harris 2005; Guthrie and Wigfield 2000; Sinatra and Taasoobshirazi 2011).

The focus on teaching through explicit and reflective methods has shown promise in improving views of NOS (Khishfe and Abd-El-Khalick 2002). These explicit, reflective approaches are focused on what the teacher should do, not on what students should be doing to learn NOS. Various learning theories are helpful in designing efficient and effective student-centered curricula and instruction (Driscoll 2000), but SRL theory aligns particularly well with approaches to learn NOS in the classroom because the theory is goal oriented and reflective, much like explicit and reflective methods. The application of SRL to NOS learning during guided inquiry lessons has been tested and found to result in improved student NOS and science content learning (Peters-Burton 2015, 2017; Peters and Kitsantas 2010b). Because SRL is more detailed in explaining the processes of learning and motivation than current approaches to teaching NOS, it offers distinct ways to support learner strategies that include affective, motivational, and cognitive factors.

## 9.1 Architecture of a Teaching Strategy for Teaching NOS

The strategy presented in this chapter is called Metacognitive Promoting Intervention-Science (MPI-S) and is based on a teaching strategy derived from SRL with an emphasis on learner actions (Peters 2009; Peters and Kitsantas 2010b). MPI-S enacts SRL because it prompts students to set goals, assists students in monitoring progress toward goals, and asks students to reflect on their success in reaching those goals. This teaching strategy works well for inquiry lessons because it engages students with the processes and approaches to thinking of science. MPI-S is a suite of curricular tools, made up of a suite of checklists and questions that can be incorporated into established lesson plans to support student SRL strategies. The implementation of MPI-S consists of four steps as seen in Fig. 9.2. The steps of MPI-S are the same ones as the coaching strategy founded by Zimmerman (2000) and have identical names as Zimmerman's strategy. Although MPI-S has been used to develop NOS views in students, the metacognitive prompts can also be used for learning about other science components such as content knowledge and practices in science.

This approach parallels explicit, reflective approaches because the teacher initially supports students explicitly through modeling and then drops the level of support so that students are able to articulate how they understand NOS independently (akin to scaffolding). MPI-S should be implemented in an inquiry-based setting, since the teaching focuses on student use of science process skills that are tangible. Evidence of the effectiveness of this teaching strategy was found with eighth grade students using MPI-S. Students went back to elaborate on their observations to be more aligned to the checklist (Peters 2009).

### *9.1.1 Modeling*

Modeling is the first step in the MPI-S teaching strategy and is aligned to the forethought processes of SRL (Fig. 9.2). Since students are often underexposed to the ways scientists think and conduct their work (Hogan 2000), it is important that students begin a learning task by understanding the goal they are trying to reach. The modeling step in MPI-S helps students with their forethought processes because

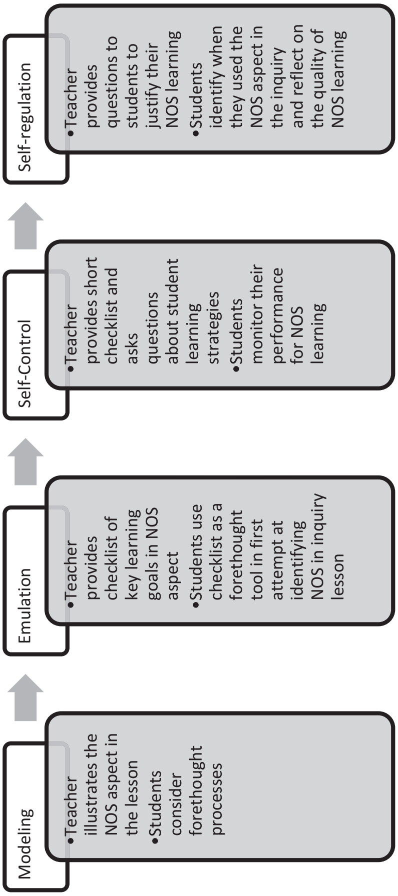


**Fig. 9.2** Steps of MPI-S with teacher role and student SRL processes

it demonstrates their learning goal, and helps them evaluate their self-efficacy and value in the task. In MPI-S, students learn what outcome is expected through teacher modeling. Modeling is much like a cognitive apprenticeship (Collins et al. 1987) where the mentor (teacher) does the activities in full view of the apprentice (students), but at the same time talks aloud about rationale, choices, and decision points with the intention that the apprentice will be able to adopt the same practices. For example, a teacher can demonstrate how she would record observational data that was replicable, because the recorded observations were expressed in standardized notation such as metric measurement. The role of the student in this first step of MPI-S is to notice key features of the skill as demonstrated by the mentor and ascertain the overall sense of the outcome. Students will learn how to reach the outcome in later steps of the teaching strategy.

### *9.1.2 Emulation*

It is during this second step when the shift from teacher-led to student-led activities begin. The emulation step is related to the SRL phase of forethought (Fig. 9.2), like modeling, but is different because it guides students to set their own goals for NOS learning. During emulation, the role of the student is to replicate the scientific thinking and skills from the teacher model given a similar task as the model. However, the student is not expected to do this without support, and the teacher provides the students with a checklist to focus attention on an NOS aspect in the investigation. For example, when helping students to figure out what evidence they need and might be able to gather, students are supported in making observations with a checklist of the following statements:

- My observations describe what I see, hear, or touch.
- My observations are made up of measurements that other people can agree upon. For example, instead of saying "It is big," I say "The blue car is 20 cm long."
- My observations are clear so that other people who are not performing this lab could do exactly the same thing.
- My observations are clear enough so they can be used later to make conclusions.

Students use these statements to make their observations more empirical and less interpretative. Like cognitive apprenticeships, MPI-S helps students who may not have had prior access to ways of knowing in science. In later lessons, teachers can use different checklists for different aspects of NOS.

### 9.1.3 Self-Control

The self-control step of MPI-S is related to the performance phase of SRL (Fig. 9.2) because it helps students monitor their performance in learning an aspect of NOS. Students engaged in MPI-S to this point have observed what they are supposed to be accomplishing through the model (Modeling) and have attempted similar skills and knowledge with support from the teacher (Emulation). In the third step, the teacher continues to support student self-regulation of NOS learning but reduces support to allow students to actively reflect on their metacognitive strategies. Teachers should provide students with a more difficult attempt at the skill they are trying to build and give students only a few basic standards from which to check. Students are expected to take over more responsibility for learning and the teacher acts as the facilitator by providing basic support, only intervening when misconceptions arise. Using the NOS aspect of "evidence is required," teachers support students by providing the following shortened checklist during their inquiry investigation:

- My observations are clear to other people who are not performing this lab.
- My observations come only from my five senses, and are not inferences.
- My observations can be used later to make conclusions.

To check for appropriate metacognition in this step, teachers should ask a few questions about the choices that students make when they perform the skill such as

- How do you know something is true?
- Is your observation clear to other people? How do you know?
- What evidence do you have to support your idea? Is it directly connected?

If a student responds that something is true because they heard it from their parents, the teacher can move back into the emulation step and give more support to the student. When students can answer these questions in a way that is appropriate for scientists, then teachers can fade all support in the next step, self-reflection.

### 9.1.4 Self-Reflection

In the self-reflection step of MPI-S, students perform the targeted practice entirely on their own and reflect on the outcome. This last step of MPI-S is aligned to the self-reflection processes of SRL (Fig. 9.2) and build upon the self-control step because students are expected to regulate their learning without any support. Students should be able to demonstrate they can both understand and implement the NOS objective without any teacher support. In this step, the teacher gives the inquiry task and ensures that the student was able to accomplish it in a way that parallels scientific thinking. For example, a student may demonstrate her understanding of tentativeness in science by describing how new evidence has changed her conceptual model for a scientific phenomenon and how this is parallel to the way scientists decide on the strength of competing theories. Students provide evidence of their understanding of NOS by accomplishing the scientific task and by rationalizing their actions. The teacher can decide if the student has mastered the NOS aspect by evaluating student answers to the rationale. Prompts that a teacher would use regarding empiricism are:

- Explain how other people understand your observation out of context.
- Explain how your observations are detailed enough to be replicable.
- Explain how your observations are relevant to the purpose of the investigation.

Prompts for other elements of NOS have been developed and tested, and can be found in Table 9.1 (Peters 2012). Students who participated in MPI-S were able to answer these questions in a way that was scientific, and most notably, went back to the evidence when they had disputes within their group to the reason why a natural phenomenon happened. Students who did the same inquiry investigations but did not participate in the MPI-S often asked the teacher to tell them what the "right" answer was when faced with divergent conclusions for the evidence (Peters and Kitsantas 2010a; Peters 2012).

## 9.2 Sample Lessons

To demonstrate how the teaching strategy works, let's consider the following guided inquiry lessons with embedded metacognitive prompts. Each lesson will feature one science content area and focus on one of the aspects of NOS. In the first lesson, students participate in an inquiry-based lesson on the gas laws and reflect on empiricism as an NOS aspect, while in the second lesson, students participate in an inquiry lesson on the science of atomic theory and the NOS aspects of tentativeness, durability, and the self-correcting nature of the scientific enterprise.

### *9.2.1 Inquiry Lesson on Gas Laws with Empiricism as an NOS Instructional Goal*

This sample inquiry-based lesson on gas laws is intended for high school students and is planned for three block classes of 1.5 h each. At the conclusion of the lesson, students will be able to identify the properties of gases, know how to accurately measure each property, determine the relationships among pairs of the variables (e.g., temperature and pressure) through personal investigation, and to predict gas behavior based on the gas laws that they derive as part of this lesson. The NOS objective for this lesson is that evidence is required in science. Of course, this lesson could be adapted to focus on other NOS attributes such as shared methods (observa-

**Table 9.1** Suite of metacognitive prompts for selected NOS elements

| Steps of metacognitive prompts | Prompts |
|---|---|
| *NOS element: Science is distinct from technology and engineering* | |
| Step 1: Observation | Science and technology are used together when testing different materials to see if they conduct electricity, but they are distinct ideas. A circuit is built with a space to insert different materials. If the light bulb in the circuit lights up, then that material conducts electricity. If the light bulb in the circuit does not light up when a type of material is inserted, that type of material does not conduct electricity. The circuit and materials are technology, but the idea of electricity moving around the circuit and changing from electricity to light is science. Technology helps us to think of scientific ideas and scientific ideas help us to improve technological tools. |
| Step 2: Emulation | I made measurements that are based on a standard system like the metric system.<br>I thought how I could use the measurement tools most accurately in this lab.<br>I did not use measurements that were based on non-standardized tools, like my hand or height.<br>I thought about many different tools that could have been used in this lab and chose the most useful one.<br>I thought about how my measuring tool can interrupt what I am trying to measure.<br>I thought about how people in history had different tools to measure and how these different tools could produce different results compared to my results. |
| Step 3: Self-control | I made measurements that are based on a standard system like the metric system.<br>I thought about many different tools that could have been used in this lab and chose the most useful one.<br>Would other people understand your measurement method?<br>Could other tools be used to perform the measurement? How might that tool be more or less useful?<br>Does your measurement method have a standard to against which to compare? |
| Step 4: Self-reflection | Does your measurement method have a standard to compare against?<br>How does your measurement interrupt the phenomena you are measuring?<br>What technologies are available to better describe the phenomena?<br>What degree of accuracy can your measurement method offer? |
| *NOS element: Tentative, durable, and self-correcting* | |
| Step 1: Observation | William Gilbert in the 1700s noticed that a piece of iron on top of St. Augustine's chapel was magnetic. Gilbert thought that the metal became magnetic because of the winds. In the 1900s it was found that the piece of metal was magnetic because it was struck by lightning. The lightning magnetized the iron. Ideas in science are usually long-lasting but can sometimes change when new information is introduced. |

(continued)

**Table 9.1** (continued)

| Steps of metacognitive prompts | Prompts |
|---|---|
| Step 2: Emulation | I know how scientists throughout history thought about this idea.<br>I can see how this idea has changed when scientists got more information about it.<br>I know that ideas in science change scientists agree the old idea doesn't fit with new information that is reliable.<br>I know that scientists are strict about how they get information, so ideas in science are long-lasting. |
| Step 3: Self-control | I know that ideas in science change scientists agree the old idea doesn't fit with new information that is reliable.<br>I know that scientists are strict about how they get information, so ideas in science are long-lasting.<br>How has this lab changed the way you think about the phenomena?<br>Was there a point in the lab where you were surprised about what happened?<br>Explain the part of your lab that made you surprised and why you thought it was unusual. |
| Step 4: Self-reflection | What did people long ago think about the phenomena you were studying?<br>How did people's ideas change over time about the topic for your lab?<br>How can scientific knowledge be believed if it keeps changing over time? |

tion, inference, induction, deduction, lack of a stepwise scientific method, distinction between laws and theories, and subjectivity). Planning lessons on the topics of gas laws are a good fit for the Metacognitive Prompting Intervention because the lessons give students multiple chances to explore solving similar problems (property of gases) leading to the synthesis of the relationships among pressure, volume, and temperature (gas laws). Each time students engage with a concept, they can also engage with the next developmental step of the metacognitive prompts.

#### 9.2.1.1 Modeling

The first step for using MPI-S is for the expert (the teacher) to model the NOS concept of empiricism for students, noting the key features of the ways experts think and behave with respect to evidence and the need for evidence. Recall that this step in MPI-S is called modeling in the psychology sense of the word, so that the teacher demonstrates the expected learning outcome for students. For the gas laws, the teacher can begin by discussing the need to measure properties of gases in a way that allows others to understand the measurement system used. In other words, a standardized system of measurement is necessary for empiricism to be communicated accurately in the scientific community.

The teacher can begin by asking what types of variables can be measured for a mylar balloon. The teacher can guide the class discussion to be sure the key properties that can be measured about gases are accounted for: pressure, volume, amount, and temperature. Then, small groups of students should explore the system of measurement for each variable; this is not always an easy task with gases. For example, the property of volume requires some clever thinking about how to measure what is inside a balloon which is a large, non-uniform three-dimensional shape that compresses if you hold it too tightly. When considering how to measure pressure, students will need some kind of technology. Students assigned to explain "amount of gas" should address the conceptual idea of a mole, since they will not be able to directly measure the gas. Temperature has a measurement system that is straightforward and typically well known, but actually placing a thermometer or probe in the container for the gas may disrupt the system, so students must arrange for the system to remain stable while taking a measurement. Once the groups come to consensus about the way to measure the relevant variables of the gas in a balloon, they share it with the whole class and gain feedback to refine the measurement system. The teacher models the key features of empiricism by focusing students' attention on the ways they can measure most accurately and communicate this way of measuring to other students. The teacher should also extend students' thinking by asking students to use the system of measuring gas properties for other situations with gases, such as a hot air balloon, air in the classroom, or an airbag in a car.

#### 9.2.1.2 Emulation

This step in MPI-S is called emulation because students are expected to follow the model that the teacher demonstrates. Since students are novices in learning about the NOS aspect, they will need some help. The teacher supports student engagement in another setting that illustrates the targeted NOS aspect by providing the students with a checklist to compare their thinking about the role of empiricism when learning about the relationships among the properties of gases. For this lesson, students empirically investigate the relationship of volume and temperature, and volume and amount of gas using a mylar balloon. The MPI-S checklist for this lesson is nine items long (see below), and emphasizes the view that (a) all concepts are knowable on the basis of experience, (b) beliefs or propositions are knowable only through the application of experience, and (c) words are meaningful because they convey concepts from experience (Peters and Kitsantas 2010a). Note that the prompt checklist has more items than features of empiricism listed above because the prompts are designed to give students multiple ways to check understanding of the same concept and to learn both NOS and traditional science content. The checklist for the emulation step is as follows:

- I am accurately measuring each variable in my investigation based on our group's decision on how to measure temperature, volume, and amount of gas.
- My observations and my classmates' observations align.
- I have a clear way of communicating the measurement of the variables so that others can understand what I have measured.
- I have translated my data into evidence without influence from my previous beliefs about the topic.

- I am regarding the evidence from each variable when explaining the relationships between variables (through inductive reasoning).
- I am not influenced by my previous beliefs about the variables, even if the evidence is different from my prior beliefs.
- I am providing enough detail in my procedure, results, and conclusion section of the report for others to replicate my work.
- People can do exactly the same investigation I performed based on what I have written.
- Someone who has not done this investigation could understand how I came to my conclusions based on my writing.

#### 9.2.1.3 Self-Control

In this step, students perform more investigations on other properties of gases, led by questions such as what is the relationship between pressure and volume and what is the relationship between pressure and temperature, so that they gain more experience in their use of empiricism to make conclusions. Teachers hand off the control of the performance to students by reducing the number of checklist items as support and asking questions about students' justification of their conclusions. If students are becoming more self-regulated in their learning, they come to understand that they must collect data to justify conclusions in their investigation with less teacher support and will be able to articulate answers to the questions. If students are not progressing, then the teacher can continue to model empirically based thinking and give students the expanded checklist from the emulation step until students become more familiar the NOS aspect. Note that the checklist has been shortened to one bullet point representing each key element of empiricism.

- I am ensuring accuracy by measuring each variable in my investigation based on our group's decision on how to measure temperature, volume, and pressure of gas.
- I am not influenced by my previous beliefs about the variables, even if the evidence is different from my prior beliefs.
- What were your prior beliefs? Is your evidence different from or the same as what you initially understood?
- I am providing enough detail in my procedure, results and conclusion for others to replicate my work.
- What are your standards for "enough detail" from the bullet point above?

#### 9.2.1.4 Self-Reflection

In the self-reflection step, students are expected to demonstrate they can explain the NOS element in their work without any support from the teacher. In the self-reflection step for this example lesson, students are asked to synthesize the relationships they found among pressure, volume, and temperature. Students employ the NOS concept independently and explain how they have related this NOS concept to the gas laws. Students use inductive reasoning to synthesize the results of the prior four investigations of pairs of variables for a complete statement. Students will also have to check the accuracy of the synthesized model with the evidence they collected in prior investigations.

In this step, students are expected to work independently, so there is no checklist, only questions asking them to articulate their choices.

- How do you know that your synthesized model of gases is accurate?
- Explain how your prior evidence can be used to explain the synthesized model of gases.

Once students can answer these questions in a way that is aligned with the scientific discipline, then they have the skills to be independent learners.

### *9.2.2 An Inquiry Lesson on the Development of the Atomic Theory with an Application on the Modern Periodic Table and the NOS Elements of Tentativeness, Durability, and Self-Correcting Nature of the Scientific Enterprise*

This lesson is intended for high school students and consists of five teaching blocks of 1.5 h each. The first two blocks are focused on modeling and emulation. Students are engaged in self-control for the third block. Self-reflection is emphasized in the remaining two blocks. The content objectives for this lesson are for the student to accurately describe the Bohr atomic model and Schrodinger's atomic model and explain the implications of each model on reactivity of elements. The targeted NOS objective is to describe how the nature of scientific knowledge (tentative, durable, and self-correcting) led to the development of the modern atomic theory. The historical progress of knowledge in this lesson provides multiple opportunities where MPI-S can be used to focus students on the nature of scientific knowledge. Much like the gas laws lesson, each block in the lesson is designed for students to move to the next developmental level of the metacognitive prompts. Additionally, MPI-S used in this lesson could be adapted across multiple lessons as students explore the development of new scientific knowledge (e.g., development of evolutionary theory).

#### 9.2.2.1 Modeling

As students explore the development of the atomic model, it is helpful to start by examining Democritus' model. The teacher leads a conversation on how Democritus' might have theoretically described that atoms might exist, but that it had little scientific evidence to support the model. It is important that students are made aware of the thought processes used by Democritus to theoretically describe that atoms exist. Additionally, the teacher should help the students recognize the difference between a claim and evidence in a scientific argument. As students and the teacher reexamine Democritus' claims, it should be recognized that little scientific evidence was provided to support the model. Discussions with students should explore or reinforce what constitutes scientific evidence, focusing on data collected using a systematic approach. Additionally, students and the teacher should examine how multiple lines of supporting scientific evidence would increase our confidence that a claim is valid. Students then are asked to conduct various chemical investigations that help them identify patterns, test them under new conditions, and explore what is already known to "discover" the three laws Dalton used to generate his atomic theory (law of conservation of mass, law of definite proportions, and law of multiple proportions). The teacher conducts a discussion with the students how Dalton's theory and the associated laws would constitute an example of the use of evidence in developing scientific knowledge. In addition, the teacher discusses with the students that scientific knowledge should also have explanatory or predictive power. The greater the number of settings in which the knowledge can be used (multiple lines of evidence), the more durable the knowledge becomes.

Students are then asked to conduct an inquiry investigation exploring Thomson's work with cathode rays using a simulation (for instruction, see the Concord Consortium—Crookes Tube; https://concord.org/). Once the investigation is complete, the teacher leads a discussion with students focusing their results (Thomson's discovery of the electron) on the refutation of Dalton's tenet that atoms are the smallest particles of matter. Further discussion examines other aspects of Dalton's atomic theory to determine that the evidence does not impact the overall understanding of how the atom might function in chemical reactions, but does provide a revised view of atomic structure. The teacher should focus the students on the fact that through the scientific process, Dalton's model was modified, not discarded thus making an important point about durability and self-correction.

#### 9.2.2.2 Emulation

Students are then be introduced to Thomson's plum pudding model and Nagaoka's Saturnian model of atomic structure. They will be asked to use the following checklist to determine if the model is scientific and durable:

- The model is based on scientific evidence collected in a systematic way.
- The evidence used inspires confidence in the conclusions because it includes many trials and multiple lines of evidence.
- The model can be used to predict or explain outcomes in multiple settings.

Students will likely find that both models meet the criteria which make them scientific, but the durability is weaker as each model has limited lines of reasoning and predictive/explanatory power.

Students are then asked to conduct an inquiry investigation where they simulate the Marsden–Rutherford gold foil experiment (see the King's Centre for Visualization in Science—Rutherford Experiment; http://www.kcvs.ca/site/index.html). Once they have completed the simulation, students would then be asked to use the following checklist regarding the tentativeness to reexamine the Thomson and Nagaoka models.

- The new evidence completely contradicts a critical component of the model, resulting in questioning the validity of the entire model.
- The new evidence contradicts a non-critical component of the model, but other parts are unaffected and remain valid.
- New evidence provides more detail of the model not previously understood, resulting in the revised model becoming more explanatory/predictive.

Students should determine that their evidence results in questioning the validity of Thomson's entire model and should therefore be refuted. However, Nagaoka's model would have been supported and would only need to be revised to include a small, positively charged nucleus. The instructor could then discuss the remaining evidence from Chadwick's efforts at discovering and describing neutrons that further elaborated on the atomic model.

#### 9.2.2.3 Self-Control

Students would then be asked to investigate the development of the periodic table by first conducting a classification of the elements similar to how Mendeleev approached the same challenge (Nargund and Park Rogers 2009). They will then examine the work of Mendeleev and Moseley in more depth using a Web Quest. They will be asked to describe the contributions of each scientist then focus on the following questions:

- What did they do to determine if Mendeleev and Moseley's work scientific?
- What did they do to determine if the knowledge Mendeleev and Moseley generated was durable?
- What did they do to evaluate the tentativeness of Mendeleev and Moseley work?

#### 9.2.2.4 Self-Reflection

Students complete their exploration of the atomic model by investigating a model of the hydrogen atom using a computer simulation comparing multiple atomic models (PhET Interactive Simulations—Models of the Hydrogen Atom; phet.colorado.edu). Students will first be introduced to simulation and focused on the different models and their prediction. Students will need to do some exploration of each model to understand why the simulation is behaving as it is. In particular, they would need to understand the orbital structure of Bohr's and Nagaoka's model as well as Schrodinger's electron cloud. They would then proceed to test each of the model's to determine which show promise to explain the behavior of the simulation. They would then explore a second simulation to focus on a comparison of the Bohr and Schodinger models (see the Concord Consortium—Atomic Structure; concord.org). During each of the simulations, students have to decide which models appear valid and describe their choices by focusing on the following questions:

- Why did you decide the model was scientific knowledge?
- Why did you think the models you selected were durable?
- Why would these models be tentative?

## 9.3 Creating Metacognitive Prompts of NOS for Other Lessons

In this section, we discuss how teachers can create a suite of metacognitive prompts for their own lessons and how to place them within the lesson to support student self-regulation of NOS learning. Educators can create metacognitive prompts aligned to SRL by changing the learning task, while keeping the theoretical structure of the MPI-S teaching strategy. SRL has been shown to be effective in supporting learners to be independent in many different contexts such as instructional media (Henderson 1986), volleyball skills (Zimmerman and Kitsantas 1997), science instruction (Cleary and Labuhn 2013), scientific thinking (Peters and Kitsantas 2010a; Peters 2012), teaching using inquiry (Peters-Burton and Botov 2017), and teaching using argumentation (Peters-Burton 2013). The following guide will help instructors to construct metacognitive prompts for their needs.

### *9.3.1 Format for Metacognitive Prompts*

The first step in constructing metacognitive prompts is to consider and compile what students are expected to know and do for the NOS learning task. For example, in order to teach the concept "evidence is necessary," instructors should research what makes data empirical and compose a list of characteristics of empirical data. If another NOS aspect is chosen, then the checklist items would be different (see Table 9.1). The modeling step teacher demonstration and the emulation step checklists for students are generated from this list of characteristics. The teacher demonstrates the characteristics of the NOS aspect during the modeling step in the context of the inquiry-based lesson. For example, when modeling how to make observations, the teacher models appropriate examples by explicitly describing the reason behind their actions (having a shared understanding of the measurements and providing enough detail to be replicated) as well as non-examples (making judgments such as "big and small" which can be discussed as erroneous). Once the identified characteristics are demonstrated by the teacher, possibly in written form as the class analyzes a set of written observations, the instructor should create checklist points for all characteristics of the NOS aspect in the emulation step. Teachers should write the same characteristics of the targeted NOS objective in two or more ways for the first set of checklist points to give students several chances to address the characteristic. To create prompts and questions for the self-control step, the instructor should pare down the emulation step checklist to a few core characteristics of the NOS aspect. In addition to the shortened list, the instructor should also compose a few questions asking students to verify the choices they are making related to the NOS objective. For the final self-reflection step, instructors should create questions regarding the rationale for the core characteristics are created. In other words, in the final step, students should be able to justify how their choices are aligned with the NOS objective, that is, how they are acting and thinking like scientists.

### *9.3.2 Embedding the Suite of Prompts into Inquiry Instruction*

In order to use the four sets of prompts (one prompt set of checklists and/or questions for each step), the instructor must design activities that engage students in the targeted NOS aspects multiple times. The prompts (checklists and/or questions) can be used multiple times over the course of a unit, but must be used at least once in the order of the developmental steps: observation, emulation, self-control, and self-reflection. All four steps of prompts do not need to be present in one lesson. Rather, students' metacognition, or awareness about their understanding, about NOS aspects should be built over time, giving students the opportunity to try, fail, try again, and succeed. The MPI-S strategies are designed to be employed over similar tasks, and similar tasks may not occur within one lesson. For example, if students are learning about "the tentative, durable, and self-correcting" aspects of science, this may occur across four different investigations, each with a different context but with the same focus on the NOS aspects. Doing this has the advantage of allowing students to see that NOS functions across science disciplines. Teachers can embed the modeling step in the first inquiry dealing with "the tentative, durable, and self-correcting" NOS aspect, the emulation step in the second inquiry dealing with tentativeness, the self-control step in the third inquiry dealing with tentativeness, and the self-reflection step in the fourth inquiry dealing with tentativeness.

The instructor should be cognizant of the appropriate use of the prompts by students, which is often easier to assess in the later prompts that include questions. To assess the checklists, the instructor can observe students engaging in the targeted NOS objective, and to assess the questions, the instructors can assess the answers to the questions for the appropriate use of the key characteristics developed in the formatting process. For example, when assessing checklists for "evidence is required" the instructor can look for an individual student's respect for evidence (successful use of prompt) when engaged in inquiry or student naïve adherence to prior beliefs that are not aligned with evidence (unsuccessful use of prompt). Alignment to the NOS objective may be more directly assessed with the question portions of the prompts because students are answering direct questions about their scientific activities.

## 9.4 Summary

Metacognitive prompts are a flexible instructional tool because they can be embedded into any content area to help students to focus on the ways they engage in science explicitly and reflectively (Peters 2012; Peters and Kitsantas 2010a). The prompts can be designed for all NOS aspects, no matter the model, and can be applied in any traditional science content area. Not only can the metacognitive prompts be used for any learning tasks regarding both content and NOS aspects, but as standards change, the prompts can be adapted to help students focus on the objectives. As long as a clear objective for content learning and a clear objective for NOS learning are identified, metacognitive prompts can be used in a variety of learning settings.

Metacognitive prompts also give students more confidence in science classes. Often students feel that they are left out of science because they are not aware of the underpinning traditions and behaviors that may be apparent to scientists and science educators, but are unspoken and therefore out of reach for those not yet engaged in science. Metacognitive prompts articulate the ways that the discipline of science operates but is not directly communicated. Students who have used MPI-S have explained their views of science have changed because of the prompts and have said that they knew that doing science was different than other subjects, but they didn't know how until they used the prompts (Peters and Kitsantas 2010a). The prompts can be used as an instructional tool via describing the ways scientists think and act, but they can also be simultaneously an assessment tool that gauges the level of proficiency or sophistication a student has in a particular NOS aspect. Assessment of NOS aspects is notoriously difficult because they are epistemic understandings and students may not even be aware that they hold these beliefs. However, metacognitive prompts get this tacit knowledge into the open for discussion and clarification.

Finally, metacognitive prompts build on prior work in the field of nature of science education by giving structure to explicit, reflective instructional approaches that have had some recent success in improving learners' views of NOS. Metacognitive prompts change explicit, reflective instruction into a teaching strategy, thus giving it structure and intentionality, backed by SRL that has had many years of empirical support. Metacognitive prompts also expand on the work of science educators by setting up a structure where students must make attempts at demonstrating their understanding of the NOS aspect multiple times, thus giving students more time to form an understanding of the same NOS aspect from different perspectives. Metacognitive prompts have the extended power of being supported by science education research and educational psychology, therefore bringing the necessity of evidence full circle into science classrooms.

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