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An Observational and Planning Tool for Professional Development in Science Education

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Abstract Since there is an increasing recognition to address the need to move practicing teachers to a higher standard of practice, mentoring or coaching has been receiving increasing attention. A variety of tools has been developed to make these relationships more effective. Work within a recent mentor project indicated current tools were not detailed enough for mentors to provide effective feedback to mentees. This paper presents a more detailed tool and describes categories of pedagogical practices related to an extended inquiry-cycle model. During the course of the project, mentors and mentees also used this tool for adapting existing curriculum to a more standards-based mode of instruction, thus having it function as a planning tool.

Introduction

In recent years, a number of observation tools have been developed that have been used for coaching, mentoring, or evaluation of teachers carrying out science instruction. Some of these have been used for research purposes, while others are meant to provide a common frame of reference so mentors and mentees can work on a mutually agreed upon agenda. These tools are coming to be recognized as an essential ingredient in any kind of mentoring or supervision of teachers (Beerer and Bodzin 2004).

It has also become apparent that some current curriculum offerings, such as science textbooks, do not fully address the National Science Education Standards

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(National Research Council [NRC] 1996), especially in regard to helping teachers carry out in-depth inquiry (Schmidt et al. 1997). To remedy this problem, generic pedagogical models are often presented that would allow teachers to redesign existing curricula to make their practice more aligned with pedagogical practices outlined in the national standards. One such pedagogical model is the "learning cycle" (Lawson et al. 1989).

As originally conceived, this model was a useful starting point, but it has gone through a number of revisions in past years (Bybee 1997; Dunkhase 2003; Pizzini et al. 1989). Based on current work in a recently completed mentoring project,[1] we have found that even these revisions do not provide enough description of pedagogical practices to help the novice, or even some veteran, teachers implement curricula in a manner aligned with the intent of the national standards. Science educators conducting professional development for teachers at all levels are beginning to recognize the need for planning tools that will help teachers "explore, design, and reflect on their science instructional practice" (Beerer and Bodzin 2004, p. 40).

At first consideration, it would seem that observation and planning tools would be different in their construction and in their descriptors of pedagogical practices. They seemingly serve different functions. We discovered in a mentoring project, that, in fact, the same tool could be used for these two different functions. During the 1st year of this project, we realized that the mentors with whom we were involved needed a tool that would provide for them a framework and set of descriptors by which they could work effectively with their mentees. Mentors could use this observational tool with their mentees when carrying out observations or curriculum planning. The tool comprised a list of descriptors defining good classroom practice when implementing an in-depth inquiry approach for teaching science. This tool would enable mentor and mentee to focus on very specific practices during their collaborative planning for classroom observations. We felt that the tool should list specific practices because it has been our experience that teachers are very pragmatic; they have a need for immediate relevancy. It was also clear that they need to have some kind of overall structure or framework through which the components of inquiry could be put into practice.

During the 2nd and 3rd years of the project, the mentors started using the same tool for the redesign of the curriculum they were using. In addition, they thought it useful when they were helping their mentees plan for an in-depth investigation. There was an early version of this tool, which was limited to a few descriptors for the different phases of in-depth investigations (Zubrowski et al. 2007). Toward the end of the project, we developed a more comprehensive set of descriptors to fully convey the complexity of extended (or immersion, as some have called it) inquiry.

At the time of recognizing this need, there were only a few observational tools that might have been useful (Horizon Research 2003; Piburn et al. 2000). Since then, several other similar tools have been developed (Frederiken et al. 1998;

[1] EDC's Middle Grades Science Mentoring Program, funded by the National Science Foundation (grant # 0101936), comprised Bernard Zubrowski along with Barbara Brauner Berns, Catherine McCulloch, Marian Pasquale, and Vivien Troen.

Horizon Research 2003; Lawrenz et al. 2002; Online Evaluation Resource Library 2004). In considering these observational tools, we found that they were too broad to be of use for the mentor teachers. Although they listed essential practices associated with inquiry, as well as gave attention to some specific characteristics of classroom culture and the situational context, in our view, they did not fully provide enough depth and specificity for teachers who are moving from a traditional approach to one that fully incorporates recommendations in the national standards.

As an example of this problem, consider when an observation is being made during an extended investigation. Various pedagogical models (Bybee 1997; Lawson et al. 1989) delineate several phases of extended inquiry. Working within these kinds of pedagogical models will determine what kind of interactions, discussions, content knowledge, and procedures will take place. For instance, if a session is at the exploratory phase of an investigation, it is questionable whether or not the follow-up discussion to the activity should be heavily involved with sense making and whether or not there should be a full dialogue about the targeted concept.

From some science educators' point of view, the early stages of an investigation should be more about gaining a clear sense of what the phenomenon is about and how the students can sort out what the most relevant properties are on which to focus. At this stage, it is premature to engage students in elaborating a full explanation of what they have experienced. Or, at a later stage of the investigation, after collecting data, the teacher should be spending time making sure students' results are useable and consistent before having the students decide whether or not the results confirm or disprove prior predictions and hypotheses. And, toward the end of an investigation, sense making takes on a much more important role than it had in the early stages. Although students should play a very prominent role in constructing understanding, the teacher should not be in the background during this last critical stage. When an observation protocol or tool provides just teacher-behavior indicators, such as "encourages student participation" or "encourages conjectures and questions," the descriptor is too vague to be useful for the teacher who wants to improve his or her performance. It is also too vague for the mentor to use this as a guiding descriptor when working with a mentee. More specific descriptors are necessary of what kind of pedagogical practices are involved during the early stage of inquiry, during the processing of data, and in the final summing-up stage.

A similar kind of critique would apply for a planning tool. The novice teacher or teacher in transition needs a sense of the overall structure of extended inquiry, how the different phases build upon each other, how students' manipulations of materials and explanations can be structured, and how he or she can plan for embedded assessment.

Inquiry Practice as Complex and Multifaceted

Drawing upon Educational Development Center's (EDC) previous experience in the development of curricula for elementary and middle grades teachers, as well as upon literature that presents pedagogical models for the teaching of science, we developed an observational tool that mainly focuses on teacher and student behavior and is much more specific in the descriptors. The move to greater specificity was added because we were hearing from teachers that they wanted a very specific outline about the inquiry process in order to narrow down their observations and feedback to only the teaching practices of their mentees. Without some kind of observational tool, they tended to focus more on classroom management or specific practices that were not part of a larger context.

The observational tool we developed was structured around the concept of stages of inquiry. We proposed that the teachers should think of an investigation as comprising three stages: exploratory, experimental-data gathering, and sense making.

By exploratory, we mean the initial encounters students have with the phenomenon: when they become acquainted with the properties of a phenomenon and develop an overall gestalt about the nature of the phenomenon. After sorting out what they consider the most relevant properties, students and the teacher generate questions, design experiments or structured observations,[2] and collect data. The results are then evaluated, considered in light of predictions and hypotheses, followed by attempts to "make sense" of them by bringing forth their own conceptions, and then reconciling them with formal scientific explanations. This overall process can happen in the course of a few sessions or can be understood to describe a process that occurs over the course of multiple sessions as lengthy as several weeks. Our descriptors were targeted more to the latter.

The concept of three phases has some similarities to the pedagogical model called the "learning cycle," which originated in the Science Curriculum Improvement Study (SCIS) and was given a theoretical formulation by Lawson et al. (1989). The learning-cycle model is described as a process that involves the stages of exploration, introduction, and application. According to the original description of this model, during exploration, students explore a new phenomenon with limited guidance from the teacher. During introduction, the teacher introduces terminology and explains relevant concepts. During application, students apply the newly introduced concepts to other domains or phenomena. Not usually noted is that Lawson et al. (1989) presented three types of learning cycles: descriptive, empirical-abductive, and hypothetical-deductive.

With the descriptive learning cycle, students and teacher are mainly describing what they observed in terms of patterns and relationships without attempting any explanations. In the empirical-abductive learning cycle, students also develop descriptions of patterns and relationships, but they go further in attempting to develop explanations using analogies or concepts learned in previous contexts. In the hypothetical-deductive learning cycle, the investigations start off with "the statement of a causal question to which the students are asked to generate alternative explanations. Student time is then devoted to deducing the logical consequences of

[2] Structured observation is a term used here to describe situations where carefully controlled experiments are difficult to do. This would apply to investigations of living organisms, such as pond organisms, or changes in the natural environment, such as seasonal changes of trees

these explanations and explicitly designing and conducting experiments to test them" (Lawson et al. 1989, p. 48).[3]

The descriptive learning cycle has been associated with lower elementary grades, while the hypothetical-deductive learning cycle has been associated with upper elementary grades. Depending on prior science instruction, the hypothetical-deductive learning cycle can be very problematic for middle grades students because it depends heavily on already acquired scientific habits of mind, as well as prior development of some scientific concepts.

A major difference between our model and the aforementioned learning cycles is that ours can be adopted at the elementary, as well as the middle grade, levels where the first two approaches of the learning cycle model are combined. Another important difference in our pedagogical model is the recognition of a need for students to carry out an iterative process. It is iterative in the sense that the same phenomenon is investigated over multiple sessions. There may even be a return to exploration of the same phenomenon after some experimentation and sense making.

Another type of pedagogical model, elaborated on by Roger Bybee, is the 5 Es (engagement, exploration, explanation, elaboration, evaluation) of The Biological Sciences Curriculum Study (BSCS) curriculum program (Bybee 1997). The five phases of this model are similar in approach and intent to the learning-cycle model, but with some refinements and expansions of activities.

In the engagement and exploration phases, there is more emphasis given to motivating students. The explanation phase is similar to the introduction phase of the Lawson learning-cycle model but, perhaps, with more emphasis given to soliciting explanations from the students, although Bybee (1997) does write that "the teacher introduces scientific or technological explanation in a direct and formal manner" (p. 180).[4]

Elaboration also parallels the application phase of the learning cycle, in that there is application and elaboration of concepts, but it is not clearly laid out whether or not this is further exploration of a phenomenon or applying a concept to a new phenomenon. According to Bybee (1997), the evaluation phase consists mostly of the formal assessment at the end of the investigation, but he does mention that informal assessment can occur during the whole process.

Although instructional models derived from the original concept of the learning cycle are very useful and provide an explicit structure for the teacher, in our view, there is a collapsing of what needs to happen as students move through an investigation. This is especially true for activities found in many textbook programs. In addition, transitions between phases are often truncated. There was a need to expand the exploration and sense-making phases of these types of instructional models to reflect recommendations in the national standards.

The pedagogical model implied in our observational tool gives more emphasis to the exploratory phase, suggests that there is an iterative process before a full

[3] It should be noted that the second phase as originally introduced does not fit well with a constructivist pedagogical approach.

[4] It is not clear to me how the learning cycle model and the 5 E model can claim to be truly constructivist. It may be implied but there is little, if any, mention of collaboration between teacher and students where explanations are jointly developed as advocated by those of a situated cognition perspective.

explanation is developed, and suggests that application or transfer involves students with a second investigation that focuses on a phenomenon closely related to the first investigation.

Rather than a concept being introduced over only one or two activities, students go back multiple times to the same phenomenon and use a limited set of materials to help clarify their understanding of what is happening and to gradually strengthen their understanding of a new concept. Application of a concept in our model suggests that this be done with a closely related phenomenon. There is a big difference between having students apply the concept of equilibrium to several kinds of balancing toys as compared to applying the concept to three different domains, such as a balancing toy, a siphon system, and the population of an organism in pond water, as found in the BSCS Middle School: Science and Technology (1994) program. The former is applying the concept within the same domain, while the latter is asking students to apply the concept across three different domains.

Even if various curriculum programs and teachers claim to follow a learning-cycle model, it can be observed that the exploration phase is often greatly truncated or compressed in the textbook activities and even in modular curriculum programs, as indicated by the amount of time allotted to this phase. These texts and guides generally do not allot much time for students to have the opportunity to truly get acquainted with a phenomenon. There appears to be the assumption that students already are well acquainted enough that they can readily move to formal experiments, which are often fully prescribed by the curriculum guide. If this type of instructional model is going to be used, this first phase needs to be greatly expanded to meet the needs of students.

The introduction phase, described as term introduction, has also been problematic. Given other labels, such as “sense making” or “processing for meaning,” it has been observed that many teachers shortchange or move through this phase too quickly or conduct it in an unskillful manner. Experienced teachers need to develop a deeper understanding of what is involved in these phases and a wider repertoire of skills to carry them out effectively.

It is also critical to recognize that, if fully carried out, the development of even one concept would require multiple sessions instead of one or two. An extended investigation is a series of connected activities where each activity builds on the previous one until some kind of testing of explanations and introduction of alternative explanations is fully developed. With this kind of expanded pedagogical model in mind, one or two observations of a teacher would not necessarily capture the full complexity of an in-depth approach, which seems to be the intention for use of the other observational tools. If an observer, such as a mentor, visits a teacher when he or she is in the early exploratory phase of an investigation, the type of questioning and follow-up discussion would be different from the final phase of developing a concept and applying it to a new situation. There was a need to spell out the differences as students and teachers moved through an extended investigation. In addition, some recognition needed to be given to the full complexity of inquiry and the context in which it is implemented.

A More Complete Picture of In-depth Inquiry and its Context

Before introducing the observational tool that we developed and used for our mentoring project, it is useful and necessary to place it in a larger framework. Some of the tools that we reviewed did take into consideration and made distinctions and differentiations among the various components that are involved in a full implementation of inquiry. It is an undertaking involving a complex blend of practical procedures and pedagogical practices and the establishment of an open classroom culture. For instance, a few projects that developed tools or protocols (Beerer and Bodzin 2004; Online Evaluation Resources Library 2004; Piburn et al. 2000) specifically mention the importance of classroom culture, and all address the need to include various kinds of assessment practices. Drawing upon these previous elaborations and with these above differentiations in mind, it is our sense that a more comprehensive list of components would include the following categories. All of these general categories are dealt with in some manner in the National Science Education Standards (NRC 1996):

- Classroom culture
- Content knowledge
- Infrastructure—classroom management
- Pedagogical practices related to content and process
- Pedagogical practices related to student learning
- Assessment practices

Classroom Culture

Teaching inquiry as it has been suggested in the National Science Education Standards (NRC 1996) requires a paradigm shift on the part of the novice and even the veteran teacher. The novice tends to teach the way he or she experienced teaching, which is most likely a transmission model. In our experience, many veteran teachers have not fully shifted to an inquiry approach as laid out in the Standards. Shifting from a traditional approach of teaching science to one more in concert with the Standards and what is considered best practice involves a rethinking of the teacher's and students' roles. One way of describing this shift is to say that there is a move from a teacher-centered to a student-centered classroom culture. The teacher in the inquiry-oriented paradigm takes on the role of collaborator and acts as a resource. There is a shift from activities where the teaching unit changes from those involving individual students to those where students work in teams to a greater extent. Cooperative learning takes place both among students and the teacher. The diverse background and prior knowledge of the students is taken into consideration. There are specific descriptors in existing observational tools that focus on whether or not teachers take on this different role and promote these values and attitudes. We adapted some of these descriptors for our observational tool.

Content Knowledge

Content knowledge is the science background that teachers should have if they are going to conduct inquiry in an effective manner. A rather detailed and extensive listing of what is required is given in the National Science Teachers Association standards (2003) for professional development, as well as in the National Science Education Standards (NRC 1996). Often, in much of the criticism about teaching practice, greater attention is given to the sense-making phase of the inquiry cycle; and, indeed, this is the phase where content knowledge is most critical. However, teacher's content knowledge can also be revealed in their understanding of how materials can be explored and how teachers react to students' questions and comments.

Infrastructure—Classroom Management

For scientific inquiry to be carried out effectively and efficiently, material needs and some practical structures should be in place. In some protocols and accounts of inquiry, this category is combined with classroom culture. However, it is our sense that these areas should remain distinct, particularly for the novice teacher.

We would include the following practical matters under infrastructure—classroom management:

- Adequate materials and tools
- Newsprint paper to be used as public text
- Adequate space for hands-on activities
- Computer capability for sharing of data and other texts (perhaps not critical, but certainly helpful)
- Consistent procedures for the distribution and gathering of materials
- Careful time management

The first three practical matters seem obvious and unnecessary to mention. However, it has been our experience that some teachers work in systems that have neither adequate budgets nor proper laboratory space for them to carry out hands-on activities. This has been particularly relevant in large urban systems. Inadequate space can sometimes be overcome, but lack of materials is a huge handicap.

Given that many teachers have to work within a 45–50-minute time frame, careful time management needs to be carried out for each lesson. Knowing how to pace a lesson is not a low-level skill, but comes through much practice and experience.

Pedagogical Practices Related to Content and Process

These practices can be summed up by the following questions:

- What is a scientifically relevant question, either teacher or student generated?
- What are effective experimental procedures?
- What is the role of evidence in relation to explanations and conceptualization?

- What is an adequate explanation in terms of the developmental level of the student?

For teachers to answer these questions, they need to have a sense of scientific procedures and basic content knowledge. Students can generate all kinds of questions. Whether or not these are worthwhile to pursue depends on the targeted concept for the investigation and the question's relevancy to this concept. Students need guidance in how they go about designing and conducting experiments (Klahr et al. 2001). Are the experiments really going to provide answers to questions and provide experience and data useful for developing explanations? Students need help developing explanations, and the teacher needs to know how to negotiate between the prior knowledge of the student and the accepted scientific explanation. All of this involves a triangulation involving the teacher's own understanding of science content and process, students' current understanding of a phenomenon, and the limitations of the materials and instruments used in the hands-on explorations and experiments. Overall, it comes down to the critical role of asking questions. But it is not just a matter of asking questions. The process should be further refined to finding out the purpose of the questions, how to ask the questions, and when to ask the questions.

Pedagogical Practices Related to Student Learning

Effective teachers need to be sensitive to the different student-learning styles and cultural backgrounds. They need to be informed about what is developmentally appropriate. This means that they will utilize a variety of teaching techniques and combine group and individual activities, provide for multiple modes of representation, and use various strategies that allow all students to be involved in the activities and express their thinking. For instance, when there are follow-up discussions or sense making involving the whole class, the teacher should provide time for students to talk in small groups so that the less articulate students have time to formulate their thoughts and try out what they would say before presenting to the whole group. Teachers should recognize that multiple modes of representation will help students with different learning styles assimilate and represent the hands-on experiences. This would include such practices as using data graphs, schematic drawings, or even acting out in a nonverbal manner with gestures to describe or convey what a student is thinking.

Assessment Practices

There is vast literature on the various kinds of assessment practices teachers can draw upon. Much of the literature is focused on formal and explicit assessment. Given the current heavy emphasis on accountability, many teachers are quite aware of various resources they can draw upon. In our mentoring program, all teachers took advantage of various resources on the Internet to find rubrics and formal assessments that could be adapted for their particular purposes.

Less recognized and somewhat misunderstood is the role of embedded assessment, or what some call formative assessment. This latter practice can be summed up as good teaching involving ongoing assessment as students move through activities and discussions (Black et al. 2004; Wiliam and Black 1996). The teacher is continuously paying attention to student behavior and talk, while making adjustments in his or her expectations and how he or she can move student understanding forward. Embedded assessment should be closely tied to pedagogical practices and, in some ways, is shaped by the classroom culture that the teacher attempts to develop.

To enable a mentor or supervisor to be able to discuss an event or scenario that occurs during a classroom observation, the above categories and the associated descriptors are separated out. In reality, embedded assessment could be practiced involving several of the above mentioned categories in any one session. A descriptor of one pedagogical practice can involve scientific process, embedded assessment, and classroom culture. For instance, how does the teacher handle the role of evidence when talking with students about possible explanations of their observations? Observing and noting whether or not students back up their explanations with evidence is a way of carrying out embedded assessment. How students use evidence can be indicative of their understanding of scientific processes, as well as whether or not a classroom culture has been established that promotes rigor and clear thinking.

However, there is again the need to consider the event in the context of the whole investigation. What is considered sufficient evidence can differ whether or not the discussion is occurring during the exploratory phase or during the final sense-making phase, where there is synthesis and summing up of all previous observations and results from experiments. In the context of the former, argumentation can be intuitive and "evidence" questionable, because students are just starting to sort out observations and their significance. In the context of the latter phase, solid and clear evidence is needed to back up explanations that are aligned with formal scientific descriptions. Thus, it is important to elaborate what can occur during different phases of inquiry and what weight is given to student comments and teacher reactions. All of the above categories of behavior and practices are represented in the proposed observational tool that follows.

An Observational-Planning Tool for In-depth Inquiry

This observational-planning tool is meant to be used for inquiry carried out over multiple sessions (extending to as many as 20). Each of the different phases of in-depth inquiry can occur over multiple sessions, which is important to keep in mind because the titles of the phases are similar to phases in various versions of the learning cycle, often seen as taking place within one session or one activity of a few sessions. What is proposed here is a pedagogical approach based on the understanding that students need to be moved slowly through an investigation if they are going to develop a thorough understanding of targeted concepts. In this approach, the phases are outlined as below.

Phases of In-depth Inquiry

A. Exploratory phase

- Students are getting acquainted with a problem or phenomenon and deciding what kind of experiments to set up.

B. Evidence-collection phase

- Students carry out measurements or observations.
- Students report their measurements or observations.

C. Sense-making phase

- Teacher and students discuss the usefulness of the data.
- They interpret data.
- They develop explanations and conceptualizations.

Introduction and Exploratory Phase

Based on our experiences, most teachers at the elementary and middle levels are far from developing their own curriculum or are starting off with a completely open agenda whereby students pick a topic and begin to explore it. Most teachers still need a great deal of guidance regarding what topics to pick and how these can be investigated. Therefore, many will need to start an investigation drawing heavily upon published curriculum or textbook activities. Some of these materials give suggestions for how to get started and how to sequence activities.

Table 1 offers specific suggestions for how to get started and how to sequence activities during the exploratory phase. Often, this phase is moved through quickly or, sometimes, even neglected, as there is a tendency to move swiftly to some type of measurement or formal experiment. But it is during this phase that addressing student motivation is critical. Students need to see relevance and have strong interest in what will be investigated. Relating the curriculum topic to their lives in some way makes a difference in whether or not students become fully invested in the investigation.

This phase also should be an important part of embedded assessment. The teacher can solicit from the students their prior experience and knowledge about the phenomenon to be investigated. These initial responses from students can help inform how the teacher will proceed. They can also be used as a baseline reference that can be referred to at the end of the investigation. How did students perceptions and understanding about the phenomenon change over the course of the investigation?

Transitioning to Formal Experimentation and Evidence Collection

The teacher should move to observations that are more structured and to formal experiments or to the establishment of correlations and real patterns in raw data

Table 1 Exploratory phase

	Role of students	Role of the teacher	Rationale for teacher talk and behavior[a]
1		Presents a rationale to students for the purpose of the investigation as it relates to the students' interests and local science standards.	Students need a sense of why they will be investigating a particular topic. This practice of introducing a rationale to the students establishes a context, which focuses their attention and provides motivation.
2	Recall past experiences of phenomenon or topic.	Asks students about what they know about the phenomenon or topic to be investigated.	This information can reveal prior knowledge and preconceptions about a phenomenon or topic. Student comments can act as a benchmark for comparing change in understandings that came about through the activities and discussion during the investigation *(embedded assessment)*.
3	Discuss how a phenomenon or topic can be investigated and why they think it will be useful.	Sets up the boundaries for the investigation in terms of depth and breadth by showing what initial physical materials will be made available and how long the investigation might run.	This part can vary greatly, depending on previous experiences of teachers and students. If both have had extensive inquiry experiences, the teacher can solicit from students how the investigation might unfold. If there has been limited student experience in inquiry, then the teacher may need to provide a much more explicit structure.
		Either presents some open-ended questions for exploration or negotiates with students about possible ways of exploring the phenomenon with the preselected materials.	The materials should have been very carefully selected based on a published curriculum program or well-tested activities from the teacher's past experience.
4	Take notes on procedures.	Models how to use some of the materials, if necessary.	Some tools or instruments may be new to students. The demonstrations are to help students understand how to use the tools, not to show them exactly how they should be investigating.
5	Establish an understanding of who will be doing what in the exploration.	Establishes working groups. Defines roles for each member of the group.	The teacher should follow best practices for establishing a classroom culture of cooperative learning (*classroom management*).
6		Discusses with students management of materials.	This practice can determine how effectively and efficiently class time will be used (*classroom management*).
7	Discuss how they will proceed with the activity.	Checks in with each group to determine if roles have been established and students have a sense of direction of how to proceed.	This practice is also a way of getting a sense of how students are involved in the activity (*classroom management*).

Table 1 continued

8	After some preliminary discussions, proceed to manipulate materials or sort raw data.	Monitors what is happening. Operates at three levels: 1. whole class 2. groups 3. individual student Takes notes on what students do and discuss.	This is a balancing act where the teacher's attention is divided at these three levels. Mostly, it is a matter of going from group to group. But at times, individual students may need attention to keep them focused. The purpose at this time is to determine if all the groups are productively engaged, what they are interested in, what the manipulations reveal about understandings, and at what level attention is focused (*embedded assessment*).
9	Proceed with such questions as • What happens if we…. • Can we get the same result again? Record observations and discoveries.	Checks in with each group, sometimes asking general questions about how students are proceeding and asking open-ended questions to probe their reactions to and their thinking about what they are discovering.	The purpose of the questions at this point is not to get students to give explanations, but to get a sense of what they are most interested in and where they may be heading (*embedded assessment*). Some questions can be an indirect way of directing the attention of students to important characteristics of the phenomenon. Questions have to be well timed so as not to distract students from their focused attention. Answers from students may be incomplete and vague, but should be suggestive of what they are attempting to do and what they are thinking.
10	Return materials to central point.	Ends activity. Gives directions for clean up. Moves students away from materials.	Although materials are out of reach of students, it is useful to have one set of materials available for students to demonstrate what they discovered during the activity (*classroom management*).
11	Discuss what they report.	Directs students to agree on what will be reported.	
12	Report to whole group: • What happened? • What was interesting and significant?	Ask such questions as • What did you notice? • What was unexpected? • What was expected? • Were there repeatable results or patterns in the manipulations or raw data?	Putting the observations on a whiteboard or large newsprint is good practice. The newsprint can be saved and referred to at later times. This becomes a type of public text (*infrastructure of classroom*). The role of the teacher at this point is to make sure all significant observations are reported and to clarify results. If groups had conflicting observations, this is something to return to for further discussion. The teacher can report his or her own observations about discoveries or manipulations not reported by groups, but still significant (*classroom culture*).

Table 1 continued

	Role of students	Role of the teacher	Rationale for teacher talk and behavior[a]
13	Consider, discuss, and weigh significance of observations. Discuss in groups or with the whole class. Generate explanations of results. Take notes.	Asks students to sort out their observations, depending on how well students became familiar with the phenomenon or raw data, as well as their skills in manipulations. • Were results similar across groups? Why or why not? • How could the differences be explained? Some preliminary explanations can be solicited. Assesses whether students know enough to proceed for setting up formal experiments.	Students may need several sessions to get well acquainted with the use of the materials, procedures, and the significance of what they are doing. Teacher may decide to have students report and then return to further exploration to gather more observations (*embedded assessment*). Differences among groups in their observations can be a good starting point for setting up formal experiments (*pedagogical practices related to content, process, and student learning*). Teacher may alternate between having group discuss the results among themselves and having the class discussing the results as a whole group (*pedagogical process related to student learning*). The tone and purpose of questioning at this stage should not be to push students to give definite explanations. Instead of "why" questions, there could be "what do you think is happening" or "what patterns appear to be present." The purpose at this point is to get students to begin to make explicit their thinking but let them know that they can be tentative in their expression of explanations.
14	Generate questions in their groups and with the whole class.	Asks students to generate questions for further exploration or discuss what formal experiments should be designed.	This is a type of brainstorming. If students are new to this type of discussion, they may need lots of encouragement and support. All of these questions should be put on a large sheet of newsprint or be visible or available to all students for future reference (*infrastructure*).

[a] This column includes statements that provide background for suggested teacher and student behavior in a highly condensed manner. Some of these statements include indicators connected to broad categories of pedagogical practice: infrastructure, classroom management, classroom culture, pedagogical practices related to student learning, pedagogical practices related to science content and process, and embedded assessment

after students have become well acquainted with the phenomenon or technological model they have been exploring. It may take multiple sessions of open exploration before reaching this point. It is important to take this time so that all students have a feeling for what possible manipulations of the materials exist and what the most salient characteristics are, giving students greater confidence in their observations and providing a richer background for generating questions and experiments. See Table 2.

Experimentation and Evidence-Gathering Phase

During this phase (Table 3), students are gathering materials and setting up experiments or equipment. When investigating living systems, controlled experiments may not be appropriate or may be difficult to carry out because of the need for highly specialized equipment. In these situations, it is a matter of carrying out systematic observation over an extended time period. The teacher manages the distribution of materials and observes the students' procedures. This can be a time for embedded assessment.

Transition to Sense Making

There are several ways to proceed at this point. The teacher can have all the evidence presented publicly and recorded on a whiteboard or newsprint, or students can be instructed to put the evidence in some kind of graphical or schematic form. What is important now is to have students share their results in a manner such that they all know what each other has observed and found out. Also, it is important for students to first have some confidence in their results before they try to develop explanations. See Table 4.

Sense-Making Phase

This phase is a very critical part of the whole process, but it is *highly dependent on what happened previously*. If students have not had adequate time to get acquainted with the phenomenon or problem, they will have a hard time moving toward explanations and conceptualization. If the observations and data collected from the experiments are scattered or highly questionable, any explanations developed may not be convincing.

This sense-making phase (Table 5) is challenging because it encompasses negotiation. Students' prior knowledge has to be taken into account and must be made explicit so they realize whether or not their conceptions fit the evidence collected. Then they have to be moved along by using various teaching strategies, such as the use of analogies, to help them bring about in themselves a reconceptualization.

Table 2 Transitioning to formal experimentation and evidence collection

Role of the student	Role of the teacher	Rationale for teacher talk and behavior
1 Talk about how they will proceed in following up on discoveries made and on the questions they generated, first in small groups, then with the whole class. Then decide which are the most important ones to pursue.	With students, considers questions and experiments generated. May suggest some questions that student should pursue as recommended in curriculum guides or from past experience. Sorts out questions: • Which are most relevant to further pursue? • Which can be answered with materials available or other materials that could be easily obtained? Sets limits on what kind of materials can be used. May negotiate with students about whether some questions should be pursued. One question, experiment, or several are picked for immediate consideration. Other questions can be pursued latter.	If students have not had much experience generating their own questions, the teacher may have to suggest some. These need to be ones that triangulate between what students may be interested in, what is possible with the materials, and what are the targeted concepts to be developed. This triangulation is also necessary even when students have generated many of their own questions and experiments (*classroom culture, pedagogical practices related to student learning*). Teacher may have to insist on some questions being pursued because of the necessity of getting at targeted concepts and because past experience has indicated these will provide necessary experience for introducing targeted concepts. If students and teacher are new to the extended inquiry process, it is recommended that the whole class do the same experiment or structured observation. It is very challenging to have each group carry out its own experiment because of the amount of information that needs to be processed by each student when they report (*pedagogical practices related to student learning*).

Table 2 continued

2 Design experiments or structured observations in their groups then report to the whole class. Share their design with the whole class.	Helps each group in their design process. Has students share and critique their designs. • What are their hypotheses? • What are the dependent and independent variables? • Do they have the right kind of equipment?	The amount of leeway given to the students in their design of experiments depends on their past experience and background. Some groups may need direct assistance. Partly this can be carried out by asking questions about procedures instead of telling students what to do (*pedagogical practices related to content and process, embedded assessment*).
3 Gather materials and set up structured observations or experiments.	Checks in on each group to see if they have a clear understanding of how to proceed.	

Note. Some systems and phenomena are difficult to work with by way of controlled experiments. This is especially true of living things. Through structured observation, students can set up a study of specific features of the organism or system that they will observe over a long period of time. Based on these systematic observations, they can test hypotheses

Table 3 Experimentation and evidence-gathering phase

	Role of the student	Role of the teacher	Rationale for teacher talk and behavior
1	Discuss why and how they are setting up their experiments or structured observations.	Clarifies what the purposes of the experiments are and how they relate to previous activities and overall goals of the investigation. Reviews procedures.	Whether the experiments are student or teacher designed, it is important that students have a sense of why they are doing them and how they fit into the whole investigation. They are not doing experiments for the sake of doing experiments but, rather, to gain a deeper understanding of the phenomenon being investigated and to confirm or disconfirm their emerging explanations (*pedagogical processes related to student learning*).
2	One person from each group obtains materials.	Manages distribution of materials.	Efficient distribution of materials can save time (*classroom management*).
3	Work out their various roles and procedures.	Checks in with each group to see if it is proceeding in a productive manner and is not having problems with procedures or use of equipment.	Functioning at three levels: 1. whole class 2. groups 3. some individuals (*classroom management*).
4	Those not clear on procedures should be asking other students or the teacher for help or clarification.	Takes notes on how students are proceeding. Judgment call: If some groups are proceeding in an ineffective manner, the teacher needs to decide whether to intervene or not. Alternatively, when results are presented, the teacher can have the whole class evaluate and make recommendations to the poorly performing group.	This is an opportunity for embedded assessment of groups and individuals. • Do they have a good sense of how to proceed? • Do they understand the purpose of the experiment or structured observation? • Are they recording data? • Are they working cooperatively? (*pedagogical practices related to content, process, and student learning*).
5		If there is uneven completion of work, the teacher needs to have a plan for keeping those groups who are finished productively involved.	There are always groups that finish ahead of others. They can be distracting to others if not occupied productively *(classroom management).*
6	Complete data collection and observations.	Checks to see that all groups have collected evidence.	Whether the evidence was carefully collected or not, all groups should have something to report.
7	Clean up.	Supervises clean up and return of materials. Makes procedure explicit.	If not managed well, clean up can take up valuable class time *(classroom management).*

Table 4 Transition to sense making

	Role of the student	Role of the teacher	Rationale for teacher talk and behavior
1		Moves students away from materials. One set of materials should be available for use during the discussion if students need to demonstrate what they did or observed.	Students have a tendency to play with materials during discussions, which can be distracting (*classroom management*).
2	Report their observations or evidence.	Records observations or data from experiments, which are shared publicly, on large newsprint, white board, or an overhead projector.	An alternative to the teacher's writing the results is for each group to put their data or observations on large newsprint while they are doing the activity. This saves time in the reporting. Groups can rotate from one sheet to another to see what has been collected by others (carousel technique) (*pedagogical practice related to student learning*).
3	Discuss either in small groups or with the whole class the credibility of the data they have collected.	Clarify observation, evidence, data: • Were all the data in the same range or were there large discrepancies with some groups' results? • How will these discrepancies be handled?	Some groups may have results very different from the others. This is an opportunity to discuss the importance of good experimental procedure. There are differing opinions of how discrepancies among groups should be handled. Some feel that • the teacher should discard some results, • students should decide what is acceptable, or • the group with the discrepant result should either do them over again or demonstrate to the whole class what they did. In this manner, the whole class can decide if proper procedures were followed (*pedagogical practice related to science content and process*).
4	Discuss and evaluate the data collected.	Decide which observations and data will be acceptable.	How this is done depends on previous experience of students and how much time can be devoted to repeating the activity.
5	Discuss either among themselves or in a whole class the significance of the data.	Discuss with students how data can be represented. Should there be bar or line graphs or some other kind of visual representation?	The type of visual representation will vary depending on the phenomena being studied and the kind of data being collected. These can range from rough sketches, careful drawings, interpretative drawings, or bar and line graphs. This is a critical step in moving toward making sense of the evidence (*pedagogical practices related to student learning*).

Table 5 Sense-making phase

	Role of the student	Role of the teacher	Rationale for teacher talk and behavior
1	Discuss in groups or with whole class their results and develop some explanations.	After results have been clarified, asks students whether they confirm or disconfirm predictions or hypotheses and whether they clarify or were unexpected. If they disconfirm or were unexpected, can students develop explanations? If they confirm, how do the results help in understanding the phenomenon or supporting previous observations or results from previous experiments.	If results are not clear cut (all groups did not have same results or measurements are spread out), teacher and students will have to decide whether to repeat the experiment or explain the results in terms of procedures. If results are unexpected, it may be an opportunity to expand on what kind of new experiments need to be done. Even if results are expected, there will still be a need to go further in explaining why (*pedagogical practices related to science content and processes*).
2		Helps students consider different explanations and align them with accumulated evidence from observations and experiments.	Any kind of explanation needs to be backed up with the evidence gathered. Do the results fully confirm the thinking behind the predictions or hypotheses? (*embedded assessment*).
3	Brainstorm, drawing on past experiences.	Encourages students to make connections to prior experiences outside of school.	Although students may bring forth explanations that are "misconceptions," they should be considered by the teacher in a neutral stance. Do student's connections make sense in light of what they know so far? (*embedded assessment*).
4	Working in their groups, attempt to develop analogies. Later, analogies are shared with the whole class.	Encourages students to make analogies from their prior experiences and what happened in class. If students come up with their own analogies, helps the mapping between student comment and classroom experience.	Sometimes students will spontaneously come up with their own analogies. These are often half formed, and the teacher needs to coach the student to expand on their initial comment and help other students understand where the analogy is (*pedagogical practices related to student learning*).
5		Introduces analogy(ies) suggested in curriculum guide or his or her own. Helps students map the relationships in the analogies.	In introducing nonstudent analogies, care has to be taken that students understand • what the base of the analogy is, • what characteristics of the base are being focused on, • what properties are being mapped onto the target, and • how this might help in understanding the results (*pedagogical practices related to student learning*)

Table 5 continued

	Role of the student	Role of the teacher	Rationale for teacher talk and behavior
6		Challenges students to articulate the concept(s) that are embedded in the analogies.	Analogies are not conceptualizations but, rather, a means to move toward developing concepts. The teacher needs to help students discern what the common relationships are between the base and the target of the analogies introduced. Can students formulate a statement that could be applied to new situations that would predict what will happen? (*embedded assessment*)
7		Introduces the deeper explanations and concepts… or has students return to experimenting… or has students construct their own explanation.	There are different schools of pedagogy regarding how and when explanations should be introduced. One school proposes that students should “construct” their own explanations using Socratic dialogue or other kinds of verbal discourse. Another school proposes that the teacher should introduce the concept, building on what has been experienced and on the evidence gathered.
8		Moves students to continue their investigation using problems with uncertain results, unexpected results, or the need to test multiple variables. A need is established to go further.	In an extended investigation, multiple variables are usually encountered and need to be tested, or patterns or correlations between salient characteristics need to be made more evident. Or, a new set of conditions or materials is introduced that challenges the students to apply what they have just learned in terms of a concept or pattern to a situation that should be related to what they have just previously explored. The new situation needs to be sufficiently different from the previous one(s), but it is readily apparent to students that the same phenomena or technology is being investigated (*pedagogical practices related to student learning*).
9	First discuss what they want to find out and then how to proceed.	Works with students to determine what specific question or problem will be the focus, what prediction or hypothesis can be made, and how to design what will be done.	

Making Use of this Kind Tool

The above outline of pedagogical practices can serve at least two functions: (a) mentors, coaches, and supervisors, such as principles and science directors, can use it in their observations and evaluations of teachers; and (b) teachers can use it as a planning tool for designing new lessons or restructuring lessons from textbooks and curriculum guides that are not in line with the standards in terms of fully following an inquiry cycle.

Using the Tool for Observation

Imagine the following scenario: A coach, mentor, or supervisor is planning to visit a novice teacher who is starting a unit on heat transfer. The novice teacher is not confident about the exploratory phase of inquiry since he or she probably had not experienced it during formal education. The mentor arranges a meeting with the mentee to discuss the planning for this introductory session. Together they review the pedagogical practices laid out in the tool for the exploratory phase. After some discussion, the mentor suggests to the mentee that it would be more effective if all of these practices were not the focus of his or her observation. Rather, the mentee and mentor decide after some discussion that the mentor will take notes only on what the mentee does during the activity. The focus will be on how the teacher monitors what is happening during the activity. This is given attention in Number 8 in the exploratory phase (Table 1) in the tool above.

The mentor then visits the mentee while he or she is carrying out the activity, recording what is happening during the activity part of the session. The mentor also records what he or she might recommend to the mentee for improved practice. Ideally, the two would meet after the session; or, if this is not possible, they would arrange for a time to report and make recommendations. First, the mentor just reports the data he or she collected, including both the teacher's behavior, as well as the students'. The mentee is asked to reflect on what he or she felt worked or did not work. The mentor suggests some changes in how the mentee would act during activities in the exploratory phase. For instance, the mentee may have asked many questions or narrow questions, both of which distracted the students from focusing on the materials and put a burden on the students' ability to attend to what could be discovered. The mentor could point out that the tool recommends that questions in this phase, during the activity, be open-ended and could give examples of these types of questions relevant to the context of what the students were doing. If this post session were timely, the mentee could practice this type of questioning in the very next session.

The Tool as a Useful and Flexible Starting Point

At first glance, the proposed tool can be seen as overwhelming, since it is so comprehensive. As the above example illustrates, the approach to using this tool is to narrow down to one or two specific practices the scope of observation by the mentor or supervisor. In this manner, the mentoring is centered on practices that are part of a previously agreed-upon framework aligned with teaching standards. However, even though there is some specificity to what has been presented here, there is still latitude for interpreting how the suggested pedagogical practices are implemented. The tool provides a way of discussing and improving teaching practice in a concrete way that relates directly to what the mentee has actually carried out. The use of this tool should be seen as only one part of a professional development program that would include courses, lesson study, and reflective practices.

Using the Tool for Planning

Imagine the following scenario: A teacher has been using a curriculum guide for moving students through a study of heat transfer. The guide recommends that students have time to explore and become acquainted with materials and is quite explicit and thorough in the design of experiments for collection of data. However, when it comes to the sense-making phase, the guide does not provide much support for the teacher in helping students process their data and in handling student-generated analogies.

Using this tool, the teacher could review practices under the sense-making phase, especially those that involve the handling of student analogies. In addition, the teacher could use these recommendations to plan how he or she would introduce an analogy that would lead to further development of concepts on heat transfer that may have already been introduced in an earlier session. The teacher would plan to be especially careful in helping students carry out the mapping between the introduced analogy and the experiences students had during the activities.

It is not the intent of this tool to be a rigid recipe that must be followed in the observation or planning of extended inquiry. As mentioned previously, there are differences in the manner in which extended investigations of physical, life, and earth science need to be carried out. With regard to earth science, there may not be any hands-on activities during the exploratory phase. Experimentation with living organisms needs to be done differently when compared with that of physical phenomena. Coaches and mentors will vary their interpretations of specific recommendations in the tool, depending on the experience of the teacher being observed. The overall intent is to provide some way that teachers can reflect on their practice in a practical and focused way.

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