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4E × 2 Instructional Model: Uniting Three Learning Constructs to Improve Praxis in Science and Mathematics Classrooms

Jeff C. Marshall · Bob Horton · Julie Smart

Abstract After decades of research endorsing inquiry-based learning, at best only moderate success has been noted in creating effective systemic implementation in K-12 classrooms. Thus, teachers need to be better equipped in how to bring this transformation to their own classrooms. Changing beliefs and overcoming external obstacles encourages the use of inquiry, but a clear, yet dynamic, instructional model is also needed for teachers to see the potential of inquiry-based instruction. The proposed 4E × 2 (read "4E by 2") Instructional Model provides such a model for learning that links strong conceptual understanding of content with inquiry learning experiences. The 4E × 2 Model integrates what we know and understand about inquiry-based teaching and learning with effective assessment and meta-cognitive reflection. These three constructs, formative assessment, inquiry instructional models, and metacognitive reflection, are foundational to the Model. A synthesis of research tied to these three constructs provides the justification of both the need for and the value of such a model. An argument for the formation of the 4E × 2 Instructional Model is made based on the coherence and the resulting synergy that occurs when these three learning constructs are united.

Keywords Assessment · Formative assessment · Inquiry · Instructional models · Learning · Mathematics education · Reflective practice · Science education

Introduction

Current instructional models, at least those that seek to foster inquiry-based learning, seem ill-equipped to provide the curricular and pedagogical guidance

J. C. Marshall (✉) · B. Horton · J. Smart
Eugene T. Moore School of Education, Clemson University, 418G Tillman Hall, Clemson, SC 29634-0705, USA
e-mail: marsha9@clemson.edu

necessary to achieve the touted systemic reform recommendations made by many (American Association for the Advancement of Science 1998, 2001; National Research Council, NRC 1996). Collectively, existing models provide a useful global framework for inquiry-based learning. However, teachers are left with a disjunct of how to meld content and inquiry effectively and consistently in classroom instruction and learning. Further, teachers remain largely unable to implement the strategies developed and tested over the last few decades that inform and guide effective learning (Black and Wiliam 1998; Bransford et al. 2000; Donovan and Bransford 2005; White and Frederiksen 1998).

Specifically, current instructional models that lead and facilitate inquiry-based learning have remained myopically entrenched in a Piagetian-focus (1970) that seek to properly resolve student misconceptions. More progressive models also include the Vygotskian notion of scaffolded learning via the principle of zone of proximal development (1978). Collectively, the work of Piaget and Vygotsky provides an appropriate foundation for differentiating instruction and learning (Tomlinson 2003). However, many of the models, even progressive ones, stop short of incorporating the essential components proposed by learning theorists that promote strong conceptual understanding and process skill development for all students.

The names of existing models (e.g., Learning Cycle, 5E Instructional Model, 7E Model) and the number of components framing the various models (respectively, 3, 5, and 7) have changed along the way, but the ideas have remained largely the same (Atkin and Karplus 1962; Bybee et al. 2006; Eisenkraft 2003; Karplus 1977). The proposed 4E × 2 Instructional Model seeks to broaden the instructional paradigm by helping develop teachers' abilities to facilitate deeper inquiry learning experiences. Further, our premise suggests that deeper inquiry-based learning requires that teachers build conceptual understanding while providing significant inquiry learning experiences.

Historical Overview of Inquiry Instructional Models

Since the early 1900s, instructional models have become foundational to teacher education programs and classroom practice (DeBoer 1991). Instructional models proposed by Herbert et al. (Bybee et al. 2006; Dewey 1910) began this movement toward using scientific inquiry as a way for students to learn in science, technology, engineering, and mathematics (STEM) disciplines. In the 1960s, Atkin and Karplus (1962) introduced the learning cycle with three phases: Exploration, Invention, and Discovery. During the 1980s, Bybee (2002) introduced the Biological Sciences Curriculum Study, BSCS, 5E Instructional Model that has gained in popularity across the science education community over the last two decades. The 5E Model includes Engagement, Exploration, Explanation, Elaboration, and Evaluation. Eisenkraft (2003) added two more phases (Elicitation and Extension), resulting in the 7E Learning Cycle. Although these models immerse students in inquiry-based learning experiences by creating a disequilibrium experience, a Piagetian notion (1970), none of the aforementioned models explicitly addresses the importance of assessment and metacognitive reflection that need to occur during each stage of learning (inquiry).

Why is Another Model Needed?

Researchers have identified many significant understandings in what ultimately helps to improve student learning. However, teachers often find it difficult to assimilate solid research findings into a coherent structure for classroom teaching and learning—and, understandably so. For instance, do most teachers consistently embed formative assessment in inquiry-based learning experiences? Further, how does this information (if gathered in the first place) inform teaching? This one illustration demonstrates the need to help teachers incorporate what they know about their students' understanding into their lessons. The goals of establishing a new model include: (1) provide a coherent research-based model that allows teachers to develop and implement deep, meaningful inquiry-based learning experiences, (2) facilitate more intentional instructional practice that explicitly focuses on formative learning over summative performance, (3) provide a diagnostic aid for teachers to assess weak areas of instructional practice, and (4) provide a pragmatic method for strengthening instructional weaknesses.

Based on the goals, three constructs (metacognitive reflection, inquiry instructional models, and formative assessment) were identified from prior research as critical to the formation of a new model. In the following sections, each construct will be defined and its inclusion justified by research. Specific attention will be given to the effect of these constructs on learning.

Overview of Constructs

Our efforts focus on integrating the research from the three constructs (metacognitive reflection, inquiry instructional models, and formative assessment) that will allow teachers to build stronger praxis tangibly and effectively. Because of the diffuse nature of usage, each construct will be clarified and operationalized.

Metacognitive Reflection

Metacognition includes both the understanding of and control of one's cognitive processes (Sternberg 1998; White and Frederiksen 2005). While reflective practice refers to any occasions of purposeful thought (Wilson and Clarke 2004), metacognition includes deep analysis and awareness of thought processes central to effective learning. Therefore, metacognitive reflection unifies focused reflective practice regarding the concepts being investigated (Shepardson and Britsch 2001) with the self-awareness aspects endorsed by metacognitive strategies (Sternberg 1998; Wiggins and McTighe 1998).

Inquiry Instructional Models

Since the *National Science Education Standards*, *NSES* (NRC 1996) have provided guidance for critical discussions in how inquiry and content are taught in schools around the country for the last 10 years, the *NSES* definition of scientific inquiry will serve as the operational definition here as well: "a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a rich understanding of concepts, principles, models, and theories" (NRC 1996, p. 214). Since the construct is an inquiry instructional model, not just inquiry, we refine the definition to curricula and instructional practices that promote and facilitate engaging students in the aforementioned idea of scientific inquiry.

Formative Assessment

For this article, formative assessment is defined as "encompassing all those activities undertaken by teachers, and/or by their students, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged" (Black and Wiliam 1998, p. 8). This definition was selected since Black and Wiliam's synthesis of studies involving the impact of formative assessment on student learning connects essential, often cited research to this area of study. Further, their definition seems congruent with definitions used in other large synthesis and meta-analysis works (Bell and Cowie 2001; Crooks 1988; Kluger and DeNisi 1996; Natriello 1987).

Metacognitive Reflection Research

Research on in-service teachers indicates that the quality of teaching improves when teachers reflect on their practice; this results in greater student performance (Cavalluzzo 2004; Goldhaber 2004; Vandevoort et al. 2004). However, if reflective practice is left only to the professionals and pre-professionals, then a great learning opportunity has been lost. Studies (Aschbacher and Alonzo 2004; Shepardson and Britsch 2001) suggest that when students engage in well-guided reflection during the learning process, they gain in meaningful ways. A specific application of this idea is the use of science notebooks to allow students to journal their questions, comments, and observations throughout the learning process.

To extend beyond the merits of reflective practice, students need to be engaged in metacognitive strategies that tie their reflections to their cognitive processes. By helping students to focus on what has been learned and what still needs to be learned, better cognitive focus can be provided to direct future learning (Tobias and Everson 2002). Metacognition encompasses an individual's knowledge about her own thought processes as well as self-awareness of how knowledge is processed, stored, and retrieved (White and Frederiksen 2005). While reflection refers to almost any occasion of thought, metacognition includes deep analysis and awareness of one's own thought processes. Thus, metacognitive reflection suggests that, as students detail what was learned, they should also consider the cognitive process they used to achieve this learning. For instance, students should explain the strategies used to solve a scientific problem (reflection), and then they should provide details about their thought processes in selecting and implementing these strategies (metacognition). Deep understanding occurs when students are confident in what they know, recognize how they know it, and can critically examine their own knowledge (Kuhn 1999).

Instructional Models (Inquiry Focused) Research

Initial instructional models, such as those proposed by Dewey, contained powerful theoretical implications that unfortunately lacked empirical evidence to support their claims. In more recent decades, two inquiry instructional models have received great emphasis from researchers and practitioners for inquiry instructional techniques: the BSCS 5E Instructional Model and its predecessor, the Learning Cycle (Bybee et al. 2006). Because of the extensive research surrounding these two models, they will serve as the focus for analyzing this construct.

Even with the leadership provided by these two models, a consistent vision for inquiry seems lacking. The *NSES* (NRC 1996) strongly supports inquiry teaching methods and inquiry learning experiences for students, but the *NSES* and other national groups that support the implementation of inquiry (AAAS 1990, 1993; National Board for Professional Teaching Standards 1994; National Commission on Mathematics and Science Teaching 2000; NRC 2000a) use the term inconsistently (Anderson 2002).

Teacher familiarity with "inquiry" has become fairly commonplace (Weiss et al. 2001); however, consistent and coherent implementation is still lacking. Assistance in bridging the gap between theory and practice is needed. To provide evidence, results from a study of K-12 science and mathematics teachers indicate an ideal percentage of time spent on inquiry that was uniformly one standard deviation (approximately 18–20%) higher than the typical percentage of time that they reported spending on inquiry (Marshall et al. in press). Providing the necessary support structures is helpful in bridging the gap but will only partially help to achieve the goal. Specifically, a significant correlation is seen between curricular support for inquiry and the typical amount of time spent on inquiry-based instruction for K-12 science and math teachers, $r(1219) = 0.355$, $p < 0.001$ (Marshall et al. in press).

Formative Assessment Research

Numerous individual studies and meta-analyses report a significant positive effect on student achievement that results when formative assessment becomes integral to the teaching and learning process (Black and Wiliam 1998; Keeley et al. 2005; Marzano 2006; Weiss et al. 2001). Prior to No Child Left Behind, NCLB (U.S. Department of Education 2002) summative forms of assessment prevailed as the main system for assessing and evaluating learning. Students were told how well they knew the material, and then, regardless of the outcome, the class moved on to the next concept to be covered or discovered.

Since NCLB, assessing learning through summative assessment has become even more prevalent; it is the ultimate form of *high-stakes* testing and encourages students to play the *game* so they get the *right* answer (Fried 2001). Instead, to encourage learning that fosters the development of knowledge more than rewarding a single finished product, diagnostic and formative (embedded) assessments must be integrated into the learning process (Marzano 2003; Wiggins and McTighe 1998).

Proposed 4E × 2 Instructional Model

By uniting these constructions, we propose a model we have named the 4E × 2 Instructional Model. Two figures are provided to help clarify this Model. Figure 1 provides an overview of how the three major constructs (metacognitive reflection, inquiry instructional models, and formative assessment) interrelate. Figure 2 provides a template to guide planning when using the 4E × 2 Instructional Model. The different components of the Model are discussed below.

Engage

Engaging the learner through an effective *hook, mind capture, or perturbation* provides motivation to initiate the learning process, but engaging students in inquiry-based learning is more complex than just considering student motivation. In the 4E × 2 Instructional Model, the Engage phase of inquiry requires that consideration be given to the following: probing prior knowledge, identifying alternative conceptions, providing motivating and interest inducing stimuli, and developing scientific questioning. These four foci are guided by a significant body of research (Bransford et al. 1999; Driver et al. 1994; Hake 1998; NRC 1996). The *NSES* emphasize the importance of developing scientific questioning skills in students, stating that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (NRC 1996, p. 31). Further, bringing students' alternative conceptions and prior knowledge to the foreground is critical to facilitate the perturbation or disequilibrium experience necessary to begin conceptual development. In order to facilitate the various aspects associated with engagement, teachers need to be explicitly cognizant of how, once identified, each plays a role in the inquiry learning process.

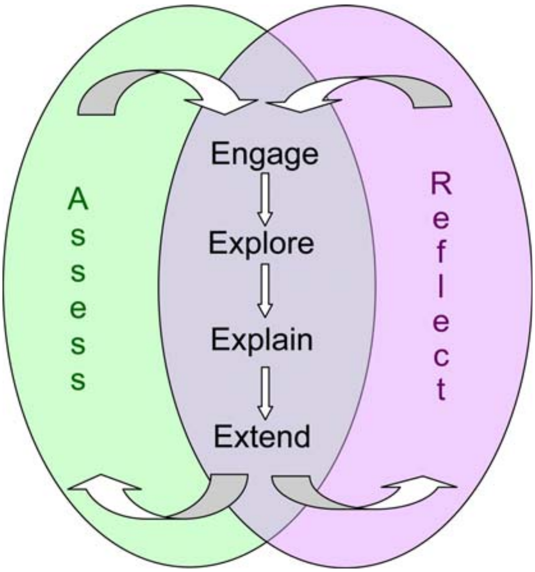

Fig. 1 Interaction of three constructs in the 4E × 2 Instructional Model (Marshall 2007)

Key Focus or Essential Question:
Standards Addressed:
Objective(s):
Materials:
Safety:
Sources/References/Ancillary Materials:

Reflect (R)	Central Framework	Assess (A)
Engage Metacognitive Reflection: R1: (Select One) R2: (Select One) Other:	**Engage** Check all that apply: ☐Prior knowledge; ☐Misconceptions; ☐Motivation/Interest; ☐Develop scientific question **Check Representative Questions:** ☐What do you know about…? ☐What have you seen like this? ☐What have we studied that might apply here? ☐What have you heard about…that you aren't sure if it is true or not? ☐What intrigues/interests you about…? ☐What is confusing about…? ☐What questions do you have about…? ☐What would you like to investigate regarding…? ☐Other: Anticipated time needed to complete engage: **Description of Engage:** **Post Section Decisions:** ☐Proceed; ☐Quick Review; ☐Remediate	**Engage Assessment Context:** ☐Knowledge-centered ☐Process-centered ☐Skill-centered ☐Individual ☐Small Group ☐Class Performance A1: (Select One) A2: (Select One) Other:
Explore Metacognitive Reflection: R3: (Select One) R4: (Select One) Other:	**Explore** Check all that apply: ☐Predict; ☐Design; ☐Test; ☐Collect; ☐ Reason **Check Representative Questions:** ☐What if…? ☐What would you expect to happen? Why? ☐How can you best study this problem? ☐What do you need to collect? ☐How will you organize your information? ☐How much data/information do you need to collect? ☐What are some changes you noticed in…? ☐Other: Anticipated time needed to complete explore: **Description of Explore:** **Post Section Decisions:** ☐Proceed; ☐Clarify; ☐Remediate; ☐ Re-Engage	**Explore Assessment Context:** ☐Knowledge-centered ☐Process-centered ☐Skill-centered ☐Individual ☐Small Group ☐Class Performance A3: (Select One) A4: (Select One) Other:
Explain Metacognitive Reflection: R5: (Select One) R6: (Select One) Other:	**Explain** Check all that apply: ☐Interpret; ☐Evidence; ☐Communicate; ☐Alt. explanations; ☐Verify; ☐Justify; ☐ Analyze **Check Representative Questions:** ☐What took place? ☐What changes did you notice? ☐What visuals help to explain your findings? Explain them. ☐What surprised/puzzled you? What is still confusing? ☐How is this similar or different from…? ☐What pattern(s) did you notice? ☐How does this apply to what we learned before? ☐Explain what happened? ☐What has been learned? ☐What evidence do you have for your statement? ☐How would you explain…? ☐What trend does the data show? ☐How is your idea different from…? ☐What do you mean when you say, "…?" ☐Do you agree with…? Why/Why not. ☐Where have you encountered a similar phenomenon? ☐What do you think will happen if? ☐Other: Anticipated time needed to complete explain: **Description of Explain:** **Post Section Decisions:** ☐Proceed; ☐Re-Engage; ☐Re-Explore; ☐Remediate; ☐ Have Students Clarify	**Explain Assessment Context:** ☐Knowledge-centered ☐Process-centered ☐Skill-centered ☐Individual ☐Small Group ☐Class Performance A5: (Select One) A6: (Select One) Other:
Extend Metacognitive Reflection: R7: (Select One) R8: (Select One) Other:	**Extend** Check all that apply: ☐Apply; ☐Elaborate; ☐Transfer; ☐Generalize **Check Representative Questions:** ☐What would happen if…? ☐How do you think … applies to….? ☐Explain from another viewpoint. ☐How can this be used in the real world? ☐What questions/problems are still unresolved? ☐What decisions need to be made? What consequences/benefits/risks accompany certain decisions? Other: Anticipated time needed to complete extend: **Description of Extend:** **Post Section Decisions:** ☐Debrief; ☐Re-Engage; ☐Re-Explore; ☐ Have Students Clarify; ☐Another Extension	**Extend Assessment Context:** ☐Knowledge-centered ☐Process-centered ☐Skill-centered ☐Individual ☐Small Group ☐Class Performance A7: (Select One) A8: (Select One) Other:

Teacher reflection/comments:

Fig. 2 Template for 4E × 2 Instructional Model (Marshall et al. 2007)

Effective questioning is critical during all phases of inquiry-based learning. The following provide examples of effective questions to guide teacher facilitation during the four foci of the Engage phase: (1) What do you know about…? (2) What have you seen like this? (3) What have you heard about…that you aren't sure is true? (4) What would you like to investigate regarding…? Intentional, effective questioning is necessary, but not sufficient, to determine if the class is ready to proceed to the Exploration phase, if they need a quick review, or if they need remediation before further investigation is possible. Further, effective questioning encourages but does not require that students become invested in the learning experience.

To achieve student investment in the learning process, teachers need to incorporate metacognitive reflection with effective questioning. Metacognitive strategies coupled with effective formative assessment raise the achievement of all students—more so for low performing students (Black and Wiliam 1998; NRC 2000b). Once the goals and objectives have been clearly identified, an appropriate reflective engagement component can be adopted to achieve the desired focus. This may include brainstorming sessions in small groups or logging individual responses in science notebooks before corporate sharing. Identifying alternative conceptions or areas of confusion should be encouraged at this point in the diagnostic and early formative learning process. Not visible on Fig. 2, drop-down boxes (R1/R2) are provided to link the strategies used by teachers to engage students in metacognitive reflection. For the Engage component, these choices include: science notebooks, drawings, brainstorming, warm-up exercises, and KWHL charts.

Assessments that provide diagnostic or formative feedback are critical before decisions to move on can be adequately considered. Formative (diagnostic) assessments for the Engage phase might include pre-tests, formative probes (Keeley et al. 2005), and/or KWHL charting (van Zee et al. 2001). A KWHL chart is a graphic organizer to help facilitate learning by asking the following: (1) What do I "Know"? (2) "What" do I want to know? (3) "How" do I find out? (4) What have I "Learned"? The more commonly known KWL chart leaves out the critical metacognitive step where students help design how the learning and the investigation will take place. Designing a procedure is explicitly addressed under the "H" portion of the KWHL chart. Integrating formative assessment and metacognitive reflection into the engagement section of the inquiry framework provides teachers with a robust model for how to engage students in the three primary learning outcomes for inquiry-based teaching: conceptual understanding, ability to perform scientific inquiry, and understanding about inquiry (NRC 2000b). Like metacognitive reflection, drop-down boxes (A1/A2) are included that link the strategies used by teachers to engage students in formative assessment. Assessment strategies for the Engage component include: discrepant event, formative probe, pre-test, test for misconception, and KWHL chart.

Explore

Once teachers effectively engage students, teachers can lead students into the Explore phase. Researchers (AAAS 1998; Llewellyn 2002; National Council of Teachers of Mathematics 1998; NRC 1996) suggest that critical aspects of the Explore phase include having students delve into one or more of the following: predict, design, test, collect, and/or reason. Examples of effective questions to help guide the facilitation of these aspects respectively include (1) What if…? (2) How can you best study this problem? (3) What happens when…? (4) What data/information do you need to collect? (5) Why did you choose your method to study the problem?

Like the Engage phase, metacognitive reflection and formative assessment are essential for keeping students directed along a formative learning path. The assessments can be contextualized into knowledge and/or process centered domains that focus on individual, small group, or class sized groupings. Further, metacognition, formative assessment, and reflective practice become meaningfully intertwined when individual responses are united with small and large group discussions. A common example of this is the think-pair-share learning strategy (Lyman 1981).

Often teachers limit themselves to an observational, fairly passive role when assessing student progress during the Explore phase. While it may be beneficial to let students *wade-in-the-muck* at times, teachers may want to assume a more active role that provides guided prompts to encourage individuals or groups to think more deeply about the investigation at hand. This encourages students to slow down and think metacognitively about their interactions with the natural world and their thought processes. Additionally, having students engage in metacognitive reflection provides teachers with critical information to better guide intentional instructional practice (Tobias and Everson 2000) while presenting excellent opportunities for differentiated instruction (Tomlinson 2003).

Metacognitive reflection during the Explore phase may include having students log individual entries in science journals or complete the "H" portion of the KWHL chart (How do I effectively study this question/problem?). Further, teachers could have students identify and then elaborate where confusion or weakness in their plan exist. If, for instance, data collection surfaces as the predominant concern, then a brief collaborative discussion with small groups could occur that focuses on how to gather data in meaningful ways. Such interactions with students emphasize assessment *for* learning instead of assessment *of* learning. When metacognitive reflection and formative assessment merge, instruction is more informed. More importantly, students are continually updated on their progress in relation to their goals (Marzano 2006; Stiggins 2005; Tobias and Everson 2000).

The unification of metacognitive reflection, the inquiry instructional model, and formative assessment during the Explore phase intentionally encourages deeper understanding. Learning throughout the investigation now becomes central to the instructional process instead of waiting to the end of the investigation before students and teachers know whether students truly *get it* (Black and Wiliam 1998; Wiggins and McTighe 1998).

Explain

Although the Model should be seen as dynamic, the framework for the Model is predicated on having the Explain phase follow the Explore phase. This framework minimizes teacher-centered confirmatory learning, which is often superficial, and encourages student-centered learning. During the Explain phase students begin to make sense of how the prior knowledge and alternative conceptions from the Engage phase align with findings from the Explore phase. This sense-making occurs when students begin to communicate results and evidence (NRC 1996). However, if explanation precedes exploration, which is typical in non-inquiry instruction, students are thrust into passive learning situations that rarely challenge them to confront deficits in prior knowledge or existing alternative conceptions. So, when Explore precedes Explain, inquiry and content can be united in highly engaging ways that help students reshape prior alternative conceptions in ways that align with their new learning (Carin et al. 2005).

During Explore, the process skills are emphasized as students grapple with ideas. The content then becomes central during the Explain phase as the process skills are used to support higher order thinking skills such as interpreting, justifying, and analyzing. Further, in this Explore-before-Explain model, students from diverse backgrounds and abilities now have shared experiences as a basis for their claims and ideas. Other prior experiences that students bring to class make the learning richer, but learning is accessible to all learners because the data collected and observations made were experienced by all. At the core of the Explain phase and inquiry learning in general, students are involved in a recursive cycle between evidence and explanations. Ideally, the process skills and content become embedded together in the investigation.

Central aspects of the Explain phase include: (1) interpreting data and findings, (2) providing evidence for claims, (3) communicating findings (written, oral, using technology), and (4) providing alternative explanations for findings. Examples of effective questions led by the teacher during the Explain phase include: (1) What pattern(s) did you notice? (2) What evidence do you have for your claims? (3) How can you best explain/show our findings? (4) What are some other explanations for your findings?

Some assessments for the Explain phase include lab reports, presentations, and discussions. These assessments can be formative or summative depending on the implementation. If students are allowed to resubmit work or if they are directed to revise their work based on peer editing, then assessment becomes formative and emphasizes the learning process over the learning product. Rubrics should be clear in their requirements but provide flexibility to allow for unique expression of ideas. The goal is conceptual understanding and understanding scientific inquiry—not whether students can fill out a worksheet properly. If interpreting data and providing evidence are central to a particular investigation, then students need to justify claims made using the documented data and results.

Improved learning has been noted when both formative assessment and metacognitive strategies are employed (Bransford et al. 2000; Costa and Kallick 2000). Metacognitive strategies create time for sense-making and thus provide opportunities for students to reconcile new knowledge with prior knowledge. Further, students become mindful of their own learning and employ strategies that assist their own progression of learning. Graphic organizers such as KWHL charts and POE (predict, observe, explain) cycles (White and Gunstone 1992) that began during earlier phases of the investigation can now be completed (e.g., What have you learned? Explain your results.). Further, concept maps can be used in a new way during the Explain phase. During Engage, concept maps are used diagnostically to provide insights into knowledge gaps; during Explain students develop links among new concepts, prior knowledge, and skills learned.

Extend

If learning stops after the Explain phase, when conceptual understanding begins to take hold, then students may quickly revert back to prior knowledge and understandings held before the investigation. Providing one or more opportunities for students to apply their knowledge in meaningful and authentic contexts helps students to begin solidifying their conceptual understanding, developing a more permanent mental representation. Alternative conceptions are tenacious and must be repeatedly addressed before lasting change will occur (Hestenes et al. 1992). The disequilibrium experience caused in students during Engage and Explore now begins to gain resolution as understanding and knowledge articulated during the Explain phase now is applied to new situations and to prior concepts studied.

During Extend, students are asked to apply, elaborate, transfer, and generalize knowledge to novel situations. Appropriate questions for the Extend phase include: (1) How do you think…applies to…? (2) What would happen if…? (3) Where can this be used in the real world? (4) What consequences/benefits/risks accompany certain decisions?

Assessment strategies may include having students perform a new investigation that remains focused on the conceptual ideas being studied. Using science notebooks, presentations, small group discussions, or class discussions, students can explore deeper implications of their findings. At this point in the inquiry process, assessments often are seen only as summative. By providing formative assessment even at this point, students are required to think more deeply about their work. For instance, students could be asked to address an area of weakness seen during a presentation as a science notebook entry, or they could be asked to respond to the teacher's comments in one or more of their science notebook entries. Metacognitive reflection unites learning with personal reflection by clearly addressing where knowledge is complete and where it still needs work. The number of extension activities or amount of time devoted to this phase should be determined by the difficulty of the concept(s) being studied, the importance of the concept in the curricular framework, and the degree of understanding that has been shown by all students.

As mentioned in the Engage section, drop-down boxes are available from the template that allow choices to be made that link strategies for engaging students in metacognitive reflection and formative assessment with each component of inquiry. For example, during the Engage phase of inquiry under metacognitive reflection, teachers can select from five options, such as KWHL charts and science notebooks. Under formative assessment, teachers can also select from five options, such as testing for misconceptions and determining student responses to discrepant events. Those interested in the interactive template should visit http://www.clemson.edu/iim (select Research and Evaluation and then 4E × 2 Instructional Model). For those interested in specific applications of the Model, select the lesson plan tab at http://www.clemson.edu/iim.

Discussion

Currently several inquiry instructional models exist (e.g., learning cycle, 5E, 7E). So why not accept the *status quo* and allow teachers or curriculum developers to determine if and how metacognitive reflection and formative assessment need to be addressed in the learning process? First, numerous researchers (Enger and Yager 2001; Keeley et al. 2005; NRC 1996) have identified that formative assessment is critical if meaningful learning is a dynamic, iterative process, not merely a superficial exercise measured by a test for which students are dutifully prepared. Further, using authentic formative assessments helps facilitate more informed, intentional instructional practice. Moreover, continual reflection upon learning reinforces Dewey's vision of reflective practice that has become enmeshed in theory and practice in recent years (Dewey 1938; Donovan and Bransford 2005; NBPTS 1994; Shepardson and Britsch 2001). Further, the rigor of the learning is boosted when metacognitive approaches are used that encourage self-knowledge (Sternberg 1998; Tobias and Everson 2002; Wiggins and McTighe 1998).

Comprehensive instructional models, such as the proposed 4E × 2 Instructional Model, allow for the introduction of the necessary perturbations required to promote deeper levels of learning. Without the necessary intervention strategies (Derry and DuRussel 1999) that are critical to the 4E × 2 Model, learners become stuck in the same problem-solving mode after a few attempts. The 4E × 2 Model provides a dynamic mechanism to guide teachers in developing and then implementing deep, engaging, and interactive learning opportunities that require learners to pause, think, interact, rethink, reflect, and journal their attempted solution patterns as well as explore other solution options. The 4E × 2 Instructional Model provides an evolved model for teaching, particularly in the STEM disciplines. The Engage, Explore, Explain, and Extend phases, which form the central tenets, or backbone, of the inquiry learning process are necessary for strong formative inquiry-based learning. However, by explicitly incorporating metacognitive reflection throughout the learning and teaching process, conceptual understanding can be deepened. Finally, by incorporating authentic formative assessment strategies throughout the learning process, both student and teacher gain.

Dynamic Variations of Model

On the surface, it seems logical to proceed sequentially through the phases supported by the model, have students demonstrate their knowledge and understanding, and then move along to the next concept. However, conceptual understanding does not always follow such a predictable path. Just as there is not one Scientific Method (Windschitl 2003), the 4E × 2 Instructional Model supports a dynamic structure. While variations from the straightforward progression through Engage, Explore, Explain, and Extend for an investigation may be appropriate, these decisions should be purposeful, with the guiding principle being what best supports strong conceptual development being achieved by students. Several variations of the model are possible—each with a clear rationale for usage.

Model 1

Engage–Explore–Explain–n(Extend) would be considered the default or typical model expressed by the 4E × 2 Instructional Model. The "n" denotes that multiple Extend opportunities should be encouraged to support transference of knowledge to new ideas by incorporating prior knowledge. The decision for how many different extension iterations are needed could be based on the following factors: (1) depth of student knowledge conveyed in prior extend investigation, (2) where in the unit or theme the investigation occurs, (3) relative importance of concepts, standards, and skills to the overall goals for the course, and (4) if prior content, skills, and ideas that have been studied can be embedded into the essential focus of the investigation. So if students understand at a significant level and can apply the knowledge to several different situations, then the investigation should justifiably be concluded. If a new concept has been introduced that will be reinforced later by another related investigation, then minimizing the number of extension opportunities may be warranted. However, if students are not likely to see this information again, then employing several Extend opportunities makes sense. Likewise, if multiple concepts throughout the course overlap with the current concept being investigated, then multiple extend opportunities are encouraged.

Other Models

Additional variations of the 4E × 2 Instructional Model are possible, but variations need to be intentional and should be predicated on Explore before Explain. For instance, students might Engage in three consecutive cycles of Engage–Explore–Explain before a final Extend is implemented. This approach might be used when three closely related ideas are studied. For instance, displacement, velocity, and acceleration could be studied in three different investigations before students transfer their prior and current learning (Extend) to motion in general.

Another variation might include Engage–Explore–Explore–Explore–Explain–Extend. This would be applicable when one scientific question is being explored several ways before students seek to explain their findings. For instance, students could investigate three different plant types before seeking to apply what they studied to a larger ecosystem application. Note that Engage was used only during the initial iteration because alternative conceptions should be clearly known and continually addressed during subsequent investigations.

Conclusions and Implications

The three learning constructs (formative assessment, inquiry instructional models, and metacognitive reflection) that form the 4E × 2 Instructional Model have individually been shown to have moderate to high effect sizes (0.4–0.8) in numerous aforementioned studies (Black and Wiliam 1998; Bybee et al. 2006; Tobias and Everson 2000). Unifying the constructs into one coherent model provides teachers with a mechanism to focus their instructional practice on core issues that improve teaching and learning. While the 4E $\times$ 2 Model should be seen as a dynamic inquiry-based instructional model, it also provides an explicit reminder of the importance and interrelationship among three essential components learning constructs. Thus, curricular preparation and implementation become more meaningful when they incorporate a synthesis of what research has suggested regarding meaningful inquiry-based teaching and learning practice.

Although the model does not claim to include all that research says regarding effective practice, the model is a significant evolution over previous models that typically neglect the role of metacognitive reflection and formative assessment in the process of inquiry-based learning. It suggests that teachers spend more time on lesson preparation and on the lessons themselves, but the result of deeper, more meaningful learning will pay dividends in the long run.

Numerous research endeavors related to the 4E $\times$ 2 Instructional Model have begun. First, the Model was piloted with pre-service teachers in elementary and secondary science. Effective questions that fit within each component of inquiry were further developed during this time. Currently, two sustained professional development initiatives for mathematics and science teachers prominently feature the 4E $\times$ 2 Instructional Model. For these initiatives, the Model is foundational to the implementation of inquiry in the classroom in addition to the exploration of the quality of inquiry led by teachers. Teachers first experienced the Model through several interactive experiences during a two-week summer institute. Working in teams of four to five, teachers then developed in-depth lessons that targeted key standards in Algebra I and Physical Science. During the current academic year, these same teachers are now implementing these lessons while researchers analyze the quality of inquiry. After this analysis, improvements will be made to the Model. Finally, the Model will be integrated into a web-based system that provides in-depth lessons for K-12 science and mathematics classrooms. These lessons will be honed based on reported evidence from teachers, observations from researches, and quality of student work. This iterative process of building lessons within the structure of the 4E $\times$ 2 Instructional Model will provide a distinct improvement over the traditional creation and sharing of lessons that rarely are based on the quality of teaching and learning. Without a coherent model to lead inquiry-based learning, reform efforts are likely to continue to meet with only moderate success.

References

American Association for the Advancement of Science. (1990). *Science for all Americans*. New York: Oxford University Press.

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

American Association for the Advancement of Science. (1998). *Blueprints for reform*. New York: Oxford University Press.

American Association for the Advancement of Science. (2001). *Atlas of science literacy: Project 2061*. Washington, DC: AAAS & NSTA.

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education, 13*(1), 1–12.

Aschbacher, P., & Alonzo, A. C. (2004). *Using science notebooks to assess students' conceptual understanding*. Paper presented at the American Educational Research Association, San Diego.

Atkin, J., & Karplus, R. (1962). Discovery of invention? *Science Teacher, 29*(5), 45–47.

Bell, B., & Cowie, B. (2001). The characteristics of formative assessment in science education. *Science Education, 85*, 536–553.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education, 5*(1), 7–74.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academies Press.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school (expanded edition)*. Washington, DC: National Academies Press.

Bybee, R. W. (2002). *BSCS 5E instructional model*. BSCS.

Bybee, R. W., Taylor, J. A., Gardner, A., Scotter, P. V., Powell, J. C., Westbrook, A., et al. (2006). *The BSCS 5E instructional model: Origins, effectiveness, and applications*. Colorado Springs: BSCS.

Carin, A. A., Bass, J. E., & Contant, T. L. (2005). *Methods for teaching science as inquiry* (9th ed.). Upper Saddle River, NJ: Pearson.

Cavalluzzo, L. (2004). *Is National Board Certification an effective signal of teacher quality?*. Alexandria, VA: The CNA Corporation.

Costa, A., & Kallick, B. (2000). *Discovering and exploring habits of mind*. Alexandria, VA: Association for Supervision and Curriculum Development.

Crooks, T. J. (1988). The impact of classroom evaluation practices on students. *Review of Educational Research, 58*(4), 438–481.

DeBoer, G. E. (1991). *A history of ideas in science education*. New York: Teachers College Press.

Derry, S. J., & DuRussel, L. A. (1999). Assessing knowledge construction in on-line learning communities. In S. Lajoie & M. Vivet (Eds.), *Artificial intelligence in education*. Amsterdam: IOS Press.

Dewey, J. (1910). *How we think*. Lexington, MA: D.C. Heath.

Dewey, J. (1938). *Experience and education*. New York: Collier Books.

Donovan, S. M., & Bransford, J. D. (2005). *How students learn: History, mathematics, and science in the classroom*. Washington, DC: National Academies Press.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science: Research into children's ideas*. London: Taylor & Francis Ltd.

Eisenkraft, A. (2003). Expanding the 5E model: A proposed 7E model emphasizes "transfer of learning" and the importance of eliciting prior understanding. *The Science Teacher, 70*(6), 56–59.

Enger, S., & Yager, R. E. (2001). *Assessing student understanding in science: A standards-based K-12 handbook*. Thousand Oaks, CA: Corwin Press.

Fried, R. L. (2001). *The passionate teacher: A practical guide*. Boston: Beacon.

Goldhaber, D. (2004). *Can teacher quality be effectively assessed?*. Seattle, WA: The Urban Institute.

Hake, R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64–74.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*, 141–158.

Karplus, R. (1977). Science teaching and the development of reasoning. *Journal of Research in Science Teaching, 14*, 169–175.

Keeley, P., Eberle, F., & Farrin, L. (2005). *Uncovering student ideas in science: 25 formative assessment probes*. Arlington, VA: NSTA Press.

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performances: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin, 119*(2), 254–284.

Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher, 28*(2), 16–25.

Llewellyn, D. (2002). *Inquiry within: Implementing inquiry-based science standards*. Thousand Oaks, CA: Corwin Press.

Lyman, F. T. (1981). The responsive classroom discussion: The inclusion of all students. In A. S. Anderson (Ed.), *Mainstreaming digest* (pp. 109–113). College Park: University of Maryland Press.

Marshall, J. C. (2007). *4E × 2 Instructional Model: Promoting stronger teaching and deeper conceptual understanding*. Paper presented at the School Science and Mathematics Association, Indianapolis, IN.

Marshall, J. C., Horton, B., & Edmondson, E. (2007). *4E × 2 Instructional Model* [Electronic Version]. Retrieved August 15, 2007 from http://www.clemson.edu/iim.

Marshall, J. C., Horton, R., Igo, B. L., & Switzer, D. M. (in press). K-12 science and mathematics teachers' beliefs about and use of inquiry in the classroom. *International Journal of Science and Mathematics Education*. doi:10.1007/s10763-007-9122-7.

Marzano, R. J. (2003). *What works in schools: Translating research into action*. Alexandria, VA: ASCD.

Marzano, R. J. (2006). *Classroom assessment and grading that work*. Alexandria, VA: ASCD.

National Board for Professional Teaching Standards. (1994). *What teachers should know and be able to do*. Washington, DC: Author.

National Commission on Mathematics and Science Teaching. (2000). *Before its too late: A report to the nation from the National Commission on Mathematics and Science Teaching for the 21st Century*. Washington, DC: U.S. Department of Education.

National Council of Teachers of Mathematics. (1998). *Technology conference: NCTM Standards 2000*. Arlington, VA.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.

National Research Council. (2000a). *How people learn*. Washington, D.C: National Academy Press.

National Research Council. (2000b). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academies Press.

Natriello, G. (1987). The impact of evaluation processes on students. *Educational Psychologist, 22*(2), 155–175.

Piaget, J. (1970). Piaget's theory. In P. H. Mussen (Ed.), *Carmichael's manual of child psychology* (pp. 703–732). New York: Wiley.

Shepardson, D. P., & Britsch, S. J. (2001). The role of children's journals in elementary school science activities. *Journal of Research in Science Teaching, 38*(1), 43–69.

Sternberg, R. J. (1998). Metacognition, abilities, and developing expertise: What makes an expert student? *Instructional Science, 26*, 127–140.

Stiggins, R. (2005). From formative assessment to assessment FOR learning: A path to success in standards-based schools. *Phi Delta Kappan, 87*(4), 324–328.

Tobias, S., & Everson, H. (2000). Assessing metacognitive knowledge monitoring. In G. Schraw (Ed.), *Issues in the measurement of metacognition*. Lincoln, NE: Buros Institute, The University of Nebraska.

Tobias, S., & Everson, H. (2002). *Knowing what you know and what you don't: Further research on metacognitive knowledge monitoring*. New York: College Board.

Tomlinson, C. A. (2003). *Fulfilling the promise of the differentiated classroom: Strategies and tools for responsive teaching*. Alexandria, VA: ASCD.

U.S. Department of Education. (2002). *The No Child Left Behind Act of 2001*. Retrieved March 14, 2004, from http://www.ed.gov/nclb/overview/intro/execsumm.pdf

van Zee, E. H., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. *Journal of Research in Science Teaching, 38*(2), 159–190.

Vandevoort, L. G., Amrein-Beardsley, A., & Berliner, D. C. (2004). National Board Certification Teachers and their students' achievement. *Education Policy Analysis Archives, 12*(46), 1–117.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge: Harvard University Press.

Weiss, I. R., Banilower, E. R., McMahon, K. C., & Smith, P. S. (2001). *Report of the 2000 national survey of science and mathematics education* [Electronic Version]. Retrieved from http://2000survey.horizon-research.com/reports/status.php

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction, 16*(1), 3–118.

White, B. Y., & Frederiksen, J. R. (2005). A theoretical framework and approach for fostering metacognitive development. *Educational Psychologist, 40*(4), 211–223.

White, R. T., & Gunstone, R. F. (1992). *Probing understanding*. Great Britain: Falmer Press.

Wiggins, G., & McTighe, J. (1998). *Understanding by design*. Alexandria, VA: ASCD.

Wilson, J., & Clarke, D. (2004). Towards the modelling of mathematical metacognition. *Mathematics Education Research Journal, 16*(2), 25–48.

Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education, 87*(1), 112–143.