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# Filling in the Gaps: An Explicit Protocol for Scaffolding Inquiry Lessons

## Abstract

The goal of this paper is to introduce an explicit protocol that preservice science teachers can use to improve the quality of the scaffolding (written and oral prompts) of their inquiry lessons. Scaffolding is an essential component of effective inquiry lessons because it keeps students focused on the target science content and divides the content into manageable bits of information, a process referred to as chunking. The significance of scaffolding for inquiry lessons and the theoretical framework, development, and implementation of the inquiry scaffolding protocol are discussed.

## Introduction

The critical nature of scaffolding for inquiry can be illustrated through a mini-case study involving a secondary preservice teacher, identified as Rachel. Rachel was teaching a lesson on synthesis and single displacement reactions to high school chemistry students. It is the authors' experience that preservice teachers, like Rachel, often teach these concepts using a lecture/slide presentation. First they introduce the generic formula for synthesis and single displacement reactions ($A + B \rightarrow C$ and $AB + C \rightarrow AC + B$). Next, they present the formulas for the actual chemical reactions, $2Fe\ (s) + 3O_2\ (g) \rightarrow Fe_2O_3\ (s)$ and $Zn\ (s) + 2HCl\ (l) \rightarrow ZnCl_2\ (aq) + H_2\ (g)$. Finally, the preservice teacher provides the students with reaction problems that involve the students writing a complete and balanced reaction and then identifying the type of chemical reaction.

Rachel did not want to use such a rote procedure. Instead, she wanted her students to experience and think deeply about synthesis and single displacement reactions. She framed her lesson using the Predict, Observe, Explain (POE) instructional model (Gunstone & Mitchell, 1998; Haysom & Bowen, 2010). The POE instructional model directs students to predict what will happen during a hands-on activity or demonstration, complete the activity and/or make observations, record and analyze the relevant data, and devise a scientific explanation for the results.

Rachel divided her students into groups of three to four. After completing a reaction at one lab station, the students moved to a new lab station with a different set of reactants. The lesson appeared to have all of the components of an effective inquiry experience. The students were presented with a problem (What type of reaction is taking place?). They worked in collaborative groups to complete the activity and discuss the results, and they derived their own explanations for what occurred. However, the students failed to learn the targeted science concepts of synthesis and single displacement reactions.

For example, at lab station #4 the students were directed to take a piece of steel wool (iron, Fe) and ignite it (adding oxygen, $O_2$). First, they placed an evaporating dish on a triple beam balance and then zeroed out the dish. Next, they placed a piece of steel wool in the evaporating dish and determined its mass. Finally, they ignited the steel wool using a Bunsen burner and reweighed it.

After observing the reaction, Rachel anticipated the students would "see" the mass of the steel wool increased and conclude that oxygen molecules in the air covalently bonded with the iron atoms in the steel wool. However, the students did not attribute the increase in the mass to oxygen or identify the reaction as a synthesis reaction. Instead, their explanations focused on macroscopic phenomena such as the steel wool was "on fire," and "became heavier." They offered no explanations for the increase in mass of the steel wool other than some type of "experimental error." A few of the students correctly identified the reaction as a synthesis reaction, but they could not offer a reason for their answer. After the lesson, Rachel met with the university supervisor and commented she was surprised the students did not "get it." It was readily apparent to the supervisor why the students did not explain the concept appropriately—insufficient scaffolding.

Students, experience, observe, and explain the physical world at the macroscopic level. Their practical, macroscopic experience with fire is that when objects burn they fall apart and decrease in mass. For example, when a log is placed on a fire the final product, wood ash, appears and feels less dense than the original log. Subsequently, when Rachel's students were asked to describe what happened during the chemical reaction, they focused on the macroscopic attributes such as the formation of a flame and increased heat. In the context of their macroscopic perspectives, the measured increase in the mass of the steel wool was nonsensical and could only logically be explained as some type of error. In order to provide an accurate scientific explanation of a chemical reaction, which is defined as the rearrangement of atoms and molecules, the students needed to think about the reaction at the molecular level.

Rachel could have guided her students thinking to the correct level by providing them guiding questions. For example, the students could have been prompted to: "Describe how the iron and oxygen atoms interact with each other during the reaction."; or to "Create a particle model

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that depicts the reaction between iron atoms in the steel wool and oxygen molecules in the air."

In our roles as science teacher educators, the authors have had many similar experiences working with preservice science teachers. They commonly submit inquiry lesson plans and teach inquiry lessons that are not adequately scaffolded. In the past, the authors approached the scaffolding issue by pointing out the gaps in the preservice teachers' lessons. Commonly, this process involved the authors sharing their ideas as to how the lesson could be improved with the preservice teacher taking copious notes. Eventually, after multiple one-on-one meetings and additional teaching experiences, most of the preservice teachers developed a sense of how to scaffold inquiry lessons. However, there were always preservice science teachers who consistently struggled to provide appropriate scaffolding in their inquiry lessons. The best we could hope for was that with additional years of practical teaching experience they would develop an intuition for scaffolding inquiry lessons.

## Inquiry Science Instruction

As stated in the introduction, the authors' goal is to present an explicit protocol, Inquiry Scaffolding Protocol (ISP), to help preservice science teachers appropriately scaffold their inquiry lessons. Before we introduce and demonstrate how to use the ISP, the authors discuss the context in which it was developed. First, we discuss our working definition of inquiry science instruction and make a case as to why explicit scaffolding is needed. Second, the inquiry instructional model on which the scaffolding protocol is based is presented. Third, the compatibility of the instructional model with the Next Generation Science Standards (NGSS) is discussed.

### The Nature of Inquiry Science Instruction

The significance of inquiry as an instructional approach is highlighted by its inclusion in the 2014 National Science Teachers Association (NSTA) Preservice Teacher Preparation Standards. Specifically it is stated that, "Preservice teachers will plan multiple lessons using a variety of inquiry approaches (NSTA, 2012)." Additionally, the Next Generation Science Standards (NGSS) state that cross-cutting science concepts, discipline-specific concepts and the science and engineering practices should be integrated and taught through inquiry (NGSS Lead States, 2015). What is less clear in the national standards and the research literature is what constitutes inquiry science instruction (Furtak, Seidel, Iverson, & Briggs, 2012). The diaphanous nature of inquiry makes it difficult to develop a generalizable approach for scaffolding inquiry lessons. Subsequently, the authors reviewed the literature with the intent of developing a definition of inquiry instruction that would (1) incorporate the major philosophical perspectives and (2) be applicable to diverse instructional approaches.

### The Attributes of Inquiry Science Instruction

After reviewing the science education literature, the authors identified three major approaches or paradigms for inquiry science teaching: discovery learning, the call for authentic inquiry experiences, and constructivism. First the imminent educational psychologist Jerome Bruner introduced the idea that students can learn science and mathematics through a process of discovery (Bruner, 1961). When engaged in discovery learning, students develop hypotheses that they use to guide their investigations and to uncover latent mathematics and science concepts.

Second, the biologist Joseph Schwab introduced the paradigm of authentic science instruction (Schwab & Brandwein, 1962). He envisaged that students should be engaged in thinking like scientists and using the equipment that scientists use in their investigations. The goal of authentic inquiry instruction is to have students concurrently learn science content and develop a deeper understanding of how science is done.

Third, is the idea of constructivism that can be parsed into the public or institutional creation of scientific knowledge and the personal construction of scientific knowledge (Driver, Asoko, Leach, Mortimer & Scott, 1994; Novak, 1998). Public or institutional constructivism refers to how scientists construct new scientific understandings of the world. For example, the physicist Ernest Rutherford could not directly observe an atom. Subsequently, he could not discover or find the structure of the atom as if he was an explorer on an expedition (Orzel, 2014). Instead, he devised an experiment whereby invisible alpha particles were directed at a thin sheet of gold foil. A glass window coated with zinc sulfide was placed in various positions around the gold foil. If an alpha particle collided with the coated glass a small blip of light was produced. By comparing the number of light blips and the positon of the coated glass, Rutherford was able to construct a model of the atom. Based on the observable data and some calculations, he was able to infer that atoms are comprised of a dense, compact nucleus surrounded mostly by empty space.

The second constructivist tradition refers to the slow, and often error-filled, process by which individuals learn and retain science concepts. In order to successfully integrate a novel concept into existing schema learners must (a) be aware of their present understandings or conceptual schema, (b) compare differences between their existing schema and new concepts, and (c) modify or possibly replace schema in order to accommodate new concepts (Vosniadou, 2013). The efficiency of this concept integration can be optimized through open discussions among learners and instructors (Vosniadou, 2013).

Using the above information the authors developed the a definition for inquiry science instruction as an approach that (1) probes students' previous knowledge and experiences, (2) provides students with a problem or unknown situation so they can construct their own mental models and explanations, (3) engages students in thinking and discussing science content and (4) involves students using authentic science equipment. The authors contend this definition is applicable to a diverse set of research-based inquiry instructional models including the

3-step Learning Cycle (Atkin & Karplus, 1962), 5-E Learning Cycle (Trowbridge & Bybee, 1990), 6-E Learning Cycle (Chessin & Moore, 2004), 7-E Learning Cycle (Eisenkraft, 2003), Problem-Based Learning, PBL, and Problem-Based Instruction, PBI (Krauss & Boss, 2013), and Predict-Observe-Explain (Gunstone & Mitchell, 1998; Haysom & Bowen, 2010). All of these inquiry instructional models incorporate, at some point, (1) analyses of students' prior knowledge or preconceptions, (2) problem situations whereby students can construct their own mental models and explanations, (3) opportunities for students to apply scientific thinking and (4) situations whereby students can use authentic scientific equipment.

### Scaffolding of Inquiry Lessons

Based on the relative level of scaffolding, inquiry lessons can be classified as open inquiry, guided inquiry or structured inquiry (Furtak, Seidel, Iverson, & Briggs, 2012; Zion & Mendelovici, 2012; Bevins & Price, 2016). Open inquiry lessons emulate an investigation conducted by working scientists. The students are responsible for devising a research question or problem, developing the data collection procedures, and analyzing the research results. No systematic scaffolding is provided in an open inquiry lesson.

Guided inquiry lessons are more scaffolded because the research question or problem is provided by the instructor. The students use the instructor's question to guide the development of their data collection procedures and to analyze the research results. Finally, a structured inquiry lesson is the most scaffolded. The research question and the data collection procedures are established by the instructor and the students are responsible for analyzing the results.

In reality, effective science instructors provide localized scaffolding during open, guided and structured inquiry lessons. For example, during an open inquiry lesson the instructor may conduct a think-a-loud session in order to assist students in the development of more focused and tractable research questions. The research literature in cognitive science and educational psychology indicates this type of localized scaffolding, using written and oral prompts, facilitates student learning and is especially effective when students are learning new content (Lazonder & Harmsen, 2016).

### Why Scaffolding Works

The Information Processing Model (IPM) of Cognition is a widely studied and accepted explanation of human learning (Schacter, Gilbert, Wegner & Nock, 2011). It is an internal cognitive model, but it can readily be integrated with external social learning theories such as Vygotsky's Social Cognitive Theory and specifically the notion of the Zone of Proximal Development (ZPD). Combined the IPM and ZPD effectively explain why scaffolding is an essential component of inquiry instruction (Figure 1).

The IPM explains how students process the information they are presented in the science classroom. First, the student intakes sensory information: visual, auditory, tactile, taste, and olfactory stimuli. Second, the student filters the extraneous stimuli and focuses on the relevant information. Third, the student actively thinks about the sensory data, a condition described as perception. Fourth, the student's working memory processes the information, and if the student is sufficiently engaged, the information is transferred and stored in long-term memory. Finally, by actively reflecting upon the target content and with practice, the student can readily access and apply the information when prompted to do so.

A key factor affecting the integration of science concepts into students' long-term memory is their ability to focus on the relevant information. Students have limited background knowledge and subsequently they are often unable to identify and focus their attention on the relevant information (Brophy, 2010). The issue of how science instructors can help students focus on the relevant information is addressed through Vygotsky's

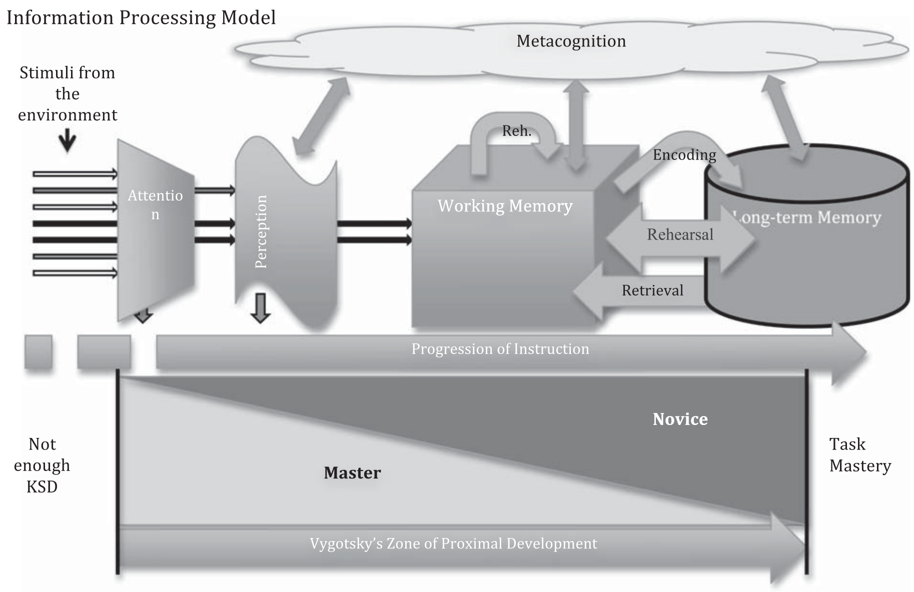

**Figure 1.** Integration of the Information Processing Model (IPM) and the Zone of Proximal Development (ZPD). **(A)** The IPM is the top figure and it depicts how students learn science content. The students intake sensory stimuli, sort through this stimuli to identify relevant information (perception), process this information in working memory, if the working memory is engaged for a sufficient period of time the information is then transferred to the long-term memory, and with additional practice and reflection the target science concept is effectively integrated with the student's thinking. (B) The Zone of Proximal Development (ZPD) model depicts how the student (novice) receives guidance through scaffolding prompts and questions during the initial phases of learning and then gradually the student assumes more responsible for learning the target science concepts.

notion of the Zone of Proximal Development (ZPD).

The bottom half of Figure 1 shows the basic tenets of the ZPD. In the progression depicted, the Novice has deficiencies in some combination of the knowledge, skills, and/or dispositions (KSD) that are prerequisite to progressing toward mastery of the task or learning of interest. At the point when the Novice has acquired the requisite KSD and the Master begins instruction, the two have entered the Novice's ZPD. The roles of Master and Novice are represented opposite each other depicting the gradual release of responsibility for learning through scaffolding from the Master to the Novice (from left to right in the figure.) Ultimately, the Novice will become independent and achieve task mastery.

Combined, the Information Processing Model (IPM) and Zone of Proximal Development (ZPD) explain how information is processed and why it is essential for students to focus on the relevant science content. They also explain why seemingly engaging hands-on science activities may fail to improve students' understandings. Through the process of inquiry, students utilize a variety of skills, gather multiple forms of data, and engage in multiple dialogs with their classmates. As a result, inquiry lessons generate a significant amount of information that students must winnow through in order to learn the targeted science content. The quantity of information can be overwhelming for students and result in cognitive overload (Willingham, 2010). In order to prevent cognitive overload, instructors should scaffold their inquiry lessons by incorporating guiding prompts and questions (Lazonder & Harmsen, 2016). Scaffolding guides the students' thinking and helps them to focus on and process the relevant information.

## The Framework for the Inquiry Scaffolding Protocol (ISP)

### Three Levels of Thought Instructional Model

Johnstone (1991) developed the Three Levels of Thought (TLT) instructional model primarily to explain chemistry concepts, but he indicated it is applicable to concepts in other science fields such as biology and physics (Figure 1). The TLT identifies three levels or scales at which concepts can be described—the macroscopic, sub-microscopic, and symbolic. The macroscopic level refers to the tangible or visible attributes of science concepts. The sub-microscopic level refers to phenomena that occur at the level of atoms or molecules. Finally, the symbolic level refers to the terms, definitions and mathematical formulas that are used to explain a science concept. For example, the concept of a chemical reaction has observable macroscopic attributes (color, temperature and phase changes), sub-microscopic attributes (the arrangement of atoms and molecules) and symbolic attributes (the formulas representing a chemical reaction). The Three Levels of Thought (TLT) has been used to help chemistry teachers develop student-centered lessons (Lewthwaite & Wiebe, 2011). Additionally, lessons based on TLT instructional model have been demonstrated to improve students' chemistry content knowledge and reasoning skills (Dori & Barak, 2001; 2003).

In order to make the TLT instructional more compatible with topics in other science fields, such a biology and physics, Hitt and Townsend (2004; 2007) redefined the sub-microscopic or particle level as the model level (Figure 1). The rationale for this conceptual shift is that (1) models are ubiquitous cognitive and physical tools that are common to all scientific disciplines and (2) the concept of a model can be applied to a broad range of phenomena from the extremely large (ecosystems and galaxies) to the very small (genes and atoms) (Gilbert & Ireton, 2003; Gilbert, 2011). This version of the TLT instructional model has been reported to be an effective tool for training novice science teachers to develop student-centered, inquiry lessons and to improve middle level and high school students' understandings of science concepts (Gilman, Hitt & Gilman, 2015).

### The Three Levels of Thinking Model Version II (TLT-II)

The authors have used the TLT instructional model to train multiple cohorts of preservice science teachers to plan and teach inquiry lessons. Based on our experiences, we have made several modifications to the model in order to make it clearer and more effective (Figure 2). First the triangle is inverted to create a wedge and the model attribute is positioned at the bottom as the fulcrum of the wedge. This change was implemented in order to highlight the critical role that model construction plays in learning science content. For example, an inquiry lesson with too many or too intensive activities distracts students from learning the targeted concepts. This is a phenomenon identified as activitymania (Moscovici & Holmlund-Nelson, 1998). Conversely, focusing too much on terms and definitions results in the students superficially memorizing the information (Willingham, 2010). What is needed to balance an inquiry lesson is ample opportunities for students to reflect and to create their own models and explanations. Through the construction their own models, the students can make connections between the macroscopic attributes (observable properties) and the symbolic attributes (terms and definitions) used to describe a targeted concept (Hitt & Townsend, 2007).

Second, the literature on the psychology and philosophy of mathematics indicates mathematical formulas are more accurately classified as a type of model (Lakoff & Nunez, 2000). Subsequently, the model attributes now refer to the following types of models: propositional models (analogies and metaphors), visual models (analog representations of external phenomena like cartoon models of an animal cell), and mathematical formulas and equations (Johnson-Laird, 1986; Lakoff & Nunez, 2000; Bryce et al. 2015). The symbolic attribute refers specifically to the words and syntax (language) used to communicate science concepts.

Third, a hook question was added to Three Levels of Thinking (TLT) instructional model. The purpose of the hook question is to engage students in thinking about the target concepts and to provide the instructor with information

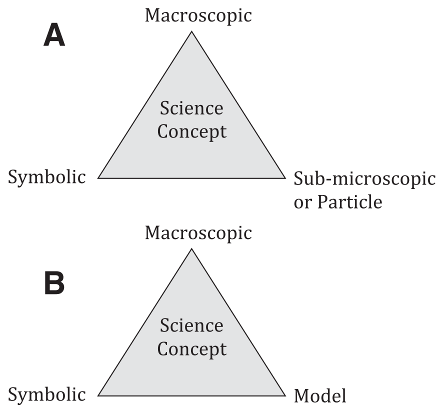

Figure 2. **(A)** The Three Levels of Thought (TLT) concept analysis and instructional model proposed by Johnstone (1991). This model focuses on the physical scale of a science concept. The macroscopic level refers to the observable properties of the target concept such as a color change that occurs during a chemical reaction. The sub-microscopic or particle level refers to the phenomena that are too small to observe directly and subsequently must be represented using a molecular or particle model. The symbolic level refers to the science terms, definitions and formulas used to represent the target science concept. **(B).** The modified TLT instructional model proposed by Hitt & Townsend (2004; 2007). The only difference between this model and the original TLT models is the reconceptualization of the sub-microscopic or particle level as the model level. A model can be a physical representation (3-D model, diagram, etc.) or an image for a phenomenon. This change was implemented to reflect the significant role of models in science research. Additionally, the concept of a model is more applicable to diverse science fields and physical scales. For example a model can be used to explain a phenomenon that is too large (galaxies or plate tectonics) or too small (atoms and molecules) to observe directly.

about the students' existing schema. Finally, the need to provide scaffolding in order to focus students' attention on the relevant macroscopic, model and symbolic attributes is explicitly incorporated in the model.

These modifications to the TLT instructional model do not represent a paradigm shift because the core components are intact. However, the authors believe the changes do significantly alter its appearance and how it used. In order to avoid confusion, the authors refer to the modified version of the TLT instructional model as the Three Levels of Thought Version II or TLT-II.

### The TLT-II Instructional Model & the Next Generation Science Standards

To recap, the authors define inquiry as an instructional approach that meets the following conditions: (1) probes students' previous knowledge and experiences, (2) provides students with a problem or unknown situation so they can construct their own models and explanations, (3) engages students in thinking about and discussing science content and (4) engages students is the use of authentic science equipment. The TLT-II emphasizes the need to provide some type of hook question in order to determine students' prior knowledge and beliefs (condition 1). Next, the students are presented with a macroscopic phenomenon they must investigate, and the students then develop their own models and explanations for what they have observed (conditions 2 and 3). Finally, during an investigation, the students use a variety of scientific instruments and equipment in order to record and analyze the emerging data and to make conclusions (condition 4).

The TLT-II also aligns with the vision of science proficiency espoused in the National Research Council's *A Framework for K-12 Science Education* (2012). Within the context of the *Framework,* science proficiency is defined as understanding science as a continuously refined and revised body of knowledge that is produced through evidence-based and theory building processes (Schweingruber, Keller, & Quinn, 2012). In order to achieve this depth of science proficiency, students need to experience inquiry-based instruction that integrates the disciplinary core ideas, crosscutting concepts, and science and engineering practices (Schweingruber, Keller, & Quinn, 2012, Huff, 2016). The authors contend the TLT-II instructional model is compatible with the three dimensional instructional approach presented in the *Framework.*

First, the TLT-II has been used to create lessons and to improve students' understandings of diverse discipline specific concepts (Gilman, Hitt & Gilman, 2015). Second, the crosscutting concepts can be addressed by having students reflect on the attributes of targeted science concepts. For example, an instructor can have students address the model attribute of a targeted concept through the creation of models that (a) reveal *patterns* in the data, (b) explain a *cause and effect relationship*, (c) display various *quantities*, *proportions* or *scales*, (d) explain the connection between a *structure and its function*, and (e) display trends such as *stability or change* (Gilbert, 2011; Bryce et al. 2015). These crosscutting concepts are inherent in certain types of models. Science instructors can further help students' focus and reflect on these crosscutting concepts through guiding prompts and questions integrated into the lesson.

The NGSS Science and Engineering Practices can also be integrated into the TLT-II instructional model. When students examine and reflect on the attributes of a target concept they are utilizing science and engineering practices. For example, students can be prompted to *ask questions* about and to *investigate* a macroscopic phenomenon. Through the construction of their own models students can be engaged in *analyzing and interpreting data, using mathematics and computational thinking*, and *constructing explanations and designing solutions*. Finally, when students address the symbolic attributes of a target concept they can potentially be *engaging in arguments from evidence* and *obtaining, and evaluating and communicating information*. By creating explicit scaffolding questions and prompts, a science instructor can facilitate students' use and awareness of the relevant Science and Engineering Practices.

## Inquiry Scaffolding Protocol (ISP)

A key factor leading to the successful implementation of the TLT-II instructional model is scaffolding. It is the authors' experiences that the TLT-II instructional model (figure 3) improves the scaffolding in our preservice science teachers' lessons. However, analyses of lesson plans and feedback provided by our preservice science teachers, indicated the TLT-II did not provide enough explicit guidance for developing and scaffolding inquiry lessons. In order to address this issue the authors developed an explicit approach to scaffolding, the Inquiry Scaffolding Protocol (ISP).

The ISP consists of two phases. Phase I-Content Analysis, involves the lesson developers examining their understandings of the macroscopic, model, and symbolic attributes of the target science concepts. Phase II-Instructional Planning, involves the development or selection of an inquiry lesson and evaluating the effectiveness of the scaffolding for the macroscopic, model and symbolic attributes of the target concept.

Prior to introducing the Inquiry Scaffolding Protocol (ISP), the lesson developers should become familiar with the idea of science concepts as categories of information that have macroscopic, model, and symbolic attributes. A useful way of introducing this perspective is to practice analyzing the macroscopic, model, and symbolic attributes of science concepts from different science disciplines. After the lesson developers have a robust understanding of the three attributes of science concepts, they are primed to use the ISP to analyze and develop a variety of inquiry lesson plans and activities.

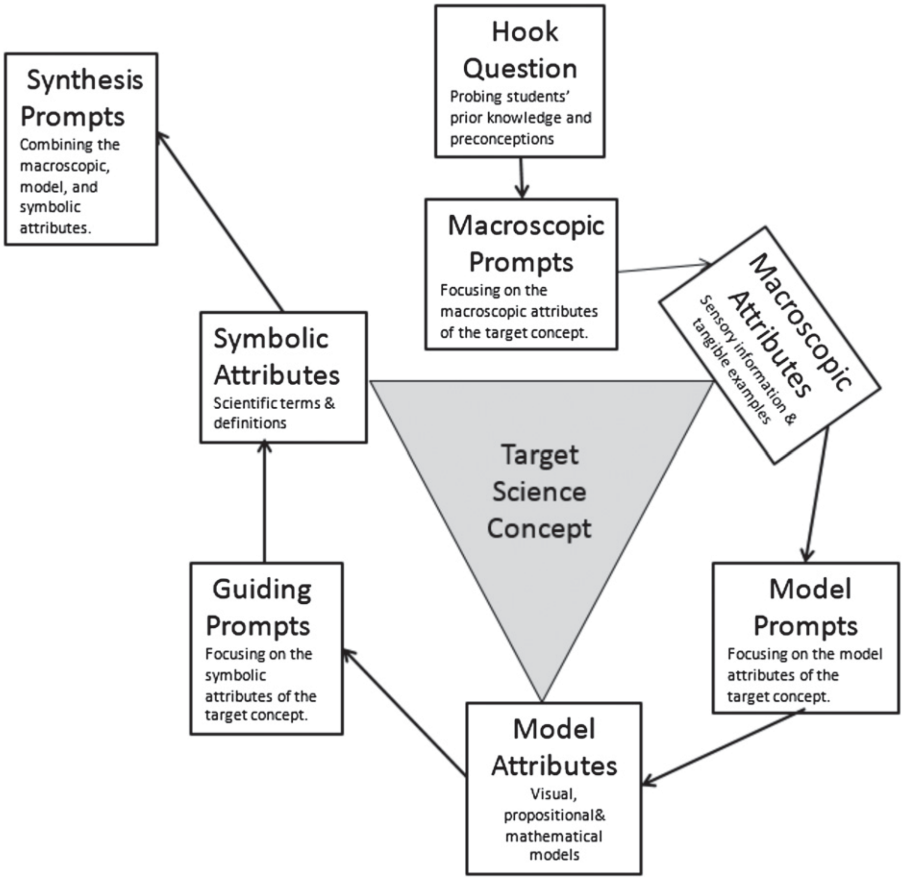

**Figure 3.** The Levels of Thought Version II (TLT-II) as proposed by the authors. The TLT-II instructional model explicitly incorporates pedagogical principles that were implied in the two versions of the TLT instructional model. There are four key differences. First, the instructional model starts with the students answering a hook question designed to probe their understandings and preconceptions of the target science concept. Second, the model attribute of a science concept includes mathematical models that were identified as a symbolic attribute in the TLT model. Third, instruction targeting each attribute of the target science concept is scaffolded with guiding questions or prompts designed to focus the students' attention and thinking on the respective attribute. Finally, a synthesis prompt designed to probe the students' understandings of the connections between the three attributes of science concepts is included. The synthesis prompt serves as a summative assessment for the students' understanding of the target science concept.

In the following sections, the individual steps in the ISP are listed and described. Each step is followed by a description of how the protocol can be applied to an inquiry activity designed to teach students the concept of density.

**ISP Phase I- Concept Analysis**

**Step 1. Identify the target science concepts within the appropriate standards.** The appropriate national, state, or district standards are selected and the target concept or concepts are identified. Additionally, the key action verbs describing the performance and level of understanding the students must demonstrate are noted. This information will be used to guide the development and/or selection of the specific activities related to the target science concept.

> 7.P.2B.1 **Analyze** and **interpret** data to **describe** substances using physical properties (including state, boiling/melting point, density, conductivity, color, hardness, and magnetic properties) and chemical properties (the ability to burn or rust)

*This seventh grade science standard inclu*des 10 concepts related to the nature of matter (South Carolina Department of Education, 2015). *(Each concept is underlined). The action verbs, appearing in bold, indicate the students should be engaged in analyzing and interpreting data in order to describe a substance. Since the target concept is density, the inquiry lesson developed or selected should engage students in analyzing and interpreting data to explain the concept of density.*

**Step 2. Identify the macroscopic attributes of the target concept.** There are two general categories of macroscopic attributes: (1) basic sensory experiences (e.g. color, texture, smell, motion, etc.) and (2) concrete examples and/or applications of the target science concept (Johnson-Laird, 1986).

*Macroscopic attributes of density can include (a) the perceived tactile differences between a cork sphere (light) and an iron sphere (heavy) that occupy the same volume, (b) the visible layering of liquids in a column due to differences in* *density and (c) a 355 mL can of regular soda sinking but a 355 mL can of diet soda floating in tap water due to differences in density.*

**Step 3. Identify and construct <u>models</u> for the target concepts.** Different types of models representing the target science concepts are identified or created. Models can include visual models (simplified images for the target concept), propositional models (analogies and metaphors or simple, non-technical explanations) and mathematical models (numbers and variables) (Lakoff & Nunez, 2000). If possible, the target concepts should be represented through multiple models. This is especially true for concepts such as *density* that are commonly represented using mathematical models. Mathematical models are the most abstract type of model and are the most difficult for students to connect to their existing schema. Presenting students with more tangible visual and propositional models prior to introducing the mathematical models enhances their ability to integrate and retain the mathematical models (Gilbert, 2011).

*The concept of density can be represented visually using particle models that depict equal volumes of two different solids, liquids or gases consisting of different quantities of particles or different sized particles. (The greater the number of particles or the more massive the constituent particles the greater the density). An example of a propositional model is a thought experiment involving the placement of a 1kg bag of feathers and a 1 kg block of lead in a container filled with water. The bag of feathers occupies a greater volume than the lead block and is less dense. The differences in the densities explains why the feathers float on water while the lead block immediately sinks. Finally, density can be represented using the algebraic expression of D=m/v.*

**Step 4. Identify the <u>symbolic</u> attributes.** The relevant scientific terms and definitions used to describe a target science concept are identified.

*The terms connected to the concept of density include: mass (the relative amount of matter in an object or material), volume (the amount of space a substance occupies), and density (the ratio of mass to volume of a specific substance).*

**Phase II – Instructional Planning**

**Step 1. Create or identity an inquiry lesson or activity for a target concept.** Once the lesson designers have a robust understanding of the target concept they are primed to develop or select inquiry lessons that will effectively teach students the target science concept(s). An original inquiry lesson plan based on the TLT instructional model or other instructional models such as the Learning Cycle, Predict-Observe-Explain and Problem-Based Learning (PBL) can be created or an existing lesson can be selected.

*For example, the lesson developer may select a 5-E Learning Cycle lesson designed to teach students the concept of density through the process of constructing a clay boat. First, the students answer a hook question about density **(Engage Stage)**. Next the students investigate how they can construct a clay boat that will float on water **(Explore Stage)**. The students are provided with a clay sphere. They weigh the sphere and measure its volume and record the data in their science notebooks. Next, they place the clay sphere in a container filled with water and observe what happens; it should sink immediately. The students then manipulate the clay sphere in order to create a structure that will float. The students may have to try several designs. Once they have produced a clay boat that floats, they record its volume. The mass of the clay remains constant throughout the activity.*

*The students record the masses and the volumes of the clay spheres and their boats in a class data table. Next, they examine their data (qualitative observations and quantitative measurements) in order to devise a model that explains why the clay sphere sinks and their clay boat floats (**Explain Stage**). Then, students pool their data in a class data table, identify any trends in the data, and use this information to confirm of modify their model/explanation for sinking/floating (**Elaborate Stage**). At this stage of the activity the students are also prompted to explain how the relationship between mass and volume relate to density. Finally, the students respond to an open-ended question that reveals their relative understanding of the concept of density **(Evaluation Stage)**.*

**Step 2. Analyze the hook question.** An effective hook question probes both the students' relative understanding of the macroscopic, model, and the symbolic attributes of the targeted science concepts. If a hook question is ineffective, it can be modified, or a new one can be inserted into the activity. An example of an effective hook question targeting the concept of density is provided below:

> *Cargo ships are comprised of many steel sheets and carry tons of cargo across the world's oceans. However, if you were to take a single steel sheet from a cargo ship and drop it into the ocean it would sink. **(macroscopic attribute)***
>
> *(a) Create a diagram and write a non-technical explanation for why a single steel sheet sinks but a cargo ship comprised of thousands of steel sheets floats. **(model attribute)***
>
> *(b) If possible, use the terms density, mass and volume to explain why a cargo ship floats but a single steel sheet sinks. **(symbolic attribute)***

**Step 3. Analyze the macroscopic prompts for the target concepts.** The macroscopic attributes of a targeted science concept are identified. For each inquiry activity the guiding prompts should focus students' attention on the relevant macroscopic attributes of the target concept. If no prompts are present or if the prompts are ineffective, new prompts should be created.

*For the clay boat inquiry lesson, prompts effectively targeting the macroscopic attributes of density during the **Explore Stage** can be: "What are the two properties of matter that you will measure during this activity?" and "How do you think these properties affect sinking and floating?"*

**Step 4. Analyze the model prompts for the target concepts.** The model prompts should direct students to (a) develop different types of models (propositional, visual, or mathematical) and (b) discuss their models and ideas with their classmates. If no prompts are present or if the prompts are ineffective, new prompts should be created.

*For the clay boat activity, the students can be directed to create a diagram that depicts how mass and volume relate to sinking and floating. The students can then discuss their models with their classmates and record any new information they gleaned from their discussions.*

*Next, the students can create a mathematical model by analyzing the class data. For example the students could be asked to, "Compute the mass to volume ratios for the clay spheres and clay boats. Use these data to explain the pattern of sinking and floating." The students can discuss their ideas with their classmates and to record any new information they gleaned from their discussions.*

**Step 5. Analyze the symbolic prompts for the target science concept.** The symbolic attribute prompts are designed to (a) introduce the relevant scientific terms and definitions and (b) help students connect the language of science to their macroscopic experiences and models. As stated previously, if no prompts are present or if the prompts are ineffective, new prompts should be created.

*In the context of the clay boat activity, the key terms are density (ratio of mass to volume), mass (amount of material comprising an object), and volume (the space an object occupies). The students should respond to prompts designed to help them make connections between both the symbolic terms and definitions and macroscopic experiences and mental models. For example the students can be directed to, "Explain why the clay boat floated and the clay sphere sunk using the terms, density, mass and volume."*

**Step 6. Analyze the macroscopic, model and symbolic synthesis prompts.** The last part of the lesson should consist of prompts designed to assess the students' ability to connect their macroscopic experiences, models, and the symbolic terms and definitions for the target. The synthesis prompt constitutes the summative assessment. If a synthesis prompt is not included in the lesson one should be added. A sample synthesis prompt for the concept of density is provided below:

> *You observe a glass column that has 4 liquids inside. The liquids remain in distinct layers due to differences in density.* ***(macroscopic)****.*
>
> *(a) Create a particle diagram that explains the layering of the liquids in the column.* ***(model)***
>
> *(b) Explain why the liquids remain in separate layers. Include the following terms in your explanation, density, mass and volume.* ***(symbolic)****.*

## Conclusions

The authors have used the Inquiry Scaffolding Protocol (ISP) with multiple cohorts of middle level and secondary preservice science teachers. Subsequently, we have gleaned several benefits to using the ISP. First, the ISP provides the preservice teachers an explicit set of procedures for scaffolding inquiry lesson plans. As a result, the quantity and quality of scaffolding within the preservice science teachers' lesson plans increased. Specifically, the preservice teachers tend to include more explicit questions that focus the students' attention on the target science concepts and provide clearer directions for students.

Second, the ISP improves the location and quality of prompts within preservice science teachers' lesson plans. Prior to using the ISP, a majority of the lesson plans produced by our preservice science teachers consisted of (a) a brief introduction, (b) a set of procedures for completing the activity and recording the data, and (c) a set of summary questions designed to connect the lab or activity to the appropriate scientific terms and definitions. Generally, the preservice teachers' lessons provided minimal or no guiding questions during the lab or activity. Also, the summary questions were commonly disconnected from the lab or activity and could be answered by simply reviewing the glossary or specific pages in a science textbook. However, the preservice teachers who use the ISP, generally incorporate more guiding questions and prompts throughout their lessons. Additionally, the summary questions tend to require students to use information obtained during the lab or activity in order to answer the questions. Often, the summary questions require students to use information from both the lab/activity and the textbook.

Finally, the ISP facilitates the development lessons incorporating a reasonable number of novel concepts. Prior to using the ISP, the preservice science teachers tended to plan lessons that contained a relatively large number of concepts. As a result, their lessons often overwhelmed or cognitively overloaded the targeted middle level and high school students. Conversely, when the preservice science teachers use the ISP, their lesson plans and classroom instruction focus on fewer concepts. It is the authors' view that the analysis and reflection on the macroscopic, model, and symbolic attributes of the target concepts increases the preservice teachers' awareness of the complex nature of science concepts. Subsequently, they become aware that they need to (a) reduce the pace of their lessons/instruction, (b) cover fewer concepts per lesson, and (c) provide students with sufficient time and opportunities to integrate the targeted science concepts into their existing schema.

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