Generating Testable Questions in the Science Classroom:
The BDC Model

SHU-BI CHEN, CHING-MEI TSENG AND WEN-HUA CHANG

ABSTRACT
Guiding students to generate testable scientific questions is essential in the inquiry classroom, but it is not easy. The purpose of the BDC (“Big Idea, Divergent Thinking, and Convergent Thinking”) instructional model is to scaffold students’ inquiry learning. We illustrate the use of this model with an example lesson, designed to help 5th-grade students understand the concept of plant growth. The BDC model functions as an exploration of, and a connection with, related information among students’ scientific knowledge, skills, and practice, so that students can further generate research ideas. Students are able to more easily formulate testable questions and are also highly motivated throughout the course of their inquiry practice. This instructional model provides teachers with a practical and meaningful tool, one that increases students’ capabilities to formulate researchable questions and sustains their motivation to engage in activities of scientific and creative inquiry.

Key Words: Divergent thinking, convergent thinking, inquiry learning, visualization; plant growth.

Guiding Students to Formulate Questions

Scientific inquiry begins with questions and questioning, which influence the quality and direction of the research. The ability to pose questions has also been identified in the Common Core state standards and the Next Generation Science Standards as essential to preparing students for advanced education and the future workforce (D’Costa & Schlueter, 2013; NGSS Lead States, 2013). Posing questions also stimulates students’ motivation and thus helps them achieve meaningful learning (Chin & Osborne, 2008). Krajcik et al. (2003) noted that in the inquiry-learning classroom, questioning by students needs to be integrated into the instruction in order for meaningful scientific learning to occur.

In practice, students tend to formulate questions that are loosely associated with the content and purpose of the curriculum. They usually determine variables intuitively, rather than considering the causality among the variables. In our example, from a 5th-grade seed-germination investigation unit, the BDC (“Big Idea, Divergent Thinking, and Convergent Thinking”) model functions as an exploration of, and a connection with, related information among students’ scientific knowledge, skills, and practice, so that students can further generate research ideas. Before the BDC instruction, students tend to ask questions simply concerning “facts” (e.g., Why does a seed germinate?) and questions that lack refined variables (e.g., Does the environment affect seed germination?). After the instruction, students’ questions are transformed into mostly inquiry-based questions that comprise more operational variables (e.g., To what extent does the depth at which a seed is buried in soil affect seed germination? Do different pH values of the water affect seed germination?). Students’ ideas are represented in writing activities, and visualizations and creativity are used to stimulate learners’ thinking and presentation. This focus facilitates the development of skills for organizing information. In addition, students generate more new ideas, since writing plays the role of interacting with the environment to effect meaningful learning (Bereiter & Scardamalia, 1987).

The BDC Instructional Model: Stage-by-Stage

The BDC model consists of three stages: identifying big ideas, using divergent thinking, and using convergent thinking. The model is intended for elementary science teachers to use in their science classrooms. Each stage begins with an overview of its purpose, followed by an introduction to the students’ artifacts for the classroom activities during each stage.
Suggestions on how to support and guide the students as they practice are also provided.

**Stage 1: Identifying Big Ideas**

The “big idea” is the main theme to be introduced to the students. This theme is usually grounded in the national benchmarks/standards and further transformed into kid-friendly language in classroom practice. On the basis of the big idea, teachers come up with corresponding instructional techniques. With the big idea identified, students are able to form adequate, focused thinking spaces to conduct learning activities. In the plant investigation, for example, the purpose of the lesson is to understand how the environment affects, or regulates, plant growth. The big idea here is the interactions between the environment and plant structures that influence plant growth. In this lesson, students learn to associate environmental conditions, such as air, sunlight, and water, with plant growth.

**Stage 2: Using Divergent Thinking**

The purpose of this stage is to boost students’ divergent thinking by visualizing the brainstorming process. Students’ thoughts are frequently limited before they recognize the range of ideas and possibilities. The visual tool (Figure 1) was modified on the basis of a divergent creativity strategy, the Mandala strategy (今泉浩晃, 1987). This three-by-three grid acts as an enclosed thinking space. The main concept is in the center, surrounded by eight related ideas or conditions. For example, seed germination is placed in the center of the three-by-three grid, and the other eight wells are reserved for students to generate as many related elements as possible. In our example, students fill in the surrounding wells with the following possible elements: air, sunlight, water, temperature, depth in soil, nutrients, water quality, and soil (Figure 2).

**Stage 3: Using Convergent Thinking**

In order to further make sense of the ideas generated from the divergent thinking activity, the convergent thinking stage is used to screen and select useful and appropriate ideas. When students first come up with ideas related to the main concept, they might not yet thoroughly understand how to connect them to the sequences of science learning activities. When teachers specify concrete materials or interrogative prompts for further exploration and reasoning, students are invited to select ideas, screen the feasible conditions, convert their hypothetical thoughts into manageable tasks, and finally generate testable variables based on their own interests. Students are then asked to write down one or more testable questions based on “the malleable variable” and “the measurable variable.” For example, when introducing seed germination, teachers provide various seeds, containers, soil, or facilities for refrigeration and lighting to stimulate discussion of the conditions and characteristics of the germination of seeds. Alternatively, the teacher may ask a prompting question, such as “Is light an important trigger for germination?” or “Do green beans and soybeans germinate under the same conditions?” Such questions can assist students with associating, organizing, and elaborating their thoughts. Table 1 is a template that briefly summarizes the suggestions for both teachers and students to consider in applying BDC during the whole process.

The benefits of this activity are as follows:

1. The technique is intuitive and playful. Students are able to understand, employ, and apply what they do in the activity to their scientific learning, without spending extra time to learn how to do the activity itself. Students’ thinking and learning...
processes are thus enhanced, since their natural inquisitiveness is inspired.

2. The three-by-three grid not only provides a vivid visualization tool but also produces appropriately challenging levels. When students are learning with this tool under reasonable guidance, sufficient thinking spaces are also created. This also allows feasible curriculum design and time management.

3. The grid provides a logical visualization structure that guides the students’ thought processes as they transform their implicit ideas into explicit ones. Teachers are thus able to provide timely guidance based on students’ original ideas and prior knowledge.

Our example illustrates the structure and function of the model and the way this instructional model works. It provides an adequate description of both the teachers’ instructional strategies and the students’ development of competencies necessary in scientific inquiry.

○ Conclusions & Implications

Generating testable questions that can be investigated empirically is essential to the pursuit of advanced knowledge and skills. Developing this ability also increases one’s science literacy and understanding of the nature of science (NGSS Lead States, 2013). Teachers ought to encourage students to conduct various and creative inquiry activities. Our various studies of the BDC in different student populations make us confident that this model has great potential to increase students’ competencies necessary in scientific inquiry.

This process creates a sound basis for encouraging students to test different dependent variables and makes it possible to conduct multiple comparisons across variables and conditions. Toward the end of the activities, teachers can challenge students by asking follow-up questions, such as “Where do the nutrients come from during germination?” In seeking the answer, students link the inquiry activities back to the big idea, “The interactions of the environment and the structures of plants affect plant growth.” Our instructional model can also be extended to a larger scale, based on the practice teaching and learning activities. For example, one extended topic could be “What are the factors that influence plant growth?” These classroom dialogues are expected to extend from and reflect on students’ prior knowledge to deepen their understanding of continuation issues.

This model can be used as a template or a guideline not only for addressing a newly designed lesson but also for aligning lesson goals with those of existing curricula.

Guiding students in generating testable questions might require additional effort; however, providing such guidance helps students gradually transform their focus on not only learning outcomes but the learning process, which is often ignored in the science classroom. When the visual tools/frameworks are integrated and the ownership of learning is returned to the students, they are stimulated and motivated. This also better aligns classroom activities with the nature of science and scientific inquiry. Ultimately, embedding this BDC model in the inquiry practice will promote scientific thinking and reasoning, as well as metacognition, whereby learners become aware of the basis of their thought processes and are able to monitor their learning more explicitly.

Table 1. Template of the BDC model for teachers and students.

<table>
<thead>
<tr>
<th>A Plan for Teachers</th>
<th>A Plan for Students</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identifying the Big Idea</strong></td>
<td><strong>Identifying What Is Known</strong></td>
</tr>
<tr>
<td>Exploring students’ understanding through students’ concept mapping.</td>
<td>Students are actively generating their concept.</td>
</tr>
<tr>
<td><strong>Using Divergent Thinking</strong></td>
<td><strong>Using Mandala Thinking Strategy</strong></td>
</tr>
<tr>
<td>Encouraging students to transform implicit ideas into explicit key words that are related to experimental design. Asking students to place the main idea in the center and fill in one blank well.</td>
<td>Excessively forming related key words based on the main topic. Continuously filling in the remaining blank wells in the three-by-three grid, until reaching the maximum possibilities.</td>
</tr>
<tr>
<td><strong>Using Convergent Thinking</strong></td>
<td><strong>Making a Plan</strong></td>
</tr>
<tr>
<td>Guiding students to choose one of the ideas/conditions from the previous divergent thinking as the initial experimental variables. Providing necessary equipment and facilities or asking students to prepare desired ones to instigate further learning.</td>
<td>Students proposing a testable variable. Transforming abstract ideas into concrete experimental objects. Writing down “the changeable variable” and “the measurable variable” from the experiment. Composing the above changeable and measurable variables into a testable question.</td>
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References


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