The notion that mathematics is a set of rules and formalisms invented by experts, which everyone else is to memorize and use to obtain unique, correct answers, must be changed.

Thomas Romberg, 1992

DISCOURSE AND QUESTIONING FOR HIGHER-ORDER THINKING

The National Council of Teachers of Mathematics indicates that classroom discourse about math, or "the ways of representing, thinking, talking, agreeing, and disagreeing" is central to helping students develop mathematical understanding and skills.[1] The development of higher-order thinking cannot be achieved without teachers asking a variety of questions to challenge students' thinking—questions that require more than factual recall. The time teachers allow for the students to formulate answers is also important.

Effective teacher questioning contributes significantly to student learning. Achievement improves when students are asked higher-level questions.[2] Unfortunately, higher-level questioning is not happening often enough in American classrooms.

Issues

- The research of Watson and Young found that teachers ask as many as 50,000 questions a year.[3] At least 80 percent of them require only simple, general recall of information.[4]
- Teachers ask questions of students at the rate of two or three per minute.[5] The period of silence that follows teachers' questions is often referred to as "wait time." Wait time is a key component in soliciting student responses to all forms of questions asked in class. A study of wait time found that if student replies were not given within *one second*, the questions were repeated, rephrased, or answered by someone else. If students did respond quickly enough, the teacher then replied immediately by asking another question or responding to the given answer.[6]

When wait times were increased to *three seconds* or longer the following aspects of children's and teachers' conversations increased as well:

- The length of student responses
- The number of unsolicited, relevant responses from students
- The number of student questions and the amount of speculative thinking
- Student confidence
- The use of evidence in student responses
- The contributions by low-achieving students
- The creativity of responses

- A *learning cycle* is a method of organizing instruction that closely resembles the way people spontaneously construct knowledge. It typically follows four stages, which are similar to the common lesson patterns of math teachers in Japan.[7]:

1. The teacher poses a complex task and asks questions that pique students' curiosity and motivate them.
2. Students explore the problem alone, in pairs, or in small groups.
3. The teacher pulls the students back together to summarize their findings.
4. Students apply their learning to similar problems.

American math teachers focus more on skill acquisition than on understanding:[8]

1. The teacher instructs class in a concept or skill.
2. The teacher solves example problems with class.
3. Students practice on their own while teacher assists individual students.

- Researchers from the University of Wisconsin were among the first to demonstrate that students learn more at schools where the teachers adopt more "authentic" math and science teaching practices.[9] The cluster of practices the researchers brought to the schools included student-centered knowledge development; disciplined inquiry into and communication about learning; and explicit connections of student, learning, and the world outside school.
- Explaining the reasons behind math and science concepts and ideas happens too infrequently. About 20 percent of Ohio math and science teachers report that they explain the reasoning behind ideas in every math lesson they teach. Fifty percent claim they explain the reasoning most of the time and 30 percent only some of the time. Twelfth-grade teachers are the most likely to explain ideas most or all of the time.[10]
- Ohio math and science teachers are much more likely to ask older students to work on problems for which there is no obvious solution.[11]
- Teachers must be conscious of their questioning practices in order to plan effective ways to stimulate and develop student-thinking skills.[12] Of equal importance are the level of the question and a well-designed sequence of questions with a focus on student responses.

Routes

Many new curriculum projects, in both mathematics and science, reinforce the learning cycle concept in their teacher support materials. The investigative nature of the tasks, supported by the questioning skills of the teacher, helps students develop and refine their thinking skills. Teachers are encouraged to pose questions that ensure worthwhile student activity and lead students to explore a concept or explain their thinking.

Several types of questions have the capacity to increase the cognitive level of student responses and shift the environment from one of "show and tell" to one of inquiry and discussion:

- Reasoning questions require students to construct logically organized information, e.g., "How do you know?" "What would happen if...?"
- Open questions allow for more than one acceptable answer, e.g., "Tell us everything you notice about ...."
- Interpretive questions focus on applications, relationships, connections, or evaluations and lead students to analyze facts, e.g., "How would this be different if..."

Certain techniques have proven valuable for increasing student participation and learning. *Think-pair-share* is a teaching strategy that gives students the opportunity to reflect individually before sharing their thinking with a partner—or within a small group that then shares its ideas with the whole group, listening to, paraphrasing, and comparing other group solutions to its own. This process complements a learning cycle approach.[13]

The following strategies can help teachers improve the effectiveness of their interactions with students:

- Use precise language.
- Acknowledge all responses.
- Paraphrase student responses to acknowledge them.
- Rephrase questions rather than repeat them.
- Use nonspecific praise sparingly.
- Acknowledge student performance by giving specific feedback.
- Ask students to "think about their thinking."
- Encourage students to ask questions of you and other students.
- Consciously plan for productive interaction
- Allow sufficient wait time after asking a question.

A relationship exists between the amount of wait time and the level of the question asked. Lower-level (fact-oriented) questions need shorter wait times than those requiring more thought from students. Moreover, as wait time increases, the number of higher-level cognitive questions that teachers ask increases as well. Some students are ready to respond quickly. They should be acknowledged, but wait time should not be curtailed. This will give more students the opportunity to engage in mathematical thinking.

Facilitating questioning and thinking skills in the classroom is an art that, with effort, develops over time. When teachers ask for explanations or follow-up responses, students have the opportunity to process and describe their own thinking. This process not only provides necessary support for student learning but also helps teachers assess student knowledge. Understanding student thinking provides necessary information for carefully planning follow-up questions and activities to move students' learning forward.

Adapted from *Minnesota K-12 Mathematics Framework,* SciMath[MN], St. Paul, MN, 1998

Endnotes

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