Teacher's Guide

for the Quantum Tutors

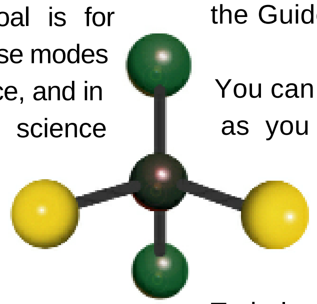
Connie M. Moss, Ed.D.

Introduction

The most effective science education gives students the chance to observe, engage, invent, or discover expert strategies in context. In this way, learning experiences move students beyond the mechanistic learning of the processes of science to the development of attitudes and dispositions toward inquiry.

Inquiry has always been the driving force behind science. Since the dawn of time, humanity has sought to bring order to the natural world by looking for patterns to make sense of the world around us, and in doing so has generated an enormous body of knowledge. This seeking of order is a uniquely human endeavor. Science and mathematics formalized this seeking of order and developed systems of reasoning and logic, rules of evidence, and means of verification and revision.

Quantum's overarching educational goal is for students to learn, practice, and adopt these modes of investigation in their everyday existence, and in doing so to become not just better science students, but better thinkers and learners. We want students to develop a disposition toward inquiry — a disposition that will enable them to develop more nuanced understandings about the world that are grounded in reason and evidence.



To make our goals a reality, we are partnering with teachers around the nation who are working daily to awaken the scientific thinker that lies within each and every student. We have developed this Teacher's Guide for the Quantum Tutors to share our underlying beliefs and assumptions about teaching and learning. We hope that it will help you understand not just how the Tutors work to support effective teaching and learning, but why the Tutors function by design in the way that they do.

In this Guide you will find an executive summary of the relevant educational research, learning theories, and effective classroom practices that support the Tutors' design. What's more, the information makes explicit the many "value added" features of the Tutors for increasing not only content knowledge, but also productive habits of mind. We hope that you will find the Guide to be both valuable and informative.

You can visit this resource at any time and revisit it as you develop experience with and questions about your students' learning, thinking, and understanding relative to the Quantum Tutors.

To help you make the most of each visit, the Guide is organized in a "Q&A" format.

How do the Quantum Tutors differ from conventional computer software programs?

Whenever we approach a new form of technology, we are often hampered by a "delusion of familiarity." That is, we tend to make sense of something new by imagining that it is just like something more familiar. In the case of the Quantum Tutors, you will be tempted to conceptualize them as conventional computer programs in which students simply select the final answers to problems through multiple-choice questions, with the computer either reinforcing correct answers or highlighting incorrect answers.

In reality the Quantum Tutors boast three important distinctions:

1. *The Tutors can create a worked-out solution with detailed explanations for any problem entered by the student or teacher.* While some example problems are provided with the Tutors for convenience, no problems are "pre-stored" in the system, and students and teachers can enter any problem they create or encounter.

2. *The Tutors are truly interactive.* The Tutors can interactively answer a variety of detailed questions and provide detailed explanations for you at each step in the solution.

3. *Several of the Tutors permit you to enter your own work in detail one step at a time,* rather than simply picking an answer from a multiple-choice list. The Tutors do much more than just tell you whether your answer is right or wrong — they give you feedback and advice, such as why your answer must be right or why it cannot be right.

This level of sophistication is simply not practical in a conventional, non-intelligent software format like Computer Assisted Instruction (CAI) programs. Furthermore, this type of intimate, personal, and thoughtful level of explanation is impossible with even the best non-interactive media like textbooks and workbooks.

How do the Quantum Tutors honor the latest research on inquiry learning and effective science curricula?

In its National Science Education Standards, the National Research Council [NRC] (1996) states, "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science." National standards emphasize the investigative nature of science and the importance of students' active engagement in the construction of scientific ways of knowing and doing (American Association for the Advancement of Science [AAAS], 1993; NRC, 1996).

The Tutors embody the essential traits of inquiry into their design and throughout the learning experiences that they foster for students. One of the most important ways that the Tutors support student inquiry is through recognizing the role of the student's prior knowledge.

What role does prior knowledge play in scientific thinking and inquiry and how do the Quantum Tutors help students to activate prior knowledge?

Each student brings a unique set of observations and experiences to the tasks of learning chemistry. In science inquiry, a student must link his/her personal science theories with the generally accepted concepts of the science community. For a student to evaluate the match between his/her current ideas and those accepted by the science community, the student must first discuss his/her understanding with others (Driver, et al., 1994a, 1994b; Vygotsky, 1962, 1978), and then actively explore the phenomenon, gaining a more accurate or deeper understanding of it.

To prompt this process, the Tutors are designed to allow the student to direct his/her own learning or inquiry by asking the questions from a menu that matches his/her current understanding. This is where the Tutors begin — where the student has a level of understanding. The Tutors use further prompts to pull a student's thinking beyond his/her current level of understanding, which helps the student rethink existing understandings, to wonder why, to ask questions, to form hypotheses, and to make explicit connections (Saul & Reardon, 1996).

Finally, the Tutors support the learning of students who have limited understanding and sketchy, limited, or missing prior knowledge. By allowing students to move from what they know — even if they know very little — the Tutors help students construct knowledge that can be activated in the future.

How do the inquiry-based experiences with the Quantum Tutors enhance what goes on in the classroom and in the textbook?

"People have to construct their own meaning regardless of how clearly teachers or books tell them things," state the writers of Benchmarks for Science Literacy (AAAS, 1993). Because inquiry as a learning process is both active and rigorous, it can significantly enhance the students' understanding of science concepts. Inherent in the notion of inquiry is the understanding that students learn not just from giving the correct answers, but also from grappling with difficult concepts and perhaps taking a wrong turn along the way.

But for inquiry to have the most effective impact on student learning, it must be built on accurate and substantive knowledge in the field and progress in logical development. Along the way, inquiry should help students integrate additional and more sophisticated ideas and concepts.

During inquiry learning experiences, the student takes increased control of his/her own learning through the guidance of the teacher, or in this case, the Quantum Tutors. The student asks questions and seeks meaningful solutions. The student designs and conducts active investigations, and thinks critically and reflects on prior misconceptions. During inquiry the student can revisit difficult concepts to note his/her new understandings and clear up misconceptions.

In traditional instruction that emphasizes lecture and individual seatwork, teachers often discourage student interruptions for questions, and in doing so decrease the likelihood that they will foster critical thinking. Furthermore, since students might not feel comfortable repeatedly interrupting a teacher to seek clarity, student misconceptions can go undetected even with the best, most attentive teachers.

Moreover, students are often paralyzed by the threat of appearing stupid or confused in front of their peers. They will struggle on with inaccurate or incomplete understanding, rather than risk perceived embarrassment in front of their classmates. For these students, the Tutors provide an optimal environment for constructing meaningful and accurate interpretations of important concepts, processes, and procedures.

What kind of inquiry produces the most effective learning outcomes?

As with any effective learning process, inquiry alone, activity alone, without guidance or connection to meaningful content, can become "mindless" involvement. For any active experience to be meaningful it must move beyond a "hands-on" activity, to a "mind-on" activity. That is to say, active learning is a state of mental engagement, not just a state of physical engagement. For example, a student may be involved in manipulating chemicals or models and have a great deal of fun doing the activity, but without gaining important skills, content, or scientific attitudes.

For learning to have a significant impact — for it to be meaningful — research tells us that learning must be embedded in a purposeful pursuit. In other words, minds are turned on to learning when the student is mentally engaged with a concept or phenomenon (Hiebert, et. al., 1996). Activity alone does not guarantee good inquiry. In fact, the literature on inquiry-based science clearly tells us that guided inquiry techniques need to include collaboration, access to many written and electronic sources, and, most importantly, focused conversations with science experts, teachers, and mentors for the purpose of concept construction.

School districts across the nation have been influenced to adopt curricula based on national standards and statements about what scientifically literate Americans should know and be able to do.

More than ever before we are coming to realize that certain mental habits — dispositions — help effective students do science. That is why there is general agreement among educators, educational theorists, and professional scientists on the importance of the essential traits of science inquiry (AAAS, 1993; NRC, 1996).

The Quantum Tutors work with national standards to produce scientifically literate Americans — students who not only reach the correct answers, but more importantly, are able to ask the good questions, even when they are at a very basic level of understanding. One way that the Tutors promote this is through guided inquiry by modeling and prompting detailed questions.

Why were the Quantum Tutors designed to answer detailed questions at each step in the solution?

The ability of the Tutors to propose and answer questions makes it possible for students to conduct exploratory and guided inquiry even before they can attempt the problems. Think about the advantage of this design decision. Beginning- and lower-performing students do not have enough prior knowledge to make any start on a problem. Other students with limited understanding or gaps in understanding do not feel comfortable attempting an unfamiliar problem, while still other students might be unable to articulate their questions or lack of understanding to the teacher.

Quantum's Tutors engage students in significant learning and inquiry regardless of their level of proficiency with a topic, concept, process, or procedure. That is because the Tutors scaffold the students' ability to approach a problem by displaying relevant scientific questions at each step in the solution process in a menu that the student can choose from as needed. Students may select as many or as few questions as they desire. Since each student directs the inquiry through his/her selection of the question(s), many different paths of inquiry are possible for the same problem.

What level of inquiry do the Quantum Tutors model?

The inquiry supported by Quantum's complement of Tutors is highly targeted and context-specific. Not only do the Tutors model good scientific thinking about the problem domain and underlying concepts, they also foster the development of the student's own self-explanation and question-asking abilities.

The Tutors provide support on several different levels, from initial "hand-holding" to advanced conceptual questions. Even when students can pose basic questions during inquiry, they may not realize the relevance or importance of those questions to the overall solution. For both the struggling and the proficient student, this type of modeling is critical to building productive habits of mind.

How do the Quantum Tutors support the productive habit of scientific inquiry through the selection of questions they provide at each step?

The first inquiry skill students need to learn is that of asking questions. Young children seem to have a never-ending supply of questions. Older students, on the other hand, rarely ask questions, preferring instead to let their teachers perform this duty. They are more accustomed to providing memorized answers to questions asked by teachers. It can be safely said that this behavior is shaped by the tendency of the educational system to be instructionally focused.

The consequence of this conditioning process is well established in most learners once they have spent a few years in school. Unfortunately, it can significantly interfere with their ability to formulate questions and conduct self-directed investigations. Teachers interested in promoting inquiry have a challenging task to overcome the tendency of many older students to become passive. The approach that the Tutors take, therefore, works hand in hand with teachers dedicated to turning the corner in their classrooms as they seek to engage their students in active thinking, problem solving, and scientific inquiry.

How do the Quantum Tutors help students to conceptualize the abstract process of learning chemistry?

Students often have difficulty constructing effective representations (mental models) of abstract and unobservable chemistry concepts such as atoms and molecules. When students are unable to formulate these understandings, they suffer significant learning impediments (e.g., Garnett, Garnett & Hackling, 1995; Nakleh, 1992) that limit their ability to think critically and scientifically.

That is why the Tutors' design goes beyond traditional instructional models and places fully formed knowledge in the learner's path. In this way, the Tutors scaffold understanding, model problem-solving strategies and increase student ability to deal effectively with the task at hand.

All along the way, the Tutors use natural language dialogue to both pull and support student learning.

How does the Quantum Tutors' design incorporate the social constructive approach to scientific knowledge?

The best minds of our day tell us that the social constructivist perspective — an approach that emphasizes the social contexts of scientific knowledge — provides a robust approach for developing student thinking and understanding in science.

Social constructivism views learning as a collaborative, socially interactive, and cultural activity (Rogoff, 1998). That is to say, students learn differently, and more deeply, when they are able to negotiate meaning through discussion with more capable others (Vygotsky, 1978). Because of this fact, the Quantum Tutors provide extensive opportunities for students to learn "with" the Tutors rather than "from" the Tutors in co-constructing knowledge (Kozulin, 2000). In other words, the Tutors act as a cognitive partner, coaching, scaffolding, shaping, modeling, and displaying scientific thinking rather than simply giving correct answers and explanations.

How do the Quantum Tutors scaffold student thinking?

One of the most powerful ways that the Tutors embody social constructivist research is through their use of natural language to scaffold student thinking and performance. To understand this cognitive process, you can compare scaffolding the construction of a concept — like balancing chemical equations or assigning oxidation numbers — to scaffolding the construction of a building. A scaffold is commonly used when a building is being erected and is gradually removed as the building becomes self-supporting. In the same way, a teacher or tutor uses prompts and hints to provide enough support and assistance so that the learner can succeed. What is most critical is that, in the same way that the scaffold is gradually removed as a building becomes stronger, the tutor or teacher gradually removes support as the student becomes more capable of performing on his/her own. To put it another way, during scaffolding, a more skilled individual (in this case the Quantum Tutor) adjusts the amount of guidance needed to fit the student's current performance level.

To do this, the Tutors replicate the actions of the best human support by providing questioning, modeling, illustration, and explanation. A good teacher "scaffolds" (Wood, et al., 1976) his/her input, taking care to provide the assistance that is needed, but not so much that the student becomes dependent, or so little that the student fails. In fact, the Quantum Tutors use a specific form of scaffolding of student learning known as cognitive apprenticeship.

How do the Quantum Tutors use natural language to engage students in a cognitive apprenticeship process that both stretches and supports their understanding?

In cognitive apprenticeship an expert (in this case, the Quantum Tutor) stretches and supports a novice's (in this case the student's) understanding and use of skills (Collins, Brown & Newman, 1989; Rogoff, 1990).

The term apprenticeship underscores the importance of modeling content-specific strategies for students. Think of the three things that apprentice learners do — they observe, they receive coaching from someone with more expertise, and they practice important tasks while being coached. Collins, Brown, and Newman (1989) summarized the components of effective apprenticeships in this way:

Modeling: Great teachers show their apprentices how to approach tasks that are important. To do this they make their thinking and planning obvious. That is, the expert tutor purposely makes overt the actions that are normally covert and automatic. Moreover, expert tutors not only let their students see their actions, but they also let their students hear their thinking by expressing the reasoning behind their actions — the why.

Coaching: As the effective tutor watches the apprentice try a specific task, he/she offers feedback, hints, and guidance as well as additional modeling and explanation. In fact, coaching is the best single word to describe the apprenticeship process.

Scaffolding: To offer just enough support in the form of guidance and reminders, the best tutors are master diagnosticians. That is to say, the tutor understands the different kinds of mistakes that the student can make and how to deal with each error. In this way, the tutor determines when the student needs help and develops the best way to support and redirect the student.

Articulation: Great teachers and tutors require their apprentices to unpack or explain the thinking that drives their decisions. Thus, an expert science teacher not only asks his/her students to explain their work, but also requires the students to discuss why a certain solution or path was chosen over another.

Reflection: Expert teachers and tutors know that helping a student think about how he/she is doing with the long-term goal of improving specific aspects of his/her performance is an important aspect of teaching.

Exploration: Expert tutors and teachers want their students to develop the ability to think for themselves and to try out unique problems of their own making.

In summary, the Quantum Tutors use natural language to negotiate meaning and understanding, thereby engaging the student in a cognitive apprenticeship. Specifically, the Tutors adjust explanations and model solutions to work within the student's range of understanding. At the same time the Tutors' design encourages the student to reach slightly beyond that level of comfort by displaying medium-level questions that help the student develop the confidence to approach a more difficult skill. In other words, the Quantum Tutors are able to work within the student's level of comfort but are mindful that with guided support each student has the potential to reach higher.

What is the benefit of using natural language to model questioning skills?

Sometimes, when confronted with new concepts a student will be unable to formulate any meaningful questions, and getting examples of good questions is of tremendous benefit. Like the very best human teachers, the Quantum Tutors use natural language questions to teach students how to ask good, thought-provoking questions about chemical concepts.

Educational researchers tell us that the ability to ask good questions might be the most important aspect of intelligence (Arlin, 1990; Getzels & Csikszentmihalyi, 1967; Sternberg & Spear-Swerling, 1996). Many students, however, do not have the scientific content or scientific process language to ask effective questions.

By modeling effective questions to ask, the Tutors prompt students toward productive directions of thought and add to their ability to use scientific language to explain and question their decisions and actions.

How do the Quantum Tutors enhance student confidence and self-efficacy?

Self-efficacy, the belief that one can be successful at the task at hand, has been shown to be an important factor in student motivation and goal setting (Bandura, 1997). In other words, students will be more apt to approach a task, like balancing chemical equations, when they feel confident in their ability to succeed. It is important to note that self-efficacy is task specific. That is to say, someone who is confident in his/her ability to complete a chemistry lab experiment does not necessarily feel confident in the ability to balance a chemical equation.

Students who have a high sense of efficacy in a given area will set higher goals, be less afraid of failure and adopt new strategies to replace those that fail. If efficacy for a specific task is low, students may give up easily, believing that they do not have the personal knowledge and skills to succeed.

The students' experience with the Quantum Tutors provides two important sources of self-efficacy: confidence in their knowledge of the content and confidence in their ability to ask good questions about a specific scientific process. Since several of Quantum's Tutors allow students to direct their inquiry by selecting the question(s) that they want to ask, students can use the Tutors in important and unique ways. For instance, when students do not know what questions to ask, they rely on the Tutor as a cognitive coach — observing the thinking and questioning expertise that the Tutor models. As students progress, or for students who are able to ask and answer the questions for themselves, they use the Tutors to confirm their answers. This confirmation works to validate their increased feelings of efficacy — or confidence — in learning chemistry.

About the Author:

Connie M. Moss is the Director of the Center for Advancing the Study of Teaching and Learning (CASTL) at Duquesne University in Pittsburgh, PA. Her research and teaching focus on the design of face-to-face and online learning environments that support systematic and intentional inquiry and problem solving. Correspondence should be directed to:

Connie M. Moss, Ed.D.
School of Education
Department of Foundations and Leadership
406 Canevin Hall, Duquesne University
Pittsburgh, PA 15282
email: moss@castl.duq.edu
http://www.castl.duq.edu

References

American Association for the Advancement of Science. (1993). Benchmarks for science literacy: Project 2061. New York, NY: Oxford University Press.

Arlin, P.K. (1990). Wisdom: The art of problem finding. In R.J. Sternberg (Ed.), Wisdom: Its nature, origins, and development (pp. 230-243). New York: Cambridge University Press.

Bandura, A. (1997). Self-Efficacy: The Exercise of Control. New York: W.H. Freeman and Company.

Collins, A., Brown, J.S. & Newman, S.E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L.B. Resnick (Ed.), Knowing, learning, and instruction (pp. 283-305). Hillsdale, NJ: Erlbaum.

Driver, R., Asoko, H., Leach, J., Mortimer, E. & Scott, P. (1994a). Constructing scientific knowledge in the classroom. Educational Researcher, 23(7), 5-12.

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

Garnett, Patrick J., Garnett, Pamela J. & Hackling, M.W. (1994) Students' alternative conceptions in chemistry: A review of research and implications for teaching and learning. Studies in Science Education, 25, 69-95.

Getzels, J.W. & Csikszentmihalyi, M. (1967). Scientific creativity. Science Journal, 3(9), 80-84.

Hiebert, J., Carpenter, T.P., Fennema, E., Fuson, K., Human, P., Murray, H., Olivier, A. & Wesarne, D. (1996). Problem solving as a basis for reform in curriculum and instruction: The case of mathematics. Educational Researcher, 25(4), 12-21.

Kozulin, A. (2000).Diversity of Instrumental Enrichment applications.In A. Kozulin and Y. Rand (Eds.), Experience of Mediated Learning. Oxford: Pergamon Press.

Nakhleh, M. (1992). Why some students don't learn chemistry. Journal of Chemical Education, 69, 191-196.

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

Rogoff, B. (1998). Cognition as a collaborative process. In D. Kuhn & R.S. Siegler (Eds.), Handbook of child psychology (5th edition) (Vol.2,. 679-744). New York: Wiley.

Rogoff, B. (1990). Apprenticeship in thinking: Cognitive development in social context. New York: Oxford University Press.

Saul, W. & Reardon, J. (Eds.) (1996). Beyond the science kit. Portsmouth, NH: Heinemann.

Sternberg, R.J. & Spear-Swerling, L. (1996). Teaching for thinking. Washington, DC: American Psychological Association.

Vygotsky, L.S. (1962). Thought and language. Cambridge, MA: MIT Press.

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

Wood, S.S., Bruner, J.S. & Ross, G. (1976). The role of tutoring in problem solving. Journal of Child Psychology and Psychiatry, 17.