

Skill Development Takes Time for Students (and Teachers!)

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Abstract

Teachers are often surprised or frustrated that students are unable to understand basic science concepts or identify what seem to be obvious scientific phenomena. Yet, compared to a professional educator who has studied and practiced for several years, students may be examining these in depth for the first time and do not have the experience to immediately connect their observations to explanations. If educators take a step back and assist students in developing their experience by helping them understand the theoretical basis for these phenomena through scientific inquiry, conceptual understanding can emerge more easily and in a less stressful atmosphere. In addition, the bridge to STEM engineering projects then becomes more easily crossed.

I recently gave professional development workshops in science inquiry to teachers at three international schools in different Asian countries. The activities were basically the same, but the similarities ended there. Due to the nature of the school environments and teacher backgrounds that had been described prior to my visits, I had expected there to be differences so I was not terribly surprised at the processes I observed and how vastly the activities differed as the teachers went about their investigations.

I began the workshops with a "Nature of Science" activity that was described by William McComas, professor of science education at the University of Arkansas, who designed an open-ended exploration of sunflower seeds to illustrate how scientists work, saying to workshop participants only, "Find out everything you can about these seeds" (McComas, 2014).

In the workshops, the teachers of two schools quickly set about exploring: using scientific measuring devices, comparing findings, using multiple modalities, finding and describing patterns, and had to be stopped after 20 minutes as their curiosity and creativity kept them going. The teachers at the third school were far more reserved, making few measurements and only cursory observations without recording them. This group did not venture from their tables, did not see what others were doing, and ended the investigation in less than 10 minutes, despite my rather obvious attempts to encourage them to make more observations. So when I asked the third group if they had found out all they could about their seeds, and they all nodded, I said, "Great! What is the average length of the seeds?" Nervous glances and giggles followed. "Oh, okay, maybe not everything," I replied to further laughter. "What about the range in lengths?" The point made, the teachers resumed their investigations with enthusiasm and what I detected as relief to be released from their strict understanding of what students are "supposed" to do, or often it is thought what they "are able to do".

The ensuing discussions were also stark in comparison. While the exchanges between participant groups in the two "active" science faculties were lively and rich in contrasting strategies and findings, the discussions of participants of the third faculty were less so. This was, in part, no doubt due to their cultural backgrounds: Science faculty at the

first two schools were nearly all from western countries and had already designed science curricula to embrace science inquiry; their purpose in attending the workshops was to find ways to improve their inquiry teaching and make the curricula more inquiry- and project-based, and more integrated as STEM activities. Faculty at the third school were all from Asian countries and were the products of a very different type of science education, which showed up in their teaching as lecturing, “cook book” labs and test taking. Yet, they were very interested in learning about inquiry and its strategies, about which they had no prior experience.

I had similar experiences when teaching students at international schools in Thailand compared to teaching inquiry lessons to students in Thai government school honors programs in science. Although both student groups were primarily Asian, and mostly Thai (The Thai school student population was 100% Thai), the same sort of observations were made as with the teachers, that is, the international school students made far more observations, asked many more questions, gathered more data and used critical thinking to design unique ways to gather information. Despite the less rigorous investigations made by students at the government school, they were no less enthusiastic than students at the international schools. Indeed, they relished the opportunity to explore. They just hadn’t had the opportunity to develop those process skills, generally sitting in lecture oriented classes day after day.

Do these observations of my workshops and classes show that the lesser involvement of the Asian teachers and students indicate that they are in some way less talented than those in the other groups? Are they less capable? Are they less academically inclined or serious about their work? I think that most, if not all, educators would argue that it does not mean we can draw these conclusions at all.

Although only anecdotal, my observations support the notion that even as teachers, it is not possible to learn something new and practice it in a polished methodology in a short amount of time. In fact, one cannot expect teachers new to inquiry science to design an inquiry lesson or come up with good questions without using it incrementally in the classroom. Just as important, the students also cannot be expected to use the skill sets that professional teachers employ every day for years, which is why teachers are often frustrated by students not understanding concepts or memorizing content in a few short days of 50 minute periods.

As explained by Michael Clough, Professor of science education at Texas A&M University, educators need to realize, as do science students, that “theory must precede observation” (Clough, 2011). In other words, experience is essential for becoming competent and confident in using scientific skills. “Students cannot,” says Clough, “be compelled to see what the teacher sees.” Clough uses the example of the student novice who sees a cell under the microscope, whereas the teacher sees an air bubble. Students simply do not have the experience, or theoretical knowledge to identify a cell under magnification when first using a microscope. Only after having multiple opportunities to use the scientific equipment are they able to observe with a critical eye (Clough, 2014).

The same can be said of science teachers learning new skills needed to effectively incorporate inquiry in their classrooms. It must be done incrementally and with ever increasing amounts of time allotted. Additional meeting times regularly scheduled to discuss experiences and receive feedback and suggestions from an experienced instructor is essential if teachers are ever to become masterful at teaching inquiry, or any other methodology skill set. I am often frustrated to know that a one or two day inquiry workshop will be the only professional development that many science or STEM teachers will ever have; I know that the chance of success for implementing effective inquiry strategies is

limited, although some will surely develop the skills through a desire to want to be better teachers of inquiry.

The Essential Features of Science Inquiry identify those research-based strategies to be used in maximizing student learning (NRC, 2000):

- The learner engages in scientifically oriented questions.
- The learner gives priority to evidence in responding to questions.
- The learner formulates explanations from the evidence.
- The learner connects explanations to scientific knowledge.
- The learner communicates and justifies explanations.

Teachers new to science inquiry (or now science “practices”), or who have misconceptions about it (e.g., it is “discovery” or “free exploration”) are often surprised to learn that they do engage their students in inquiry, sometimes frequently, even though it may be considered “incomplete inquiry”, that is, using some, but not all of the essential features of inquiry, which would be “full inquiry” (See Appendix). It is not necessary, indeed not practical, to be engaged in full inquiry all of the time. However, incorporating as many of the essential features as possible into a lesson boosts student interest and critical thinking that much more. As Robert Yager, Professor Emeritus of science education at the University of Iowa, quipped during a seminar, “If every science teacher would use inquiry just once a year, it would revolutionize science education”. Teachers regularly report to me that like I did, they found their students to enjoy science much more when engaged in inquiry. Additionally, scientific inquiry naturally employs aspects of STEM education, since science study regularly incorporates mathematics, innovative design (engineering) and technology.

A science lesson that incorporates essential features of inquiry may be teacher centered (guided inquiry) or student centered (open inquiry), or any combination depending on the experience of the teachers and students, and the nature of the lesson. In today’s atmosphere of test-driven curricula, it is generally necessary for teachers to guide the initial activity in order to fulfill curriculum requirements. However, I have found that with effective teacher questioning, the initial exploration often stems from student-formulated questions about the topic, especially if they are given an opportunity to raise questions about a concept prior to studying it. This can be simply using the “KWL” (What I **K**now, What I **W**ant to Know, What I **L**earned) strategy incorporated into many primary lessons, but also used by secondary lessons in a slightly different form. Arthur Eisenkraft, now professor of science education at the University of Massachusetts-Boston, used a “KTW” (What I **K**now, What I **T**hink I know, What I **W**ant to know) when he taught honors physics at a high school in New York (Annenberg Learner, 2016).

Schools around the globe continue to stubbornly cling to the notion that “telling is teaching”, and “listening is learning”, resisting the opportunity for students to learn ways to be independent learners, and develop critical thinking skills, problem-solving techniques and creative ways to apply knowledge to real world situations. Yet nearly all have some sort of school motto that alludes to those as goals. In my experience, it is clearly not reasonable to expect a teacher who does not have these experiences to teach students to develop them. If a school does not offer teachers opportunities for sustained professional development over the school year or longer, one can hardly be surprised if students are unable to think outside the box, which is being demanded by increasing numbers of universities and companies.

The model from which I offer the standard two-day workshop on science inquiry is in actuality a three year program designed by a team of science and technology consultants, at Heartland Area Education Agency in Johnston, Iowa, a regional state agency. In that model (“Content Area Capacity Building [CAB]”), teams of science teachers and an administrator

from each participating school spend 12 full days in professional development workshops over two academic years, then three days in their classrooms the third year teaching lessons they designed with support from agency consultants. It was felt that it was the minimum amount of time necessary to fully implement inquiry teaching effectively. Other Iowa agencies developed similar programs.

In offering the two day workshop, I caution participants that it is but an introduction to teaching inquiry science, somewhat like the first few weeks of piano lessons: one cannot be expected to play a Beethoven sonata in such a short amount of time, or indeed, be a master inquiry science teacher the following week. However, there are some things that can be done to begin to find success and build confidence and competence in teaching science inquiry, and extending it to include STEM design challenges:

1. Start modestly. Choose an activity that lends itself to science inquiry and decide how best to begin it. Then, once that is done, continue until you feel it is necessary to stop. Don't worry about completing the activity, taking up the full class time, or incorporating all of the Essential Features (you might only use one).
2. Make a video of your teaching and review it, using the Essential Features and knowledge of inquiry skills modeled in the workshop. It is a powerful and humbling experience, and will improve your teaching.
3. Know not only your limits, but also those of your students. Don't push too hard for a full inquiry. Make that your ultimate goal. It could take all year. Take small steps at first.
4. Remember Clough's adage: "Theory must precede observation". If you are experienced in science inquiry but your students are not, expect them to acquire inquiry skills gradually. Likewise, if you find that your students are more experienced in inquiry than you (it happens), let them help you learn!
5. Practice, practice, practice! Never give up on the strategy.

Science inquiry is a natural springboard to STEM investigations. Indeed, a master science teacher *is* a STEM teacher: they provide students with challenges for problem-solving that relate to the real world, and if the investigation is done as scientists work, then it is necessary to include mathematics and technology to research, collect and organize data, and analyze evidence. By asking students to design a prototype to solve a problem, they incorporate engineering as well. This methodology supports the development of 21st century skills, most notably, the "4 Cs" (collaboration, critical thinking, creativity and communicating).

Science inquiry and STEM investigations are powerful methodologies that help students become independent learners and critical thinkers. If one is patient but persistent, the classroom eventually becomes a buzz of activity, one I like to walk into and not be able to find the teacher because s/he is right there in the thick of inquiry with the students!



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Appendix

Essential Features of Classroom Inquiry and Their Variations

Five Essential Features of Inquiry	Teacher Centered (A)	Teacher Driven (B)	Teacher Guided (C)	Student Centered (D)
1. Learner engages in a scientifically oriented question	Question provided by teacher, materials, or other source	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner selects among questions, poses new questions	Learner poses a question
2. Learner gives priority to evidence in responding to questions	Data provided by teacher and told how to analyze	Data provided by teacher and asked to analyze	Learner directed to collect certain data	Learner determines what constitutes evidence and collects it
3. Learner formulates explanations from evidence	Evidence provided by teacher	Learner given possible ways to use evidence to formulate explanation	Learner guided in the process of formulating explanation from evidence	Learner formulates explanation after summarizing evidence
4. Learner connects explanation to scientific knowledge	All connections provided by teacher	Possible connections provided by teacher	Learner directed toward areas and sources of scientific knowledge	Learner independently examines other resources and forms the links to explanations
5. Learner communicates and justifies explanations	Step and procedures for communication provided by teacher	Broad guidelines to sharpen presentation provided by teacher	Learner coached in development of communication	Learner formulates reasonable and logical argument to communicate explanation

(Adapted from: National Research Council. 2000. *Inquiry and the National Science Education Standards, A Guide for Teaching and Learning*. Washington, DC: National Academy Press, P. 29)