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OPINION

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Learning science and doing science. How closely are they related?

Science education in many countries is being re-examined and in some countries such as the United States and the United Kingdom is being restructured to emphasize what is called "inquiry-centered learning". Unfortunately, this term has been used so frequently that its meaning has become blurred. It has been used to refer to the process component of science, and even equated to how scientists actually carry out their work. When these analogies are overdrawn they carry the risk of undermining the desired outcome — increased interest and understanding of science. The purpose of this essay is to point out some of the dangers of over stretching the resemblance of inquiry-centered science education to "doing science".

To begin with, there is a difference between what can be called "the general process of inquiry" and "scientific inquiry", as practiced by scientists (Table 1). The general process is applied in any field or discipline: history, literature, etc. An excellent example of the latter is developed in Josephine Tey's book *The daughter of time* [3]. The hero, a detective immobilized by an accident, devotes his hospital time to investigating the commonly-held belief that Richard III caused the two young heirs to the English throne to be murdered. The detective questions the validity of this view. Through frequent bedside visitors he gains access to a wide range of literary source material, sorts it as to credibility, and concludes that not Richard III but Henry VII, his successor, was in fact responsible for the murders. Now, here's the rub. On the available evidence the detective's case is strong, but he cannot perform an experiment to confirm his prediction. One cannot rerun the tape of history.

Here scientific inquiry differs. Materials are similarly gathered to help frame a question, refine it, and of course to insure that the question has not already been answered. We propose hypotheses to answer the questions, and predict the outcome of new experiments to test the validity of these hypotheses. The results of the experiment will be repeated both by the original experimenter, and by others in other settings (laboratories). Repetition of the results lies at the very heart of the process of scientific inquiry. Through the prediction and the experimental outcome we create new knowledge.

Thus, *the* key difference between inquiry in general and scientific inquiry is that in the latter case the question is framed in a form that can be tested by experiment. And, typically, the question is framed with the means for testing in mind (spectrophotometers, super computers, etc.). So progressive science education attempts to move from the general process of inquiry towards use of scientific inquiry. In this respect these educational efforts make sense.

Now, what has all this to do with science? Science includes both the process for inquiring about natural phenomena, *and* the content derived therefrom. The content of science is the accumulated and ever-expanding body of knowledge in any field of inquiry to which scientific inquiry can be applied. The

Table 1 Steps in the inquiry process

	General inquiry	Scientific inquiry	
1.	Frame the question in a form that can be tested	Hypothesis	
2.	Develop a plan to answer the question in a definitive way	Same	
3.	Gather materials on which to base answer (literature, etc.)	Same	
4.	Sort the materials-as to degree of credibility	Same	
5.	Formulate an answer using credible materials	Prediction	} Create new knowledge
6.		Experimental test	} Create new knowledge
7.		Replicate test results	} Create new knowledge
8.	Articulate the conclusion	Same	
9.	Optional-frame a new question	Same	

process is the tool kit through which knowledge is acquired — but it alone is *not* science.

In the United states the new National Science Education Standards [2] clearly distinguish between scientific *inquiry* and scientific *content* in science education at all K-12 grade levels. Extensive sections are devoted to broad areas of content — the Science Content Standards. The text (p. 21) states further "An essential aspect of scientific literacy is greater knowledge and understanding of science subject matter...".

This distinction has important implications for science education. Over the past decade or so science education has shifted from emphasis on content — facts, names, numbers — to the inquiry process itself. Clearly, the opportunity for open-ended exploration of a child's environment is beneficial in engaging interest in science and technology, in stimulating development of the inquiry process, and understanding its power for analysis. There is little question that this swing of the pendulum is important and overdue. The fact is, however, that the larger part of science is content. Without process the content of science would become static — or even decay. Without content we lose the accumulated knowledge of the millennia.

For one thing, not all science can be learned through the inquiry-centered process. A good part of the content of science, especially in the higher grades, must be learned through other methods — lectures, dramatic presentations, studying a textbook, and even by systematic memorization. The factual and conceptual content in any disciplinary area (and this applies to any subject matter, not just science) is so rich that to understand it, not to mention mastering it, requires rigorous, intensive study. Of course, these experiences can be reinforced through inquiry-centered learning, but one cannot construct in this way an understanding of photosynthesis, for example, unless one is prepared to reinvent all that has gone before.

Another misconception with the potential for undermining interest in science arises from the frequent comparison of children's play, and children's innate approach to constructing knowledge, to "doing science". We are told, in science museums as in schools, that "we are not trying to teach them anything, only developing their ability for inquiry-centered thinking". This concept can be useful in the earlier grades, where engaging and channeling innate interests is important. In higher grades, certainly by middle school, this approach must be phased into one where inquiry and content are fused. As embodied in the title of a recent book, some consider "The Young Child as Scientist" [1]. Children do use the inquiry-centered process for adding to the content of *their* knowledge and they learn through a social process, as scientists often do. But, despite these superficial similarities, children are not practicing science.

The goal of science id the acquisition (or invention, or creation, whatever word you prefer) of knowledge new to human society. One acquires new knowledge only by moving beyond the limits of existing knowledge. To even recognize that frontier one must have mastered the content of the area under investigation.

Further, science is characterized by 3 essential elements: rigor, measure and content. Development of these attributes requires time and hard work. (Not necessarily unusual intellectual ability — but certainly hard work.) At a time when we are trying so hard to interest a broader segment of the citizenry in science, to characterize the inquiry process as the essence of science and to present it as "child's play" can be self-defeating. There will be a rude awakening when the 3 elements above heave into view, an awakening that can only adversely affect the student's interest. Developing habits of mind that are essential for natural use of the inquiry process is vitally important, but even at the lower grades, content, measure and rigor must be introduced, reinforced, and built upon to prepare students for a realistic view of science.

Now, bearing process and content in mind, a further issue can be addressed — where can science best be laught — and learned? The classroom is undoubtedly the arena for learning content, using inquiry centered instruction as one pedagogical tool. Science centers, on the other hand, can provide effective supplements to classroom learning through inquiry-centered learning. This is the main focus of the more recent, interactive types. The better ones provide the opportunity for a learned lesson, as well as engaging interest. And they provide another important feature of the learning environment which is difficult to achieve in the classroom — individuals learn at their own pace.

Leaders in the promotion of content and inquiry process as the essence of learning science believe firmly that this combined approach in early years will make a significant contribution to scientific literacy in later life.

References

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