EDITORIAL
CONDUCTING HIGH QUALITY EDUCATIONAL RESEARCH

> There was no doubt atoms could explain some puzzling phenomena. But in truth they were merely one man's daydreams. Atoms, if they really existed, were far too small to be perceived directly by the senses. How then would it ever be possible to establish their reality? Fortunately, there was a way. The trick was to assume that atoms existed, then deduce a logical consequence for the everyday world. If the consequence matched reality, then the idea of atoms was given a boost. If not, then it was time to look for a better idea. (Chown, 2001, p. 6)

During the past three decades I have had the pleasure of serving on the editorial boards of several journals in science and mathematics education. Some of the submitted papers that I reviewed were of high quality and some were not. What makes a high quality paper – a paper worthy of publication? At the risk of appearing to pontificate, in my view one factor is of central importance and stands well above the rest: the paper must represent good science. Although my view is by no means unique, allow me to attempt to explain what I mean by good science in five steps.

(1) The paper must address an interesting and important educational question. In some cases that question can be descriptive in nature (i.e., a who, what, when, where question), but in most cases the question is about causes (i.e., a why or how question).

(2) Once an important causal question has been raised, the next task is to propose one or more plausible and tentative answers. This means that the researcher has identified some reasonable explanations (i.e., reasonable in light of current theory, past research, and/or one's own experience). And the author needs to convince us that the reported research has not previously been conducted, or at least not been conducted well enough to remove reasonable doubt about its outcome.

(3) The next task is to figure out how one or more of those tentative explanations can be tested. This requires some creativity as testing methods must be invented that lead deductively to some specific expectations or expected results. By expected results, I mean results that should reasonably occur assuming that the proposed explanation(s) is in fact correct and the test is conducted as planned. In other words,

    If . . . the proposed explanation is correct,
    and . . . we conduct some sort of planned test,
    then . . . we should find/see/observe that such and such occurs.

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This is a crucial step, a step that is often missing in educational research and publications. But the step is necessary for explanation testing. Suppose for example that our proposed explanation leads us to expect that X will occur when the test is conducted. Once the test is conducted and we find that X did occur, then we would have reason to believe that our proposed explanation may be correct. Even more importantly, once the test is conducted and we find that X did not occur, we would then have reason to believe that our proposed explanation is wrong. Hence, it may be "time to look for a better idea."

(4) Having stated the proposed explanation(s) along with the expectation(s), the next task is conduct the planned test and to observe its result (i.e., the data, the evidence). Once results are observed, it becomes relatively easy to compare those results with the prior expectations. As suggested above, a good match between observed results and expectations implies support for the explanation that led to the expectation. Here it is better to speak of support, instead of proof, because some as yet unidentified explanation may lead to the same expectation. And a poor match between observed results and expectations implies lack of support. Likewise, here it is better to speak of lack of support, instead of disproof, because the poor match may be due to a faulty test, rather than a faulty explanation.

(5) Lastly, because the research is educational in nature – that is it is applied research as opposed to so-called basic research – the author(s) should state the implications of their results and conclusions for educational practice. Here caution is advised to limit the stated implications to the current results and conclusions.

Notice that nothing in these steps implies that the data must be qualitative or quantitative in nature. Instead, the nature of the data should match the nature of the research question. Clearly each type of data has strengths and weaknesses. Hence, it is often best to include both types. Again, the key point is that the study provides a test of the proposed explanation(s) (i.e., is theory/explanation based), not that it reports qualitative or quantitative data.

Three examples of this *If/and/then* type of explanation testing may be helpful. Consider the simple pendulum often explored in elementary school classrooms. Students might notice that pendulums often swing with different speeds. This observation raises a causal question: What causes pendulums to swing with different speeds? Several tentative explanations can be proposed. Perhaps the amount of weight hanging on the end is the causal factor. Perhaps the length of the pendulum's string is the causal factor? Perhaps how far one pulls the weight to the side before letting go is the causal factor. And so on. How can these alternatives be tested? Consider the following argument:

> *If* . . . the pendulum's weight is the causal factor (weight explanation)
> *and* . . . we vary the weight while holding all other proposed causal factors constant (planned test),
> *then* . . . the pendulums should swing with different speeds (expectation).
> *But* . . . when the planned test is conducted we find that the pendulums do not swing with different speeds (observed result).
> *Therefore* . . . we have a poor match between expected and observed results and we conclude that the weight explanation has not been supported (conclusion). And we need to look for a better idea.

Next consider a case from the history of science. One of the first persons to investigate the origin of new plant matter was the Belgian physician Jan van Helmont (1577–1644). More specifically, van Helmont asked: What materials do plants take in to grow? In other words, what causes plants to grow, to add weight? He suspected that new plant matter comes either from soil or from water, which he thought plants took in through their roots. To test these tentative explanations, van Helmont conducted a lengthy five-year experiment. He started by filling a tub with 200 pounds of dry soil. After watering the soil, he planted a five-pound willow tree in the tub. To keep out debris, he covered the tub with an iron plate full of tiny holes. Accordingly, van Helmont's test can be summarized like this:

> *If* . . . new plant matter comes from soil (soil explanation),
> *and* . . . a tree is grown in soil for five years (planned test),
> *then* . . . the soil's weight should decrease by the amount that the tree's weight increases (expectation).

Alternatively,

> *if* . . . new plant matter comes from water (water explanation),
> *then* . . . the soil's weight should be the same as at the start (expectation).
> *And* . . . at the experiment's end the tree had gained 164 lbs and 2 oz. and the soil still weighed 200 lbs, minus about 2 oz. (observed result).
> *Therefore* . . . van Helmont concluded that new plant matter did not come from soil, except perhaps about 2 oz. (conclusion). Interestingly, due to his failure to consider other important alternatives (i.e., air), van Helmont erroneously concluded that new plant matter came from water. In his words, "Therefore, 164 pounds of wood, bark, and roots, arose out of the water only."

Lastly, let's consider an example from science education. Secondary school science teachers often find that many students have difficulty in understanding the more abstract topics that they present to their classes. Quite naturally teachers wonder about the cause or causes of such difficulties. A tentative explanation may exist in part in Jean Piaget's theory of intellectual development. That theory claims that development progresses though four sequential stages (i.e., sensory-motor, preoperational, concrete operational, and formal operational). The theory also claims that formal reasoning patterns are needed for the construction of theoretical science concepts (i.e., concepts such as atoms, cellular respiration, evolution, continental drift, and hydrolysis, which lack directly perceptible exemplars). Interestingly, evidence suggests that many secondary school students have failed to develop formal reasoning patterns in spite of the fact that their brains have presumably matured sufficiently to do so. Accordingly:

> *If* ... formal reasoning patterns are needed to construct theoretical concepts (formal reasoning explanation),
> *and* ... several secondary school students who vary in the extent to which they have developed formal reasoning patterns are "taught" and then tested on their understanding of several theoretical concepts (planned test),
> *then* ... only those students who have developed formal reasoning patterns should demonstrate understanding of the theoretical concepts (expectation).

Alternatively,

> *if* ... formal reasoning patterns are not needed to construct theoretical concepts (let's call this the null explanation),
> *then* ... no significant difference in demonstrated concept understanding should be found between concrete and formal operational students (let's call this the null expectation).
> *And* ... after "teaching" and testing for student understanding, none of the concrete operational students demonstrated understanding of the theoretical concepts, while many of the formal operational students did (observed result).
> *Therefore* ... support has been found for the formal reasoning explanation – and not for the alternative null explanation (conclusion). The educational implication here is that instruction should be redesigned to help students develop the formal reasoning patterns presumably required for the construction of theoretical conceptual understanding.

Although research reports do not need to explicitly state their *If/and/then* arguments in this formal manner, nevertheless, I believe that educational studies would almost certainly be strengthened if such arguments were at least implicit in their design, execution and reporting. At least then we would be collectively engaged in the business of proposing and testing chains of causal relationships that could provide a much needed theoretical (i.e., explanatory) basis for what teachers should and not do in the classroom.

REFERENCE

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