## Research on Student Learning

Upper elementary-school students can reject a proposed experimental test where a factor whose effect is intuitively obvious is uncontrolled, at the level of "that's not fair". [1] "Fairness" develops as an intuitive principle as early as 7 to 8 years of age and provides a sound basis for understanding experimental design. This intuition does not, however, develop spontaneously into a clear, generally applicable procedure for planning experiments. [2] Although young children have a sense of what it means to run a fair test, they frequently cannot identify all the important variables, and they are more likely to control those variables that they believe will affect the result. In evaluating what can be learned from a certain experiment, students may be less likely to detect a problem in controlling variables when the outcome is expected than when the outcome is not expected. [3] Student familiarity with the topic of the given experiment influences the likelihood that they will control variables. [4]

Students of all ages as well as adults may change variables one at a time to test a claim whose outcome may be construed as negative (e.g., honey makes a cake taste bad). But when the outcome is construed as positive (e.g., honey makes a cake taste good), they may hold constant what they believe is contributing to the positive outcome. [5]

After specially designed instruction, students in 8th grade are able to call attention to inadequate data resulting from lack of controls (see for example Rowell & Dawson, 1984; Ross, 1988). Explicit instruction that includes positive and negative examples of control-of-variables designs and justification for why the strategy works, combined with hands-on experimentation, can help upper elementary-school students make progress toward designing unconfounded experiments and evaluating experiments designed by others. [6]

Lower elementary-school students can select conclusive (over inconclusive) tests for specific simple hypotheses. [7] Most 6th graders can judge whether evidence is related to a theory, although they do not always evaluate this evidence correctly. [8] When asked to use evidence to judge a theory, however, students of all ages may make only theory-based responses with no reference made to the presented evidence. Sometimes this appears to be because the available evidence conflicts with the students' beliefs. [9] High-school students are more capable of evaluating theories in terms of the their consistency with evidence, regardless of whether or not they believe the theory. [10] This does not necessarily indicate that students appreciate the centrality of this kind of reasoning in science or that they will be inclined to evaluate claims in terms of consistency with evidence if they are not explicitly prompted. [11]

Students may cite data in their arguments, but they may fail to cite sufficient evidence for claims. In addition, references to data in students' arguments often fail to articulate how specific data relate to specific claims. [12] Students may believe that data literally speak for themselves -- that they are self-evident -- rather than providing raw material for supporting or judging a claim. [13]

Some middle-school students tend to invoke personal experiences as evidence to justify a particular hypothesis. Specifically, they seem to think of evidence as selected from what is already known or from personal experience or second-hand sources, not as information produced by experiment. [14]

Students do not necessarily consider only the evidence that is presented to them but make additional assertions about the context of the problem, or even introduce inferences that go beyond the boundaries of the evidence presented and that introduce bias in the outcome. [15]

## References

[1] Shayer, M., Adey, P. (1981). *Towards a science of science teaching*.

[2] Wollman, W. (1977). Controlling variables: Assessing levels of understanding. *Science Education*, 61, 371-383.

Wollman, W. (1977). Controlling variables: A neo-Piagetian developmental sequence. *Science Education*, 61, 385-391.

Wollman, W., Lawson, A. (1977). Teaching the procedure of controlled experimentation: A Piagetian approach. *Science Education*, 61, 57-70.

Zimmerman, C. (2005). The development of scientific reasoning skills: What psychologists contribute to an understanding of elementary science learning. *Paper prepared for the National Research Council, Committee on Science Learning Kindergarten through Eighth Grade*.

[3] Wollman, W. (1977). Controlling variables: A neo-Piagetian developmental sequence. *Science Education*, 61, 385-391.

[4] Linn, M., Swiney, J. (1981). Individual differences in formal thought: Role of cognitions and aptitudes. *Journal of Educational Psychology*, 73, 274-286.

Linn, M., Clement, C., Pulos, S. (1983). Is it formal if it's not physics? The influence of content on formal reasoning. *Journal of Research in Science Teaching*, 20, 755-776.

[5] Zimmerman, C. (2000). The development of scientific reasoning skills. *Developmental Review*, 20, 99-149.

Zimmerman, C. (2005). The development of scientific reasoning skills: What psychologists contribute to an understanding of elementary science learning. *Paper prepared for the National Research Council, Committee on Science Learning Kindergarten through Eighth Grade*.

[6] Klahr, D., Chen, Z., Toth, E. (2001). Cognitive development and science education: Ships passing in the night or beacons of mutual illumination?. In Klahr, D. and S. Carver (Ed.), *Cognition and Instruction: 25 Years of Progress*.

[7] Sodian, B., Zaitchik, D., Carey, S. (1991). Young children's differentiation of hypothetical beliefs from evidence. *Child Development*, 62, 753-766.

[8] Kuhn, D., Amsel, E., O'Loughlin, M. (1988). *The development of scientific thinking skills*. Academic Press.

[9] Kuhn, D., Amsel, E., O'Loughlin, M. (1988). *The development of scientific thinking skills*. Academic Press.

[10] Driver, R., Leach, J., Millar, R., Scott, P. (1996). *Young people's images of science*.

[11] Driver, R., Leach, J., Millar, R., Scott, P. (1996). *Young people's images of science*.

[12] Sandoval, W.A., Millwood, K.A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction*, 23, 23-55.

[13] Driver, R., Leach, J., Millar, R., Scott, P. (1996). *Young people's images of science*.

Sandoval, W.A., Millwood, K.A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction*, 23, 23-55.

[14] Roseberry, A., Warren, B., Conant, F. (1992). *Appropriating scientific discourse: Findings from language minority classrooms. (Working paper 1-92)*.

Ratcliffe, M. (1999). Evaluation of abilities in interpreting media reports of scientific research. *International Journal of Science Education*, 21, 1085-1099.

[15] Driver, R., Newton, P., Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, 84, 287-312.