suggesting that he had chosen to persevere through the pain. Opiates were the likely painkillers of the day, and these would have affected the clarity of his mind.

Lead is one of the world's oldest known metals. It has been used for thousands of years as a building material, for water piping, and to make pottery and other things. The symbol for lead, Pb, originates from the Latin word for lead, plumbum. In Roman times, a person who worked with lead pipes was called a plumber, a term which we still use today. For more information about lead poisoning, refer to the question in the *Your Questions Answered* section of this issue.

Social Constructivism

How do students best learn in science? The traditional, teacher-centered view was that students, viewed as "empty vessels" waiting to be filled with new knowledge, "received" understanding by absorbing information supplied by teachers and found in written materials. This information included facts, good explanations, and the use of algorithms to solve problems. There appeared an underlying assumption that, after memorising a critical mass of facts, students would interconnect concepts and develop understanding spontaneously.

We have evidence that such an approach has been less effective in developing understanding than is desirable. For example, "many of the most able students (such as university physics majors and engineering students) have as many misconceptions about science as the average high school student" (Yager, 1991, p. 52). Rather than being "blank slates," students bring their own unique experiences and personal beliefs to the science classroom, and some of these intuitively held ideas differ from the ideas accepted by the scientific community. What is more, students' conceptions are resistant to change through traditional teaching strategies, may be context dependent (i.e. a student may apply different, and even conflicting, concepts in different contexts) and, most significantly, students' prior conceptions, by providing the interpretative schema through which new ideas are viewed, highly influence what their new understanding will be like (Osborne & Wittrock, 1983; Palmer, 2001; Tsai, 2000). "Domain-specific preinstructional knowledge has proven to be *the* key factor determining learning and problem solving in research in all science domains" (Duit & Treagust, 1998, p. 19).

Supplying information to students, without accounting for their existing beliefs, often doesn't do much to help ideas "make sense" to them, and learners frequently develop immature, incomplete, or even dual understandings (Ciascai, Chiç, & Pop, 2002; Wandersee, Mintzes, & Novak, 1994). The latter refers to the situation in which a student adopts one perspective in the classroom and yet a different way of understanding away from the classroom, as in the case of the student who understands the reasoning for why both a small and a large dense mass, when dropped simultaneously, will hit the ground at the same time, but not believe it. Information not connected with a student's prior understanding may also be easily forgotten and not readily transferred to similar, or novel, situations.

The prevailing learning theory in science education, social constructivism, is a more student-centered perspective which embodies the notion that learners construct their own knowledge and understandings based on their existing ideas and the socio-cultural context in which they find themselves (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Solomon, 1993). Meaningful learning occurs when new information is integrated within a coherent conceptual framework (rather than stored in an isolated manner), and such integration requires existing knowledge to be extended and/or restructured. This is a highly individual process, as a learner's prior experiences will influence what aspects of a new learning experience are selected and attended to, what links are created to the long-term memory, and what interpretations are made of the language used in the communication (Osborne & Wittrock, 1983).

Now, the idea of students actively constructing knowledge is not new, and many teachers have been constructivists long before they knew it! However, the theory of social constructivism does provide us with some useful recommendations for the classroom, so let's summarise a few of them.

1. Connect learning with everyday contexts. Where possible, organise courses around problems, of local interest and impact, which have been identified by students.

2. Elicit students' existing ideas, including any alternative conceptions.

3. Implement activities which build upon students' current understandings, and which promote conceptual change by challenging these understandings. Discrepant events (an event in which the result is different to that expected by many students) and student predictions (with reasoning), for example, are useful tools for confronting students' misconceptions.

4. Prepare and use higher order questions, questions which ask how and why, rather than what alone. Remember to allow wait time, since challenging questions demand time to think.

5. Encourage students to take responsibility for their own learning, and this includes reflecting on their own thinking and learning processes. "An appropriately metacognitive learner is one who can effectively undertake the constructivist processes of recognition, evaluation and, where needed, reconstruction of existing ideas" (Gunstone, cited in Tsai, 2001, p. 970).

6. Plan for both teacher-student and student-student social interaction (Tobin, Tippins, & Gallard, 1994). While constructing new understanding is a highly individual activity, communicating with others can enhance learning because it allows students to test their ideas and to consider the ideas of others. Small group discussions, cooperative learning, role plays, and simulation games, for example, all have a place.

7. Practical work needs to be an integral part of the learning sequence, rather than a "tack-on" for practical work sake alone. It also needs to be minds-on, as well as hands-on (Skamp, 1998). Rather than restricting hands-on activities to cookbook or confirmation-style experiences only, provide opportunities for more open-ended investigations which better challenge students' thinking.

8. Plan for the fact that, in addition to having different prior experiences, students will also have different preferred learning and working styles (Gardner, 1992) and learn at different rates.

9. Employ formative assessment frequently (Bentley & Watts, cited in Wellington, 2000.)

10. Use a variety of assessment techniques, including authentic assessment which is conducted while students are engaged in non-contrived activities like practical work or other real-life situations. This caters for diversity in the ways students represent their knowledge and understanding.

If this is the path down which we seek to travel, it is probably fair to assume that some of us are further into the journey than others, and that we all would appreciate any help we can get. By sharing classroom practices which reflect social constructivist principles, much of the content of *The Science Education Review* will assist in implementing the above recommendations.

The Constructivist Learning Environment Survey (CLES) (http://surveylearning.com) is a tool for assessing how consistent a particular classroom environment is with a constructivist epistemology. It may be completed on-line by students and/or the teacher, and the results are compiled and reported automatically. The plausibility of the CLES has been established, and its statistical integrity and robustness validated (Taylor, Fraser, & Fisher, 1997).

In accord with findings that students achieve better when their actual learning environment matches their preferred environment (Fraser & Fisher, 1983), the survey provides for responses to perceptions of both the *Actual* environment and the *Preferred* environment. Each survey comprises five scales: *Personal Relevance Scale* (addressing the use of everyday contexts, and the connectiveness between school science and students' out-of-school experiences); *Uncertainty Scale* (assessing the extent to which students experience science knowledge as arising from theory-dependent enquiry involving human experience and values, and hence as evolving and culturally and socially determined); *Critical Voice Scale* (examining the extent to which students feel free to question their teacher's approaches and to share impediments to learning; *Shared Control Scale* (concerned with the involvement of students in sharing planning, implementation, and assessment with the teacher); and *Student Negotiation Scale* (examining the opportunities provided for students to exchange and consider views).

The CLES could be employed in varied ways, and would be a particularly useful tool in action research projects. It could be used, for example:

- to assist teachers to reflect on their epistemological assumptions and to modify their teaching practices;
- to monitor the effectiveness of such attempted changes in practice to a more constructivist approach; and
- to evaluate the impact of constructivist approaches to teaching and learning on student outcomes.

A constructivist view can be a uniting view, because it can include so many strategies, like enquiry learning, cooperative learning, and science/technology/society, which have at times been labelled fads by some. "Far from being faddish, the teaching practices supported by constructivism represent the best practices of science teachers since time immemorial!" (Colburn, 2000, p. 12).

Peter Eastwell

References

Ciascai, L., Chiç, V., & Pop, A. (2002). Investigating and changing elementary school learners' conceptions in "sciences." *Science Education International*, *13* (1), 19-26.

Colburn, A. (2000). Constructivism: Science education's "Grand Unifying Theory." *The Clearing House*, *74*(1), 9-12.

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

Duit, R., & Treagust, D. F. (1998). Learning in science: From behaviourism towards social constructivism and beyond. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 3-25). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Fraser, B. J., & Fisher, D. L. (1983). Student achievement as a function or person-environment fit: A regression surface analysis. *British Journal of Educational Psychology*, *53*, 89-99.

Gardner, H. (1992). *Intelligence reframed: Multiple intelligences for the 21st century*. New York: Basic Books.

Osborne, R. J., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education*, *67*, 489-508.

Palmer, D. (2001). Students' alternative conceptions and scientifically acceptable conceptions about gravity. *International Journal of Science Education*, *23*, 691-706.

Skamp, K. (1998). Effective primary science teaching: Can we describe it? *The Queensland Science Teacher*, *24* (6), 2-9.

Solomon, J. (1993). The social construction of childrens'scientific knowledge. In P. J. Black & A. M. Lucas (Eds.), *The practice of constructivism in science education* (pp. 85-101). London: Routledge.

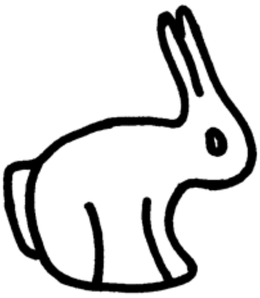
Taylor, P. C., Fraser, B. J., & Fisher, D. L. (1997). Monitoring constructivist classroom learning environments. *International Journal of Educational Research*, *27*, 293-302.

Tobin, K., Tippins, D. J., & Gallard, A. J. (1994). Research on instructional strategies for teaching science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 45-93). New York: Macmillan.
Tsai, C. (2000). Enhancing science instruction: The use of 'conflict maps.' *International Journal of Science Education, 22*, 285-302.
Tsai, C. (2001). A review and discussion of epistemological commitments, metacognition, and critical thinking with suggestions on their enhancement in internet-assisted chemistry classrooms. *Journal of Chemical Education*, *78*, 970-974.
Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177-210). New York: Macmillan.
Wellington, J. (2000). *Teaching and learning secondary science: Contemporary issues and practical approaches*. London: Routledge.
Yager, R. E. (1991). The constructivist learning model. *The Science Teacher*, *58*(6), 52-57.

Demonstrations

What do you See?

Look at the sketch below. What do you see? What do others in your class see? A rabbit? Now rotate the image 90º counterclockwise. What do you and others see? A duck? What do you conclude?



In identifying the features of the nature of science (NOS), Eastwell (2002) included that "different scientists can observe the same things, and interpret the same experimental data, differently" (p. 45). This activity might be used to demonstrate this point; and even that the same scientist can interpret data in different ways!

Reference

Eastwell. P. H. (2002). The nature of science. *The Science Education Review*, *1*, 43-48. (http://www.ScienceEducationReview.com)

The Magic Candle

Needed. A medium-sized candle, "Magic Candle" (a candle which automatically relights after being blown out, and available from party shops and some supermarkets), box of matches, and draft-free room.