An Interview with RICHARD T. WHITE
Una entrevista con RICHARD T. WHITE

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Abstract

Dr. RICHARD WHITE , Faculty of Education, Monash University, gives some suggestions on the conditions that help teachers to do their work effectively. WHITE discusses the meaning of laboratory work and the links between the laboratory and learning, and the importance of episodes in learning science. Learning science must not be restricted to learning facts, formulae and substituting numbers in them: laboratory work is an essential and vital part for the understanding of science. He also discusses the meaning of constructivism for a science teacher, and the value of the pedagogical content knowledge. If we believe that students can use their existing knowledge to interpret what they now hear, and that they might be constructing different meanings from each other and from what the teacher intended, we as teachers have to take this fact seriously. We have to check what those constructions are, and we have to act if necessary to amend them. WHITE also discusses the preparation and inservice support of pre-college chemistry teachers, problems faced by researchers in chemical education, and some of his opinions about teaching problem solving, the importance of pedagogical content knowledge, and the proper role of textbooks in instruction. Finnally he shares his view on how to rise standards in education: it all comes back to the central figure of teachers.

Key words*: constructivism, teaching strategies, episodic memory, alternative conceptions, metacognition.*

Resumen

El Dr. RICHARD WHITE , de la Facultad de Educación de la Universidad de Monash, hace sugerencias sobre algunas condiciones que pueden ayudar a los docentes a realizar su trabajo efectivamente. WHITE discute el significado del trabajo en el laboratorio y los vínculos entre laboratorio y aprendizaje, y la importancia de los episodios en el aprendizaje de la ciencia. El aprendizaje de la ciencia no se debe restringir a aprendizaje de hechos, fórmulas y sustitución de los números: el trabajo de laboratorio es una parte esencial y vital para la comprensión de la ciencia. Él, también discute el significado del constructivismo y la importancia del contenido pedagógico del conocimiento. Si se cree que los estudiantes pueden utilizar su conocimiento existente para interpretar lo que oyen, y si pueden construir significados diferentes entre ellos y lo que el docente intenta, como docentes, se debe tomar este hecho con seriedad. Hay que chequear estas construcciones, y si es necesario actuar para corregirlas. WHITE también discute la preparación y el apoyo a los docentes de química de secundaria, los problemas enfrentados por los investigadores en enseñanza de la química y su resolución, la importancia del contenido pedagógico del conocimiento y el papel de los textos en la instrucción. Finalmente, comparte su perspectiva de cómo mejorar la educación: para realizar esto, la figura del docente juega un papel fundamental.

Palabras clave*: constructivismo, estrategias de enseñanza, memoria episódica, concepciones alternas, metacognición.*

INTRODUCTION

RICHARD WHITE taught General Science, Physics, and Chemistry in high schools in Victoria, Australia, for ten years. He also had a year teaching at a teachers' college, a year teaching in New Zealand, and two years visiting schools to help the introduction of the PSSC physics course in Australia. His experience as a teacher and with the curriculum led to appointment as the chairman of the board of examiners responsible for the external examination in year 12 Physics for the state of Victoria. His interest in improving learning led him to research, completing his PhD on the learning of physics, supervised by PETER FENSHAM, in 1971. He then became a lecturer in Monash University's Faculty of Education, and in 1981 its Professor of Educational Psychology, then Dean of Education in 1994. He left the Faculty of Education in 2000 to found Monash University's office in London. He retired at the end of 2001.

Most of his work has concerned the learning of science. Research on GAGNÉS notion of learning hierarchies led him to ponder what it means to understand, and how to improve it. This drew his attention to episodic memory, in which he did research that included a twenty year long study of his own memory for events. He was one of the early investigators of alternative conceptions, and the first president of the AERA special interest group Cognitive Structure and Conceptual Change. He has also written on general aspects of education, including the organization of schools for better learning. Interest in metacognition involved him in the beginning of the Project for Enhancing Effective Learning.

RICHARD WHITE 's publications include *Learning Science*, (with DICK GUNSTONE) *Probing Understanding*, (with SUSAN SWAN) *The Thinking Books*, (edited with PETER FENSHAM and DICK GUNSTONE) *The Content of Science*, the chapters on science in the third and fourth editions of the *Handbook of Research on Teaching*, and numerous articles in research journals of science education, general education, and psychology.

1. Why did you choose to become a teacher?

No one in my family had ever been to a university. My grandfathers were a house painter and a wheelwright, my father a clerk, and my mother a dressmaker. Nor did I know anyone who had been a university student other than my teachers. So teachers were my only professional role models. I was aware, of course, that you could study to become a lawyer or a doctor, but neither profession attracted me. I liked physical science. I thought of engineering, but then there was the matter of cost. My parents were not desperately poor, but were not well off. The State offered studentships that covered university fees and paid a living allowance on the condition that you taught in a government school for three years after qualifying, so I thought that I would use that to support me through university, would teach the three years, then decide whether I liked teaching enough to continue. I thought that I would like teaching, since I liked people and was interested in knowledge, both of which teaching seemed to fit. So I did a science degree and a diploma of education, and taught.

2. What was the best time you had teaching?

The best of my ten years of school teaching were the five I spent with the same students, one group from grade 8 through to 12, another from grade 7 to 11. My getting to know these students so well, and their getting to know me, led to a productive, mutually supportive, and relaxed partnership that I recalled many years later when I was involved in projects on metacognition. The students and I were metacognitive then, long before the term had been invented.

3. What caused you to move from teaching to a university post?

I left schoolteaching for a negative reason and for a positive one. The negative one was that in the 1960s Australian schools were hit with a flood of enrolments, brought on by the baby boom that followed World War II, by immigration, and by increased community interest in education. The population doubled in a decade, and the secondary school enrolments went up even faster. Teachers, however, were from a depression period birthtime, and were scarce. The government of the day let class sizes soar and teaching loads rise, so that it became difficult to teach as well as one would wish. The government also began to employ as teachers people who were unqualified in any subject, untrained in pedagogy, and inexperienced in dealing with children. The first-ever strikes of teachers began. Morale fell. At the beginning of 1967 I found myself, in a high school of 800 students, the sole teacher who had a science degree, the one teacher of science who had any training as a teacher, and the only one who had ever taught before. So, as did many of my trained and experienced professional colleagues, I began to look for other things to do.

I managed to get seconded to the board responsible for school curricula in the State of Victoria, where I had the task of helping teachers with the then new PSSC physics course. I enjoyed this work; with the opportunities that it gave me to visit many schools, but it was never going to be for more than the short term. Here the positive reason for leaving teaching came into effect: I was still keen to help students to learn better, so I became a student again, doing a PhD on the learning of science. Of all the theorists around at the time, ROBERT GAGNÉ's notion of learning hierarchies seemed most relevant to the question of why some students learned readily and others not. I immersed myself in his writings.

Looking back on my PhD thesis now, it appears a dated and maybe over-precise piece of research, yet still has some value. Although you do not hear much about learning hierarchies now, curriculum designers and teachers could return to them with advantage. When I finished my PhD in 1971, there were no more than a handful of people who had completed one at an Australian university, and few Australian educationists who were active researchers publishing in international journals. In my secondment to the curriculum board I had an office in the Physics department at Monash University, and I had learned from the physicists that academics had to do research and to publish their results. Publish! Publish! was their cry. So I mined my thesis for articles, and sent them off to the most prestigious journals that I knew. My first article was in Psychometrika (WHITE, *et al.*, 1973), the second in the *Review of Educational Research* (WHITE, 1973 a), and others in the *American Educational Research Journal* (WHITE, 1974 a), the *Journal of Research in Science Teaching* (WHITE, 1974 b), and the *Australian Journal of Education* (WHITE, 1973 b). I am disappointed when I see people who have spent so much thought and effort on a thesis walk away from it when finished without turning it into published articles.

Although I taught science in school and much of my academic writing is about learning of science, I was never a Professor of Science Education. In my first university appointment I taught research methods and statistics. My chair at Monash University was in educational psychology, while the chair in science education was occupied first by PETER FENSHAM and later by DICK GUNSTONE. This was fortunate, because in PETER and DICK, and others including Paul Gardner and Jeff Northfield, I had colleagues who were ready to discuss and share ideas about the teaching and learning of science. Without them I should not have been able to produce much.

4. What does it mean to be a constructivist teacher? (WHITE, 1988 a)

A "constructivist teacher" is aware that learning is complex, and involves interactions between what students are told, what they know, and what they want to know. So the teacher checks beliefs before and after each topic, with a range of subtle measures – more than simple tests, which is why DICK GUNSTONE and I wrote our book *Probing Understanding* (WHITE, *et al*., 1992), to empower teachers with those measures. Constructivist teachers talk *with*, not *at*, their students. There is not, of course, *The one way* to teach, constructively or otherwise. There are many ways, varying with the personality of the teacher and the personalities and needs of the students and with the context in which they are placed. I can, though, proffer one touchstone. A participant at a conference asked me for a single recommendation to give to beginning teachers. I thought for a moment, then said, "Tell them: Listen, listen to your students. You will then know what to do." There is more to teaching than that, but listening is a necessary condition for constructivist teaching.

Unfortunately, conditions in many schools do not make it easy to teach as a constructivist. Constructivist teachers need to have a good understanding of what their students already know and believe. At the beginning of each school year the school usually puts them with students they have not worked with before, which acts against them having that understanding. The best teaching I did was when I taught the same students for five years in succession; and the worst when I spent a year in another country and was supposed to educate 320 students in ten classes, when I found it impossible to find out what they knew.

5. What should the structure of an ideal lesson be?

I doubt that there is one structure, or even that there can be an ideal lesson. There are good lessons and bad, better lessons and worse. Within good lessons, there is a huge variation. The structure of a successful lesson depends on the natures of the teacher and the students, the extent of their prior acquaintance, how energetic they feel at the moment, the topic, and many other variables. This is one of the reasons why teaching is so challenging, so demanding, and so rewarding as well as punishing an occupation.

There have been attempts from time to time to promote templates for successful lessons, such as the five steps that Herbart described in the early nineteenth century of preparation, presentation, association, generalization, and application. There is good sense in such templates, but they must not be taken as rigid systems. Teaching is too complex to be codified; it has to remain fluid. That is not to say that it is unstructured. It must be planned and purposeful, and there can be principles that guide decisions on what actions the teacher might make. I made a small start on setting out some principles in a chapter in the book edited by OSER, DICK, and PATRY, *Raising the quality of learning: Principles from long-term action research.* (WHITE, 1992) One of my principles is that though teaching method and learning style must match for effective learning of content, in order for new strategies of learning to develop teaching method and learning style must not always match. An experienced teacher can develop a comfortable relationship with a class, so that lessons go smoothly and the students learn without strain. That is good, but occasional introduction of a new form of lesson is essential if the students are to grow as learners.

6. Can you describe anecdotes that depict the effectiveness of your teaching strategies?

I think you need to ask my students about this! What I recall as particularly effective was the program I implemented with grades 7 and 8, in the first of the five years that I spent with the same students. The school had taken in its first students the year before, so that although it was to grow to cover grades 7 to 12, in this year it had only grades 7 and 8. I taught science to all four classes in grade 7 and all five in grade 8. I could see that repeat lessons could become boring for me, and that this boredom would communicate to the children. So instead of standing at the front to conduct lessons, I set up many small experiments around the room. Over the several weeks on each topic, the students had to move from experiment to experiment, and write an account of what they did and saw happen. An example is on expansion: there was an empty can, a large nail, a hammer, a Bunsen burner, and a pair of tongs. The students had to use the nail and hammer to put a hole in the base of the can, then heat the nail and see if it would still fit the hole. Then they had to cool the nail and try it again. Then they had to heat the hole to see whether that let the nail fit through. This arrangement worked very well. The students were motivated and busy, and learned not only some science but also how to write descriptions. I was busy, too, moving from student to student, asking and answering questions, but far from bored. In a whole term I wrote hardly a word on the blackboard, and did hardly any whole-class teaching.

When those same students were in grades 11 and 12, I taught them physics and chemistry. At the end of both years there were highly competitive on State-wide examinations. I am not an advocate of judging the success of a teacher or a school by examination results, but I was pleased that these people who had spent so much of their secondary schooling with me did outstandingly well in those tests, as well, I think, as enjoying learning science.

7. Is making sense different from knowledge?

I have written a lot about knowledge, and about understanding. You cannot separate the two. Making sense is *Not* different from knowledge, it is an aspect of it. Suppose that you teach a parrot to say "My name is Bobbo." It might even respond appropriately when you ask it "What's your name?" But does it really know its name? Does it know what a name is? Knowledge only becomes knowledge when it begins to make sense. Making sense is a process of linking the new information with experiences and other existing knowledge. This process is the heart of constructivism. Constructivism is not different radically from much other thinking about teaching and learning. It merely emphasizes that teachers have to take seriously the fact that students use their existing knowledge to interpret what they now hear, and that they might be constructing different meanings from each other and from what the teacher intended. So the constructivist teacher will check what those constructions are, and will act if necessary to amend them.

A range of depictions is possible for any complex or subtle concept. At an extreme, democracy for example can be represented as mob rule (as indeed some political commentators did in the mid-nineteenth century). So it is with constructivism. Some have criticized it as placing equal value on all notions that students might form about a phenomenon or topic, but that is so extreme a depiction it distorts the meaning of constructivism. Constructivism does not mean 'anything goes', that one explanation is as good as another. It does mean that people construct meaning for what they see or are told, and that that meaning is influenced by what they already believe and are interested in. It is hardly possible to challenge that.

8. Rarely experiments are true problems. Could you assess the proper role of the laboratory in physics? What are the links between the laboratory and learning?

Although you may well be correct in saying that school "experiments" are rarely true problems, this does not have to be the case. It is possible to devise practical work that involves a real problem. (White, 1980) Mike Watts did this, asking students to improve the acoustics in their school hall and to find ways of keeping food hot between the school kitchen and the cafeteria tables. (Watts, 1994) Then there are tasks to measure something, where the answer is not known beforehand. An example, which I invented, requires students to find out how much work is done in stretching a catapult, then finding out the kinetic energy of the projectile it throws, and explaining where the missing energy has gone. A little dangerous, but exciting. And practical work should have an exciting edge. There is nothing more dreary than an exercise to confirm an established principle such as conservation of momentum, where the students know the answer beforehand.

Laboratory work is essential for understanding of science. Bob Gagné told me that he once took a course titled 'Gentleman's Physics' – physics without any lab work. I asked him what Ladies Physics might have been, but he said that in his undergrad days ladies did not study physics! Anyway, what the laboratory does is give meaning to what would otherwise be sterile information or mathematical gymnastics. As it is, too much of physics teaching is taken up with substitution in formulae and learning of facts. Do not misinterpret this! I am not against learning facts or use of formulae, but against concentration on them to the exclusion of other vital parts of science such as laboratory work. What you gain from the lab are episodes. An episode is a memory of an event that you have taken part in or witnessed. (Gagné, *et al.,* 1978) Some episodes stand out as highly unusual and memorable, while others become generalised through repetition. Specific or generalised, they are vital to understanding. J.E. Gordon put it this way: 'Once one has watched the Brownian movement one's apprehension of the *nature* of heat will never be the same again. It is not that one can be said to have learned anything in an objective scientific way but rather that one has come to terms with the kinetic theory of heat at a subjective level. It is the difference between having a sunset described and seeing one.' (Gordon, 1976).

9. Can you describe some interesting and unusual experiences that easily attached into the episodic memory of students?

In my first year as an undergraduate, in a chemistry lecture the professor ignited carbon monoxide in a huge gas jar. The gas burned slowly downwards, with a blue paraboloid flame, and the jar began to emit a pure musical tone which rose in pitch as the flame descended. I have kept this episode alive in my mind for over fifty years; it is an integral part of my understanding of the transformation of energy.

Of examples from my own teaching, the catapult experiment is one. Another is the one I described earlier about heating the nail and the hole in the can. One that I would not do now, but which had a strong effect on students concerned density. I staggered into a grade 9 class with a large block, which was actually polystyrene foam though I had painted it a metallic grey. I pretended to be having trouble carrying it, then feigned a trip and dropped it in the lap of a student in the front row. I think that this got over the notion of density quite well, though at the risk of giving a student a heart attack. (White, 1988, p. 45).

Andrew Mackenzie (Mackenzie, *et al*., 1982) devised exciting or intriguing experiences for an excursion on the geography of coastlines, such as walking across mud flats where the students got stuck and had to be pulled out, and chewing leaves to emphasise that the soil increased in salinity as you got closer to the sea. The episodes that the students formed acted as anchors for information, so that months later they were able to recall facts about coastlines far better than other students who had been on a more traditional style of excursion.

In an important longitudinal study, Gustav Hellden has found students repeatedly recalling the same episode, over ten years, to explain phenomena (Hellden, in press). Theorists and researchers might do well to pay more attention to the role of episodes in learning of science.

10. What observations do you have upon the quality of the preparation and in-service support of physics teachers? Are they born good teachers or can good teaching be taught?

By being "born a good teacher," people mean someone who picks up the basic skills more readily than others. Of course, no-one is really a good teacher at birth. It is curious, but being good at teaching early on is not necessarily a good thing. My Swiss friend, Andreas Dick, told me that because he did not have many difficulties when he was training to be a teacher, he did not appreciate that there were subtle skills and techniques to learn. He felt that if he had had to work at his teaching, he would have been better at it after a few years. I am sure that good teaching can be learned; whether it can be taught is another matter. Certainly some arrangements and some programs are more effective than others in helping willing people to become good teachers. To expound on this requires a book, not a short answer in an interview. I will say here, though, that a major problem that few if any programs of pre-service training appear to have solved is the integration of subject matter knowledge and didactics. In many, I think most, institutions; teachers acquire subject matter from a different group of professors than they do for didactics. Science faculties and Education faculties do not work together closely enough. Fitting into four years or so all the science and all the pedagogy that a beginning teacher ought to know is difficult, and maybe impossible. So one thing that I should like to see in all programs is internship, in which for the first few years of teaching each beginner has the support of an in-school mentor. The mentors have to be good, though, and need training themselves in the art of mentoring. And there should be frequent opportunities for teachers to refresh and extend their subject matter knowledge. If we want good teachers, we have to take more seriously both their pre-service and their continuing education.

11. What great ideas of science do our students need to learn? What is the proper role of problem solving in education?

The great idea is that science is the noblest of the humanities. It is humanity's attempt to make sense of the natural world that we experience. It is our picture of the world. Men and women made it, and continue to work at it. From time to time we have to revise it, for it is not a final product, and never will be. Science is alive, not a dead language.

Problem solving is one way of promoting this idea. They have to be real problems, however. Science IS problem solving, so a program that does not emphasise problem solving is not about science, no matter what topics it includes.

Certain topics illustrate well the human side of science. Evolution, atomic physics, energy, electromagnetic radiation, molecules and chemical reactions, genetics and DNA are examples. It is a pity if curricula do not find space for the history of their development.

12. What is the future of science education? How important is pedagogical content knowledge?

I have no certainty on what the future holds for science education. If I had been asked in 1970 what it would be like in 2000, I should have been right in predicting that what went on in the mass of classrooms would remain much the same, but I should not have been able to foresee the shifts in research that I list in 13. below. What I should like to see, as against what I think will happen, is for many more longitudinal studies, many more comparisons of practices and outcomes in different countries (I do not mean more of the large scale international comparisons such as TIMSS, but more of the subtle and far more interesting sorts of study such as Svein Sjoberg has been doing). But will these shifts in research have any marked effect on what happens in classrooms? A pessimistic or cynical view is that they will not, but I live in hope and have a more positive belief. Why? Because the new styles of research are much more relevant to the complex life of classrooms than were the old psychological experiments carried out in artificial settings, and because many more teachers are active in research. The division between researchers and teachers is being broken. I take heart from projects such as the Project for Enhancing Effective Learning and Cognitive Acceleration through Science Education.

Pedagogical content knowledge (PCK) is a powerful idea. It is not so easy, though, for teachers or researchers to apply it in practice. I should like to see two things: one, a compendium of topics that lists many examples of PCK, the other a theory of content that enables you to classify topics in a way that guides their teaching. I made a start on the second of these in a chapter in The Content of Science, the book that Peter Fensham, Dick Gunstone and I edited in 1994. I guess I should have developed that chapter further.

13. What can be done to change conceptions?

That's what many people are working at. Identifying students' beliefs is a first step. Devising demonstrations to challenge them is another. But more is involved, including getting students committed to accepting the outcome of the demonstration. As teachers, we change students' conceptions all the time. But it is a long process, not often something that happens in an instant.

What's wrong with having some misconceptions? It depends whether they lead you into actions that cause harm to you or others. Here is a dangerous, if widely held misconception: "Skin colour is related to intelligence." This has led to viciously damaging actions. Failure to understand the principle of conservation of energy has made people vulnerable to frauds peddling perpetual motion machines – we had a politician in Australia who believed that you could use water as a fuel in motor vehicles. All of us have some misconceptions, but they matter because our view of the world is then more likely to lead us into error in action.

14. Is it possible to train in metacognition?

Of course. (White , *et al*., 1994) That is what the Project for Enhancing Effective Learning is about. Ian Mitchell was successful in promoting metacognition in his classroom teaching, and Ian Macdonald was successful in out-of-classroom tutoring. Even without knowing the word metacognition, outstanding teachers have been training their students in metacognition for centuries. If they hadn't, the world would have stagnated.

15. The Project for Enhancing Effective Learning (PEEL) started almost twenty years ago. How do you evaluate this experience?

PEEL is a remarkable phenomenon. Here we have thousands of teachers from hundreds of schools helping each other to do their work better. It has had almost no support or recognition from government, yet it has flourished for nineteen years and looks like it will continue indefinitely. Few educational movements last as long. I attribute its success to these characteristics:

— it is owned by the teachers who implement it, not by university academics.
— university academics support the teachers, with suggestions for new methods, with administrative resources, and with access to a wider community of teachers and scholars in other countries.
— it provides teachers with a forum for discussing and disseminating their teaching. Typically, teachers in the past have not been active at publicising their ideas or work; the PEEL publications have encouraged them to write, and have inspired others.
— it gives teachers professional connections that enable them to escape the isolation of their classrooms.
— it provides teachers with means for enlivening and diversifying their teaching, so that their work is full of interest. Experimentation relieves them from routine, and introduces a rejuvenating element of risk to the daily round.

PEEL is the most satisfying event that I have been associated with. My part in it is small, but I feel that it justifies my whole professional life. As a result of it, many teachers have found fulfillment in their work, and many of their students have learned independence as learners.

16. What are the major shifts in research style that have occurred over the past thirty years?

I set out the changes in research style in my chapter on science teaching in the fourth edition of the *Handbook of Research on Teaching* (White, 2001). To summarize them here:

(a) An increase in descriptions, as against experiments (the work on alternative conceptions is the most prominent example). Thirty years ago you would not find in research journals any accounts of what happened in a classroom, no transcripts of interchanges between teacher and learners. Nearly all articles compared the success with regard to performance on a test of one form of teaching with another, and in most cases the teaching programs were brief and artificial.

(b) A decline in use of inferential statistics. In the experiments of 30 years ago you often compared one group's scores with another's, and wanted to know whether the difference between them was real or could have been a result of random variations in sampling. So you applied statistical tests such as analysis of variance, chi-square, t-test, and so forth, to see if the difference was 'statistically significant.' There was nothing wrong with this, and I should like to see more use of inferential statistics nowadays, rather than less. But one of our shortcomings 30 years ago was that we gave much more attention to statistical significance than we did to educational significance. Sure, the difference between the two groups was more than was likely to have happened by chance, but did it matter? You could often get statistical significance by having a large enough sample, even though the actual difference between groups was small.

(c) An increase in the diversity in measurements, with pencil and paper tests being replaced or supplemented by interviews, classroom observations, field notes, etc. You will have to look hard to find any accounts of interviews in early research. In hindsight, this is rather strange. We treated the subjects of our research as if they had no thoughts of their own. They were there to write answers to our questions. They were like laboratory animals: to be cared for, and to have their reactions monitored, but not to initiate a conversation or free to make comments.

(d) An increase in attention to content as a variable of great importance. In most experiments of the 1970s, and later, content is a vehicle, not a variable. As far as the experiment was concerned, any content was as good as another. Piaget's visit to the United States in the 1960s stimulated awareness of the subtleties of content, and was a precursor of interest in alternative conceptions.

17. You discuss the need for a theory of content. Could you sketch some traits of this theory?

Content is not homogeneous. Different forms of content need to be taught in different ways. A theory of content will identify dimensions on which content varies, and so give a lead to how any particular topic might be approached. Of course other constraints come into it: time available, class size, resources, examination system, abilities and motivations of the learners, teacher's relations with the learners, and teacher's repertoire of procedures, but the nature of the content does matter. In *The Content of Science* (White , 1994) I listed several relevant dimensions: openness to common experience, abstraction, complexity, presence of alternative models, presence of common words, mix of types of knowledge, demonstrable versus arbitrary, social acceptance, extent of linkages, and emotive power. This led me to predictions, such as

> "discussion of students' beliefs will be advantageous for topics that are open to experience and concrete, and harmful for topics that are closed to experience and abstract."

More predictions of this form would provide a useful guide to teaching.

18. In your career you had administrative responsibilities. How hard is it to reconcile ideal educational practice with the 'limitations' of financial and administrative restrictions?

In every aspect of life we work within limitations. The trick is to not let the limitations become an excuse for sub-standard work. Rather, you try to find ways to evade the limitations. Sometimes it is surprising how much you can achieve with limited resources. PEEL, for instance, started with no money; the school administration did help with time-tabling, but nothing more. At the end of its first year I found a thousand dollars to buy the teachers out of school for a day, so that they could write their accounts of their experience in trying to get their students to be metacognitive. We got great value out of that thousand dollars. In my own case, I did some of my most effective teaching in a school that had limited facilities. It has to be admitted, though, that financial and administrative restrictions can handicap teaching. See my response to 18. below.

I had not sought senior administrative responsibility in the university, being happy as a research and teaching professor, but felt obliged to become the Dean of Education at Monash when we needed someone to defend the Faculty's interests. I was 58 years old at the time. If I had taken it on when younger, I think it would have inhibited my research. As it was, I kept up a program of academic writing, by scheduling all meetings over which I had control to begin no earlier than 11 am, so that I could write for a couple of hours two or three days each week.

On a broader scene, financial restrictions do weaken practice. At Monash, in the pre-service program for teachers we used to have tutorial groups of 15 to 18 in size; government support of universities in Australia has become less and less generous, so the tutorials are now close to 30 students each. The program has to be less effective, and less satisfactory to the students, as a result.

19. What are the greatest ideas that have been made available to science teachers by educational research?

I'll restrict myself to a handful. The notion of alternative conceptions is a fundamental contribution of research to teaching. Whatever people might think now, before researchers began to uncover alternative conceptions in the 1970s, teachers were not aware of their existence. I recall going with Audrey Champagne to a school near Monash University to try out some of her probes of understanding of mechanics, and the astonishment of the teachers at what the probes revealed about their students' beliefs.

Research on alternative conceptions made prominent the notion that learners construct their own meanings from what they see, hear, and experience, which is fundamental to good teaching.

Research on discovery learning, though often not well designed, had much influence on the teaching of science from the 1950s onwards. It is, perhaps, the forerunner of the work on metacognition, which is a powerful idea for teachers.

Although there may be some way to go before it has full effect, investigations of different treatments of boys and girls in classrooms and the associated idea of gender equity are important.

20. Is it possible to raise standards in education? If a politician asks you for advice, what will be your recommendations?

Of course we could raise standards. It all comes back to teachers, and what it is possible for them to do. Conditions must be such that teachers can do their work effectively. So I should recommend the following to politicians:

— pay teachers more. Business leaders are fond of saying, when talking of their own remuneration, if you pay peanuts you get monkeys. Why shouldn't this apply to teachers? Pay is related to self-worth. Pay teachers more, so that they feel valued and feel obliged to do outstanding work.
— introduce sabbatical leave for teachers. Let them experience life beyond the classroom.
— keep class sizes small. This is absolutely essential.
— fund frequent in-service training.
— forget about mass testing, that you like so much at present. It distorts education, and acts against the outcome of good learning that you value.
— build schools that provide surroundings that are as attractive to work in as large business centres.
— stop the fragmentation of education, in which students in elementary school have a different teacher each year, and students in secondary schools can have as many as ten different teachers a week. I wrote about this in two articles, Research, and the end of schools as we know them (White, 1984), and Questionable assumptions underlying secondary education (White, 1988 b), but you took no notice. If you want students to learn well, then they have to know their teachers, and their teachers have to know them. I know what I am talking about, from my own experience – at one time I taught the same students for five years in succession, and it was the most rewarding time I had in teaching, both for me and for my students.

I know that most of these recommendations cost money. But you are pouring huge sums into schooling now. For 5% more, you would get 100% increase in return. Isn't that a good deal? And if you cannot find the money to change the whole system at once, why not do it for one or two schools and see what results? You will be astonished.

Maybe one day a politician will ask me about this.

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