Chapter 5

The Constructivist Classroom - 1990 to 1996

Questions:

Who is this person teaching physics?

What do I have to know about this subject and what do I have to teach?

How am I going to teach it?

What does it mean to teach science as opposed to being a scientist?

What is scientific inquiry?

Introduction

Parker Palmer (1993) says that when we think about teaching we often think about the *what, how and why* and tend to forget about the *who* that is doing it. As a beginning teacher in 1990 I was naturally concerned about the *what, how and why* of what it was that I was being asked to teach. How I approached these questions depended very much on *who* I was. So I start this chapter by situating myself back in 1990, speaking with the voice of a naïve teacher coming to grips with their craft. I have one foot in the scientific modernist camp and the other in the spirituality camp and am trying to reconcile the contradiction of these through the development of 'living educational theories' (Whitehead 1998) which I am testing through praxis. Who am I in 1990? What are my contradictions? How does my journey unfold?

Who is this person teaching Physics?

1990. It is my first year of teaching and I have been asked to teach physics. I am in a brand new college (Year 11/12) and I am the only physics teacher. The light blue/green paint is barely dry in my physics classroom; it is full of light with lots of windows with bright red frames. It has desks which can move, power cords suspended from the ceiling, a door to a grass area outside and a large prep room filled with spanking new equipment. It would be a teacher's dream, or would it?

There is an assumption that I am a physics teacher (because I have a degree in physics) and that being a 'physics teacher' is a coherent entity with certain experiences, understanding, attitudes and pedagogy. But the physics course is the anti-thesis of all I represent – in pedagogical approaches and its ways of inquiring and being in the world. I am confused I don't know how to approach the teaching of physics. I don't know how to be true to myself. I just know that I want to ensure that my students aren't indoctrinated into believing that what they are learning in physics is a true representation of the universe.

With hindsight from my 2006 standpoint I can perhaps best explain the inner tensions by demarcating these into three different selves – my science self, my pedagogical self and my spiritual self.

1. **My spiritual self** – this is the self that is engaged in inner spiritual practice, trying to be a better person, wanting to be of service to others and the world, struggling to make meaning of the Kosmos, and wishing for enlightenment. This is my intuitive and reflective self.

   My spiritual self has been shaped by enculturation in my childhood into Anglican Christian perspectives, my denial of that after being exposed to other religions, a determined search into creating new meaning through study across a wide range of esoteric literature, and through a determined path of self development and self realization – relationship work, experience in different healing modalities, inner practice.

   My spiritual self struggles to articulate what spirituality looks like in education, initially confused between spiritual bodies of knowledge, spiritual being, and spiritual processes. My spiritual self wants to understand who we are as multi-dimensional beings and what this means in teaching. This self struggles to reconcile teaching for subject outcomes versus teaching for the whole person.

2. **My science self** – this is my disillusioned self, feeling that science is narrow, problem-making. Yet this is the self required to teach science well. This is the self that is struggling to juggle science teachers' perceptions and requirements of science teaching with my own critiques of science. This is my analytical self.

   I have been enculturated into thinking about science in a particular way through my experiences at school, university and then as a practicing scientist working in industry… science is objective, 3rd person, methodical, analytical, validated, technically reported, independent of the researcher. However, my reading of spiritual literature has challenged this… subjectivity of research, other ways of knowing and being, other levels of reality, the issues with reductionistic and materialistic worldviews in creating world problems.

However, this scientific need for truth and answers, objectivity and generalisability is still very much a part of my make up. I might not be searching for truth in the arena of science but I am still searching for it in the broader Kosmos.

3. **My pedagogical self** – this is the self that wants to be a good teacher, creating good student outcomes. This is the self trying to reconcile good student outcomes required by the system with the good student outcomes that I believe are important based on my spiritual beliefs and my own positive experiences of learning. This is my pragmatic and action inquiry self that is on a journey of coming to understand my students, what learning is and what helps learning.

   My pedagogical self has been shaped by my previous experiences of learning. The very positive authentic learning experiences that I have had working as a scientist, economic researcher, coach and being part of a national enterprise team has shown me that there is a lot more to learning than traditional methods that I experienced while at school and university. I now believe that effective learning occurs through questioning and inquiry, collaboration, authentic projects, enterprise style learning, role plays, just-in-time training or just-to-late debriefing.

   This pedagogical self is also shaped by my experiences within particular school cultures in my roles as teacher and manager, by the metaphors which shape our state wide curriculum frameworks and conceptualization and by our western progress based culture, much of which are invisible to me at the time.

   This self is being challenged by my experiences in the classroom, by my trying to reconcile spirituality and science, by my leadership in the professional learning of teachers, my exposure to new perspectives and my processes of reflection.

My pedagogical self is I believe the 3rd space (Taylor 2006) which enables the playing out of the major dichotomy between my spiritual self and my science self – two distinct cultures. In the past I have been able to compartmentalize my spiritual self and my scientific self, living reasonably happily. But in the pedagogical space of the classroom this is not possible.

In asking *how can I help my students to learn better?*, my spiritual voice might ask, *Why is that particular learning important?, What assumptions are you making here about what it means to be a human being?* and *What is your role in helping students to realize their being?* Tension is created as I reconcile one way of thinking with the pragmatic requirements of another way of thinking and teaching. This playing out of the tensions results in all three aspects of self being perturbed and transformed, creating new possibilities and perspectives.

But I am getting ahead of myself. Who was I in 1990?

A person starting on a journey. Let us open the door to the physics classroom. A possible place for reconciliation of science and soul.

No please, can you close it again! I don't want to go in there!

I really DO have a problem with physics!

My problem with physics 1990

> *Physics tries to explain the whole cosmos, without realizing that the way it is doing it is narrow – only looking at the material world, only using one epistemology.*
>
> *It believes that it can find the Theory of Everything (TOE) or Grand Unified Theory (GUT) and if we are lucky it will be a formula that you can stick on a T-shirt.*
>
> *Physics aims to break things into bits. When you see only the parts, can you see the emergent holons?*
>
> *Some people think that physics explains atoms which explain chemistry which explain biology which explain psychology which explain love.*

The Newtonian idea, that once we break the world into bits we can determine exactly what happens next, is a powerful metaphor which has permeated modernistic society, effecting how organizations are structured including schools with grades and standard tests.

While Quantum Theory challenges this conception of the world, it is not widely understood nor applied to contemporary life.

Systems Theory tries to unite the 'bits' in a web of relationships, but reality is still demarcated in parts, relationships and whole systems.

Even Quantum Theory and Systems Theory only examine the material world and can not tell us the nature of spiritual reality.

Many problems in the world today are caused by the partial views that people bring when applying scientific methods, and Newtonian paradigms.

My problem with 'my problem with physics'

How then can we see the whole of reality and come to understand it?

If one tunes in at gnosis level, seeing with the spiritual eye, could one build a bridge that would be safe? Would we even need bridges?

Should I be teaching students to tune into reality with the eye of the spirit in order to 'come to know' that reality and appreciate it? Would this experience be something you could 'understand' or do you still need to differentiate and unpack what you experienced?

When you look at the universe with a spiritual eye, can you appreciate what you are seeing better if you already know the formula for gravity, or does this limit what you see?

Does the spiritual reality leave footprints in the physics reality as clues to the meaning of life? Is it seen in the symmetry, the beauty, the fractals, the quantum connectedness? While physics only looks at physical reality can it remind us to look deeper into the very heart of the Kosmos?

My problem with teaching physics

> *Am I perpetuating the idea that when you break things into bits you can understand them?*
>
> *The Physics course itself is a composition of bits. This topic follows that topic. A building up, bit-by-bit of knowledge. Is this the only way to teach physics? What metaphors about learning am I perpetuating here?*
>
> *I am reading about North American Indians. They don't have a separate word for a tree, rather man and tree… because the way they perceive the world is in terms of relationships. I look at a tree and still see it as separate from me. So what informs this way of seeing the world where everything is automatically in relationship? Is it a spiritual knowing or something that is a cultural perception? It seems beyond a systems understanding of reality. What might it be like to be brought up in this culture? Would I see differently?*
>
> *Who are my students and what deep insights do they have already about the grand nature of the Kosmos? What is a learnt habit, or a misconception at a mental level, and what might be a deeper inner truth?*
>
> *If I can't see nature with a 'spiritual eye' or a 'relationship eye', how can I help my students to see nature in such ways? And how would I know when my students might be using such eyes?*

The physics teaching culture 1990

While I think I might be able to close the door to my physics classroom and do what I want, I am being naïve; I am not an island, but a member of a community of teaching physics practice. The traditions, practices, attitudes and expectations of my state-wide science colleagues shape and constrain my own ways of thinking about how I teach, what physics is and my selection of practice.

My physics colleagues are all male and I am the only female in this community. I feel like I am a completely different species. In my conversations with the other teachers I realize that there are top dogs and these are the people who *know* the most. And are we actually having conversations? One person states their view and another theirs. Information. And sometimes there is debate. I am on the outer, alienated, not part of this club yet. It seems I have different aims, ways of doings things and ways of wanting to be and talk with people.

As we share materials with each other I find I am given examples of instruction based experiments – here is the formula to be tested, the method to be used and then the graph that is to be plotted.

It exemplifies all that I hate about science. Closed, empirical, mechanical, impersonal. It is counter to my own experience as a scientist who was engaged in finding out the unknown through a range of inquiry processes; some relying on the scientific method, some requiring imagination and insight as well as dialogue with colleagues and negotiation with the wider scientific community.

It seems that I am in a culture of physics as a *body of knowledge* and science inquiry is following a recipe prepared by the teacher. The syllabus is a list of important knowledge that we have to get across to the students. The experiments are there to give students technical 'know how' and experience of the scientific method within the context of this knowledge.

We are a community of *tellers* of physics knowledge and I am a member because I can not yet conceive of any other way. The *telling* is based on a standard logical development of ideas with intermittent experiments timed to follow in the double period. Is there any real understanding of what is going on in students' heads by we teachers? It is assumed that when students regurgitate the correct answer in tests that they have the right understanding. In moderation meetings we look at students work and decide on their marks based on how well they meet the expected answer. There seems to be no reading between the lines to try to understand the thinking of the student.

Fig 5.3

Do I understand the thinking of my students? What do their questions tell me? Am I interested in *how* they are thinking about what I am *telling*, or do I see their questions as a way of guiding my telling – making it more efficient. Why are my students so passive? Why

are they afraid of tentative scientific ideas and want to know what the right answer is? How can I engage them in a meaningful process of inquiry into the mystery of the universe?
I feel that I have been sucked into a vacuum cleaner with no way of finding the way out. It is dark and dusty in here. I am in a box and the lid is firmly closed.

> "In order to be better teachers we need to understand how our students think."
>
> Parker Palmer

How did I and my physics colleagues move? A key force was participation in a number of workshops over several years which looked at constructivist research and teaching practice and challenged us to realize that what we thought students were thinking was actually not the case. The videos we watched, where students were interviewed after university about science ideas learnt at different stages through their education, were a revelation to all of us. Seeing students argue eloquently to defend their alternative frameworks despite conflicting evidence was incentive to find out what in fact my students really thought and how they constructed knowledge. What were they keeping to themselves that my current teaching practice hadn't enabled them to articulate and explore?

Practicing constructivism 1992

So here am I now participating in workshops on **constructivism** which are being run for science teachers state-wide, particularly with the aim of encouraging girls into the physical sciences. (Later I find out it is the *trivial* version of constructivism). We are informed by 'how to' and 'why' papers on constructivism such as Hart (1987), Yager (1991), Tasker (1992), McDermott(1993).

I am looking at ways to *build up* students' understanding of concepts, rather than just *tell* them the concepts. The students aren't a blank slate but are bringing their own ideas and knowledge to thinking about the ideas. The

Constructivist approach

Finding out what students know -
- initial explorations
- brainstorming
- challenging question, quiz questions
- think / pair / share

Using contexts that are relevant

Enabling time to process knowledge – reflecting, discussing, predicting, designing, theorizing, applying

Opportunity for students to discover and theorize for themselves - making their own meanings.

Showing the relationship between ideas and the whole

Experiments:
- connect to previous experiences
- reinforce or build key concepts
- avoid unnecessary jargon
- time to become familiar with technology and jargon
- opportunity to be creative
- students can focus on one aspect of inquiry cycle (explore, predict, design, experiment, apply)

Fig 5.4

meaning they make is not necessarily the one I intend but personally constructed.

So my role as a teacher in front of the class is to probe for students' previous understanding by using some initial activities which help them focus in on what we are doing… to remind them what they know already. This could be asking a question, giving them some case studies to think about, getting them to explore some different phenomena, asking them to brainstorm.

Then I look at ways to effectively *build* on their knowledge. As I introduce activities or explanations I test to see how students are making their meaning by asking questions and giving time for students to tease things out with their partners (think – pair – share). I am mindful of how I talk one-to-one with my students.

A sample of the types of questions which can cement understanding:

Paraphrasing –
- explain it in your own words.
- Imagine you are explaining it to a 9 year old
- What are the key points?

Apply it
- List things that could use this principle
- What are advantages/disadvantages for using it in this case?
- How might this application work using the ideas we have discussed?
- How could this idea be used in a completely new way?

Your questions
- List 3 questions you have about this
- If the discoverer was here today what might you ask?

Commitment
- Predict which of these possibilities
- Pre and after quiz.

Fig 5.5

So rather than just giving an explanation to their questions, I am first finding out what they know and guiding them to the process of coming to understand. The more I model this process of thinking, the more autonomous they seem to become in their thinking. I am making the process transparent (but not yet explicit).

The workshop presenters suggest that classroom scientific experiments are an opportunity to build concepts as well as to develop technical skills and I begin to reconceptualise them not as instruction based experiments but as investigations or inquiry into those concepts.

The workshop presenters also explain how students might take on board knowledge in the classroom in order to pass the exam, but go through life using a different set of knowledge. There is a compartmentalization… perhaps because the students haven't really understood the physics ideas in the first place and they are not connected to their everyday reality…. the ideas do not have meaning for them.

The way physics is often taught is using sterile metal objects, complex indecipherable equipment, denuded diagrams of abstracted objects; it is not stuff that happens to bodies and real things. Therefore, they say, providing real contexts, making it personal, building understanding and eliciting and challenging misconceptions helps students to reach the agreed truth of scientific knowledge.

So science can be personal now? Is this giving me permission to think about science in another way?

I want to make physics more meaningful for my students… meaningful in that they engage with the subject knowledge, meaningful in that it speaks to something within them and engages their souls. To have the latter, I think, you need to get the former right. Students need to understand before they can be inspired by it!

How can I make it more understandable?

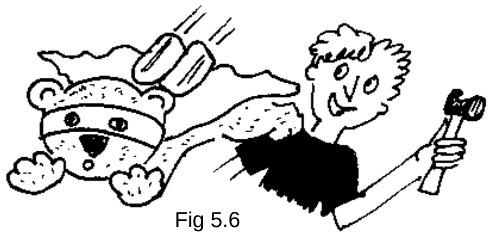


Fig 5.6

So I go to Kmart and buy bats, balls, dinky cars and skateboards. I look at getting students to use everyday items that they are familiar with. We don't use metal objects, but propel teddy bears through space. Students get to look and feel how these real objects move. They get into the spirit of this… they bring in a bear with cape, steel underpants and goggles for an adventure on a flying fox propelled by soda bulbs. They bring in Barbie dolls to sit in big toy cars that they will roll down slopes. They make up stories.

They are 17/18 years old but they seem to have discovered a second childhood of play and fun and there is a lot of laughter in my classroom. They vie with themselves to come up with the most quirky or creative thing and their presentations involve rap music or plays which are a context for their scientific explanations. The bear becomes the class mascot and even travels on excursions.

Students now also seem to be a lot more focussed on the 'real physics' – the worksheet problems (which now have Mr Bean and Raiders of the Lost Ark questions, so we can see whether some of those actions are really possible) and are more responsible in their learning.

I am beginning to see how much time I spend on *telling* the conventional physics story through my notes on the board, rather than allowing the students to discover and create meaning for themselves. I realize I am still spoon feeding, but in a much more effective way than before.

I look at making the experiments even more open ended, enabling students to explore for themselves rather than following my constructivist steps and get quite a shock in one experiment. I have asked the students to discover all the variables of an oscillating spring and one group comes up with too many variables, and can justify their conclusions based on their results. I look at the boy with lots of things running through my head, and finally release the need to have a pat answer. We then have a conversation together and I unconsciously move from *teacher* into *scientist*… looking at how we might find out why. Perhaps by me moving into this mode I gave him permission to be a scientist instead of a mere learner of ideas.

He went on to do a PhD in physics, I now reconceptualised my role in the classroom. I was teacher, constructor of understandings, designer of activities… but also someone who enjoyed the unknown and could trust in her skills as a scientist to explore what I didn't know with the students. And this very exploration opened a whole new way of teaching.

So now, when students ask me to help them with their physics problems I begin to listen to myself. How much am I constructing *their* understanding and how much is *my own* understanding being challenged? How might we be constructing understanding together? I find myself moving from saying *"Now how are you thinking about it? OK, so when I do this, what do you think is going on? What about when I do this? (disconfirming)… OK what conclusions can you make? …OK, how could you use this in your problem?"* to *"That is an interesting take on it… how could we test it?"* Or *"Let's tease that out more, what could support your argument."* or *"You know I haven't thought about that aspect of it before…. I wonder if…"*

Students are actively coming up with their own hypotheses and explanations of how things work and happen. I am doing less explaining. There is now a need to do quick experiments or checks outside the set activities to test these hypotheses and I usually have trolleys set up with lots of bits and pieces so students can cobble together what they need. I begin to give them free reign of the prep room (to the horror of the lab technician). At first they are proud to be given such responsibility and then it is just an expected part of what we do… we certainly don't wait for the double period to test things out.

Students now seem to be all doing different things within the context of our task for the day, and I realize that a classroom which has multiple activities going is actually very stimulating with lots of cross fertilization. There is now a sense that we share what we find rather than keep things to ourselves. The point is to advance the whole understanding of the group, rather than for an individual to prove that their thinking is theirs alone because of assessment requirements. The marks of most students improve and they seem to value this collaboration.

As I start asking students to tell me what they are thinking I begin to realize the interesting ways that they have thought about things and how they put ideas together. I begin to listen more and hear beneath the lines. It makes me question what I know and I become a lot more thoughtful about the physics. I realize how much I have had an agenda in my head about getting across the *true physics* version without being aware of other possibilities. I had been seeing myself as *guiding* students into the *right way of thinking*, or correcting misconceptions rather than being co-constructors of understanding with each other.

Fig 5.7

At first my students' thinking process seems quite sloppy… like an unused muscle and then they get a lot better at it. I wonder how they think and the process of thinking. Can I be better at this if I knew more about how understanding is constructed? Is learning made in the head?

Yet I am also very much valuing learning from personal experience – after all I am teaching enterprise style pedagogy in my other classes. How does this supervised meaning-making fit in with the more holistic approach to learning that enterprise gives, where learning is something that emerges from the experience? How am I taking into account the wholeness of my students?

Where is the soul in all this? The laughter? The curiosity? The wonder? The meaningful questions? In the way students be? In my improved relationships and understanding of my students?

What is science now? Does science lie in the thinking that we are doing, as well as the content that I am trying to get across? Is what we are doing *scientific thinking*? It seems to be a whole lot more. Are we now becoming scientists as well as learners of science?

Hmmm. I am so involved now in teaching science well, have I enculturated students into a scientific worldview which I disagree with? How can I counteract that? By giving other worldviews? By providing other ways of experiencing the world?

We seem to be moving from *learning information* to a much deeper understanding of the ideas. I am still in control of the classroom and the activities that we do but the students seem to have a lot more control over their thinking. I think I am giving them enough space to think for themselves.

How am I feeling now? Energetic, creative, inspired, captivated and surprised with my students and their ideas. I feel free to move from the seriousness of getting across a science syllabus, to being much more playful and relaxed. Classes are fun.

What really is scientific inquiry?

Now during this time (1991 – 1993) there is a major change in the state wide curriculum framework with movement to *criteria and standards based syllabi* instead of students getting one final mark which is *norm referenced* (students ranked in their classes and across the state). Some good thinking has gone into the new physics syllabus – giving it some process criteria reflecting aspects of the scientific method as well as content criteria. The students still sit an external exam but now the internal marks have more relevance.

I have been part of a committee coming up with standards for the course so I have benefited from being part of the creation process – not just being part of the dialogue, but also gaining a deep understanding and ownership in the new way of thinking about science learning.

But many teachers are unhappy with the physics syllabus. For example, it has one criterion on

Physics Criteria:

1. **Acquire information**
2. **convey** information *
3. safely and correctly **use** a range of scientific **equipment** to gain data
4. **design experiments** to solve problems or test hypotheses
5. **perform** practical **investigations** individually or in a group
6. **analyse data** gained from student's own practical work
7. **formulate generalizations** and make realistic predictions based on data *
8. demonstrate knowledge and understanding of the ways that Physics impacts on technology, **society** and the individual
9. demonstrate and **apply knowledge and understanding** of terminology, definitions and laws, concepts, theories and models and uses of measuring instruments of physics *
10. incorporate techniques of analysis and mathematical manipulation to **solve** complex **problems** *

* examinable criteria

Fig 5.8

students' ability to hypothesize and design experiments which I am really excited about. But there are some other teachers who say they can't measure it.

The more I allow my students the freedom to think, the more I am seeing a greater ability to hypothesize… but how am I judging this… it is so subjective… but I think I am seeing a definite change into more rigorous and iterative thinking which is way beyond the initial simplistic thinking my students have when they start my classes.

But some other teachers do not feel comfortable using subjectivity to determine students' standards - it has to be objectively measured, they say. But the disagreements between my peers now fuel discussions in areas we haven't really talked about before. In our moderation meetings we find we are spending more time discussing the *processes* of science as much as the *content* of science. We are needing to tease out what each of us mean by hypothesis and inquiry and this is helping us to become more transparent about our expectations. It is difficult at first trying to explain things which up to now have been largely intangible… trying to describe what they might look like and sound like in a classroom but we are beginning to create comparable indicators of what these things are.

So what is the *scientific method*? I have never actually been *told* what the scientific method is. I have inferred it from how it was taught to me in school and university science classes… *an aim, hypothesis, method, experiment, data, analyse, error discussion, conclusion.* Usually the aim, hypothesis and method were something that you were given rather than establishing yourself.

Is this a *scientific inquiry process* or one way of *reporting* science? It seems that many of my colleagues also associate the *reporting* of experiments with the *process* of doing experiments… that is how their experimental instructions are written. However, this reflects neither the reporting nor the process I used as a scientist working in industry.

But now there is an opportunity to reconceptualise the science inquiry process. The central curriculum office for the state have been developing inquiry sequences for primary and high schools; disseminating diagrams which have *cycles*… explore – observe – hypothesize – test – analyse – share and compare.

Scientific Inquiry process

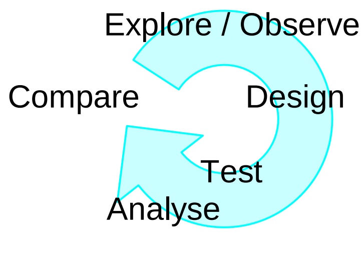


Fig 5.9

How is this model different to what we are already doing?? A key aspect is the notion of *exploring* first, rather than jumping into doing an experiment. There is more a sense of ownership in the students investigating into something rather than following a set of instructions. This cyclic process seems to better reflect what I was doing as a scientist and I embrace it… again redesigning my handouts to encourage students to engage with this explicit inquiry cycle.

I begin to realize however that some students have certain expectations about the inquiry process when they come to my classes… some expect to have points falling along lines in their graphs rather than being scattered, some can't cope with error as they conduct their experiments and some expect that what they measure will be right, regardless of applying inappropriate theory or methodology to a situation. Most want to write their lab books *after* the experiment neatly, rather than seeing a log book as something that records what they are doing *at the time*. Most expect to write their reports as aim, single hypothesis, method, results, discussion, conclusion… despite my efforts to change this culture.

I encourage them to put themselves into their log books – to use 'I' and 'we' rather than third person objective voice – to be personal, because that is being honest about the ideas and theories that they are bringing to what they are looking at. I feel I have permission to do this as the quantum paradigm says that we are no longer impartial observers of science, but we actually influence what we try to find out. But many of my students are uncomfortable with doing that and stick to writing reports neatly in 3rd person voice weeks after they have done their experiments.

I want to help students be more flexible in their thinking rather than these seemingly black and white, right and wrong views I often hear. I want to break down their need to get something 'right' and open them up to the idea that when we experiment we are *discovering*, not *proving* or *pre-empting* and it is an iterative process of refinement.

I get students to predict possible outcomes for experiments and give their reasons. I give them time to listen to each other and change their minds and to enter an experiment with multiple views, rather than a single expectation of what they might find. Afterwards I encourage them to examine their hypotheses and ask how they can refine them and how these hypotheses might have influenced their thinking. It is iterative. I am wanting them to learn to take risks with their thinking, rather than holding onto a fixed viewpoint. It seems that by establishing a culture where it is OK to change your mind that students become more playful and collaborative with ideas.

Perhaps we are now moving from *playing with objects* to *playing with ideas*. Perhaps we needed to learn how to be playful in a concrete way with teddy bears, before we could do it in an abstract way?

I wonder how I can be more playful with my colleagues. My whole manner at our meetings seems to move now into this playful mode where I tease and laugh and throw in the unexpected. But being playful means being open to changing my mind as well… yes, I can do it and I find that there is a lot to gain from my colleagues as many like me are experimenting with their teaching, coming up with innovative practice. It seems that both the change in curriculum framework and the infusion of constructivist theories has created a renewal in science teaching in the state. And many of us are enjoying sharing what we have learnt, and are building on each others' ideas. And quite a few teachers who take away my worksheets and ideas come back the following year and tell me how they went – usually very well! I am heartened to continue experimenting with my teaching.

I now wonder about actually using the experiments as **morals** to teach about the *nature* of science inquiry. So rather than improving the experiments so that they have less error, or are less prone to having inappropriate methods used, I use these to point out the issues with empirical inquiry.

So the purpose of a conducting an experimental investigation could be to develop technical skills, to develop skills in the scientific inquiry method, to develop understanding of key concepts and to develop attitudes about science and science inquiry.

My view of the scientific method is becoming more flexible. However I am still regarding it as a sequential and rational process. I am far more explicit to myself about what science inquiry is and as a result I can make it explicit to my students.

The following year I worked with a University physics lecturer in helping him create a more constructivist

Morals of scientific inquiry?

Appropriateness
The theories and viewpoints that we bring to our design can dictate what we find – we need to be critical of the assumptions we bring.

Reliability
Error is a fact of life – we need to find ways to minimize error in experimental techniques – we need to know how to statistically handle data and what it tells us about what we can claim.

Iterative
Scientific investigation is iterative – we need to be prepared to modify and refine our methods and look for a range of feedback to help us.

Comparative
We can test our results by looking for consensus, repeatability and how it fits into current theory and practice.

Limitations
What claims are we making? What are our contexts? Are we over claiming?

Fig 5.10

learning environment….

1996. I am working with a lecturer as a critical friend in helping him improve his teaching of first year Applied Physics. He has designed an experiment for his students to measure the specific heat of oil as a way of supporting his unit on heat and different ways of heating.

It took him a while to think how to heat up the oil to give reproducible results. He has asked the technicians to make little heater coils to go into beakers which are enclosed in polystyrene insulation (cut down stubby holders). This lecturer is a theorist and just designing this experiment alone is a challenge, one he very much enjoys as he gets lost in the nitty gritty.

I have a class so I can't stay for the whole of the 3 hour lab session but come back at the end.
"Sue," he sighs, "It was an absolute disaster. Every group got vastly different specific heats and no-one was close to the real value at all."
Oh no, I think. I have not been very effective in helping him. This is a disaster.
"What did you do?" I ask grimacing anxiously.
"Well once they had all written their values on the board, we had a discussion about why they were different. I really had to think on my toes, but I asked them what methods they used during the heating process… did anyone stir the oil, or just leave it… could there have been heat loss? It turned out that each group did something different and we ended up discussing how important the method you choose is in determining the result."
"Wow" I sigh relieved, " in fact it doesn't sound like a disaster at all… the disaster of the experiment actually resulted in a very good learning outcome. You were really able to tease out some of the issues involved in experimental design."
"Oh. I didn't think of it like that. Now I come to think about it we ended up having a really good discussion about convective and radiant heat with the students asking lots of questions. It stimulated them to really think about what was going on."
"So it worked really well in helping them make meaning of the concepts you had been covering in the lecture. I wonder if the original purpose of the experiment – just to measure the specific heat would have got them to think about the ideas so deeply."

"Yes, I wonder what opportunities there are to develop the concepts further in our next experiment?"

"And what about looking at what new morals of science they can learn?"

"Huh?"

"Well, look at what they learnt today about the scientific method …. the fact that just because you are using empirical methods doesn't mean you are getting real data… you have to understand the theory behind what you are doing to ensure you are designing appropriate procedures to get the data you are aiming for. Science isn't infallible just because it is based on scientific methods?"

He laughs, "So experiments which fail are just as valuable as those that succeed because there is so much more potential for learning!"

"Yes from a pedagogical point of view, because if you think like a teacher and not a scientist you are looking for everything an experiment could teach you… about science, the scientific method, about the concepts."

"This is really good Sue, I think I would like to keep this experiment exactly as it is. I was thinking how to redesign the equipment so it would be failsafe, but now I am thinking that I would like to deliberately get my students to think about the method issue before we start. Maybe each pair could try a different method during the heating of the oil and then we could compare the results. I wonder how I can get them to predict what might happen for different processes and actually get a discussion happening on the different types of heating beforehand and revisit that afterwards"

"Excellent idea…isn't it interesting that if students had just written up in their lab books their results and hadn't shared them on the board no-one would have twigged to the reason why the results were so all over the place."

"That is so true. Of course as scientists we are comparing what we find with other scientists to validate what we do, but I guess I have never have actually used this technique in a lab class. Why ever not? It is a really good idea to mirror what actually happens in science."

"I guess the reason is that assessment has got in the way…. Needing to keep student findings separate to ensure they don't cheat."

"But I still need to worry about that..."

"Perhaps part of their reporting could include the gathering of data from their peers which they then do their own discussion on, comparing their results to the others and

explaining why they are different. That way you could see how much they have understood about the concepts of heating."

"Good idea."

"And by the way, do you think the students felt the lab session was a disaster?"

"I don't think so, but they might have if we hadn't had the discussion at the end. I think they actually thought it was part of the whole learning experience. It was only me who thought it was a disaster."

"Maybe we should look more into our disasters for opportunities then! I wonder now by making all these changes to the lab session, taking into account what we know now, whether we are preventing students from experiencing failure in science, which is also part of what really happens and is therefore a useful experience for them."

"Sue, I think you are thinking too much!"

What science isn't

So where is my spiritual head now? During this time (1992-95), I was also explicitly teaching spiritual ideas and processes in the enrichment course that I was running. It was called *Earth Mysteries* - where we explored mysteries like the pyramid and Atlantis, questions like life after death and reincarnation, and interpreted dreams and practiced visualization and meditation.

My notion of spirituality at this point of time is that it is a big thing, of which I am exposing students in my enrichment class to a small aspect, and something which is quite separate to physics.

What is my intent here in running such an enrichment program? Am I indoctrinating students with another view?

Students in these groups have their own ideas, experiences and questions just like my physics students... the weird and mysterious is something that has attracted them and already they might be experimenting with Wicca or séances or have had deep experiences or significant dreams. The point of this course is to examine some ideas from a more objective and critical view…. What is the evidence, how could we know it is true, what constitutes truth when we are dealing with these areas? How do we make meaning of personal experiences? How do inner practices help us and what should we be careful about?

The opportunity to put some of my ideas out there for discussion with the students, who definitely have their own views, begins to break down my attachment to set ideas, helping me to be more fluid in my thinking. All I have learnt about constructivism and playfulness in physics has helped me be less dogmatic and more open to what emerges. I realize the benefit of students' having a forum to discuss things that they often think about or play with but are not applying a rigorous lens to or knowing how to experience safely. They seem to be more discerning and self reflective as a result of the course, and feeling not so alone.

I am seeing this course as developing spiritual literacy, not just exploring a *body of spiritual knowledge* but also developing meta-cognitive tools for examining knowledge and how we know. (I don't yet know that this is called epistemology.) And I am wondering whether I can bring across some of this into the teaching of physics.

Hmmm. Bright idea! Perhaps by asking my physics students to explore a mystery like crop circles I can encourage them to think outside the square of logical thinking, leading to discussions about how we come to know and what is legitimate. I can get them looking at the scientific evidence as well as anecdotal stories, crackpot theories and come up with some theories of their own? But is it OK to do such a thing in physics?

I did it and it was amazing…. My physics students were as much interested in the weird and mysterious as my enrichment students. There was wonderful discussion, not just about the crop circle mystery but about knowledge and knowledge claims and it continued for weeks. In the end the class put on a performance for the rest of the school, creating a mock interview where different students took on roles caricaturing the different approaches, playing out the tensions between different ways of knowing. It was a highlight of the year.

Is there something in common about the physics path and the spiritual path? Do we need to bring as much discernment in considering both? What am I developing here? Critical thinking, discernment, the beginning of understanding knowledge paradigms, meta-cognition? How am I thinking about all this? Am I still in the black and white of *spiritual paradigm* versus *Newtonian* or is the playing out of these meta-considerations with students opening me up to a wider view?

I am getting more confident that these sort of discussions are a legitimate thing to do in physics. It is OK to bring in the mysterious (and non-scientific) as long as I do it for the purpose of encouraging discernment.

How else can I bring in the notions of paradigms? Not by telling students about them, that's for sure. One day I walk into a class and say to them "I think the earth is flat, prove me otherwise." They look at me stunned. Then they have a go at giving arguments for the earth being spherical but I counter every one of them with logic or stubbornness. At the end of about 5 minutes of arguments and counter-arguments they are looking at me, almost fuming but smiling as well. One asks "How can we convince you, Sue, you are determined to see all that we say from your point of view." Yes indeed. Thank you, now lets start talking about paradigms.

Meanwhile this meta-thinking of mine about science has helped me delineate now *what is science* and *what it isn't.* At this time I am a real fan of science fiction with favorites like *The Hitchhiker's Guide to the Galaxy*. Whereas before I felt that I was not being scientific by bringing in ideas about science fiction into my classroom, now I begin to see it as a way for us to think outside the square yet bring a critical lens to it as well. Students love quoting sayings from different books (*The thing you should know about space is that it is big*) and we use science fiction ideas to both tease out science ideas as well as to ask what science is and isn't. What is the physics of Star Trek and how plausible is it? Let's be imaginative and create creatures that could live on Mars and Jupiter … what might be their fatal flaws to existence?

I can now encourage students to use their imaginations and go where no one has gone before because in my head I know *what science is* and w*hat it isn't* and can make that explicit. It is like we are moving easily between wearing different hats, knowing exactly which one we are wearing and its limitations.

But some of my colleagues are horrified at what I am doing… "That isn't science!" while others see the potential for exploring issues and ideas in science in this way and they too get their students to design creatures that could live on Neptune.

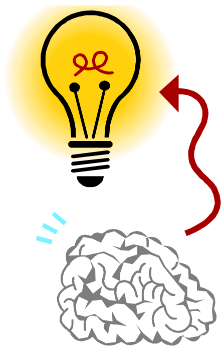
This use of the imagination frees me up to be imaginative in my design of classroom activities and to think outside the square of conventional thinking about how to teach students science. And perhaps it begins to infiltrate my notion of what scientific inquiry is.

Interlude 1: Two extracts from students' journals – reflecting on the circular motion topic (Second topic of the year).

My understanding of circular motion today

This morning I felt quite unusually energetic and I could feel my brain

TICKING! I've never ever actually felt myself thinking so well in physics before, but I think my brain must be making a lot of new connections as we are learning a completely new topic.



When we were asked to team up in pairs early in the lesson and find some words which give the definition of circular motion, I just suddenly came up with a good definition and I told Neil and Megan. As soon as I told them, they thought it would be the best definition and wrote it down. When Sue asked the class for their definition I was surprised most people came up with one word answers instead of a sentence. Neil told me that I should read out our group's definition since I was the one who came up with it.

So after reading it out I found it was basically the correct definition! I was pretty impressed with my thinking this morning and I just hope I can think and contribute more in Physics lessons every other day.

Tom

(Note from Sue: I have added the clip art where he used diagrams and they exactly represent his drawings.)

Scientific Method and the Hollow Earth

The scientific method is like a rolling ball, a snowball effect. Sometimes it rolls you where you want it to go, but you have to get it exactly right for it to do it.

Scientific method has to be carefully thought out in order to eliminate errors as much as possible. Without a correct scientific method the snowball effect is unable to occur, and this is what I think is essential to science as a whole. Without a correct scientific method there is no analysis and therefore no experiment.

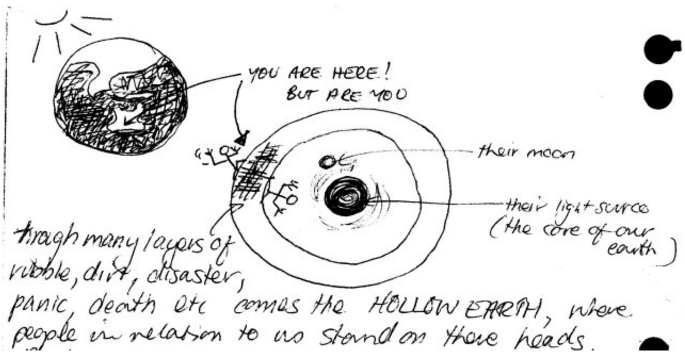
For me, a method needs to be planned exactly, all on paper, with aid of diagrams so that I can see exactly how I am going to do something before I attempt it. That way I can predict more elaborately rather than a small comment like hypotheses are.

I like doing physics experiments, but I tend to hate writing methods, maybe because I am too much of a perfectionist and tend to find faults too readily. I like analysing though. Saying what I believe to be wrong – it makes me feel powerful. Why I feel powerful doing this I am unsure of.

I love dealing with unexplainable things as well. Lately in class, weird things have been discussed as well. Like the HOLLOW EARTH!!!!!

Now if there was a hollow earth would the people inside be like us? Or would the dinosaur bones and the dead organisms from the inside of the earth be flushed out by gravity and dug up by us? Or are we in the hollow planet and some other being is on the outside thinking exactly the same as us? If so, would they be more superior as they are in a greater system?

Through many layers of rubble, dirt, disaster, panic, death etc comes the HOLOW EARTH, where people in relation to us stand on their heads. And if so is this like a parallel universe? Would the horizon be the universe, and could you still dig to China?



Would the people be the same size as us or smaller? Or did they create our system, to study how we live in order to redesign their corrupt world? Are people who claim to have seen aliens, just skipped through a dimension like the hollow earth and told things about us.

Deary me, I think I might have got a little carried away. Reality check, are you there Lisa?? Yep, I'd say it is time for bed….

April

Interlude 2: Seven metaphors for how thinking happens courtesy of Newtonian physics, and one metaphor courtesy of Deep Ecology.

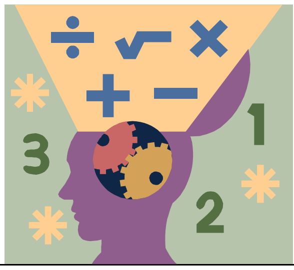
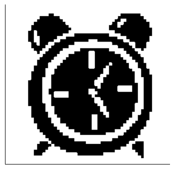
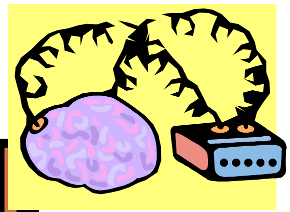
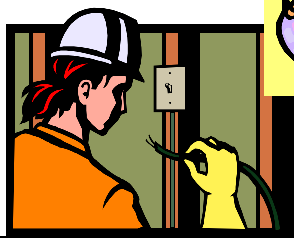
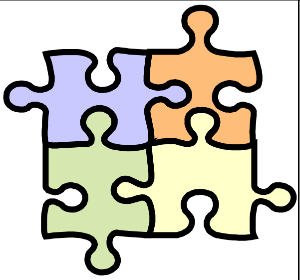
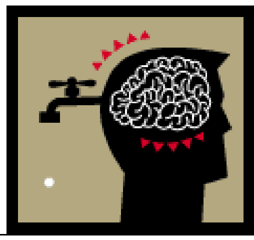
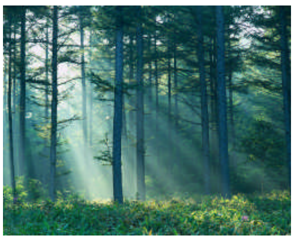
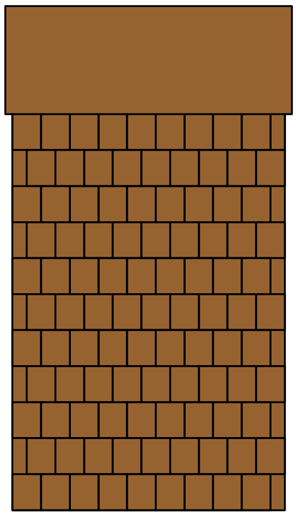
Thinking happens in the brain 	My brain is ticking over 
The wheels are turning 	I am making connections  
I can see how that all fits together 	My ideas are flowing 
Now that is an idea that just seemed to have popped up out of nowhere like a   mushroom in a rainforest	I am building up my knowledge 

Fig 5.11

Interlude 3: Don't Force Me! (First Physics topic of the year)

Welcome to my class

"Please come in, dear reader. Feel free to walk around and talk to my students. We are nearly finished the unit on forces, which is our first topic of the year. The students are working through this booklet with different case studies or problems to investigate. You'll have to step over Alex. Don't mind him lying on the floor. He has taken me at my word about having some brain dead time to allow ideas to percolate."

You notice two boys drawing up diagrams on the whiteboard, arguing. They turn to us.
"Which of us is right… we are trying to come up with a theory we can use to explain the safest way to suspend a Santa Claus decoration over the street?"
"Maybe you could test both of them and then see?" I suggest and they go "Oh, yeah, why didn't we think of that" and head off to the equipment trolley and start pulling things around.

You now head over to a group who seem to be making a device and you ask them what they are doing.
"We are making a kitchen scale… you see the way other groups have used a hanging spring with a basket, well we decided to see if we could make one which pushes down."
"Yeah, it was pretty tricky… we took a broken bathroom scale apart and saw they were using compression springs … but we only had extension ones so we have had to come up with another way of doing it … we are not sure if it will work yet… we have already had to change the spring once because the other one was too stiff."
"See here, we have to have a way of reading the weight. If the spring is too stiff the pointer doesn't move enough."
"You see Mark's over there – it is way too long… you wouldn't have room in a kitchen for that… but ours will easily fit under kitchen cupboards."

You ask them if they have ever done this sort of thing before.
"Well, I've made stuff in woodwork but nothing as mechanical as this…"
"I've never done anything like this, in fact I haven't really connected the stuff we have learnt in physics before with real things…"
"I never really thought about springs before and how they are all different."
"I went home the other day and took apart the iron just to see how it worked."

“Doing this certainly makes you think… it is one thing to just measure the extension of a spring and realize how weight and extension are related but another thing to actually make something which uses that.”
“Yeah, it is just as well we had three weeks to think about it. Well we haven’t spent three weeks on it… we started measuring a spring in the first week and in between our other case studies we have been thinking how to use it.”
“It was good seeing how other groups approached it first because we could see their flaws… see how this group’s basket doesn’t come off… how are you going to get your flour out? They are not going to get good marks on practicality.”
You ask them if this is cheating
“No, everyone is helping everyone else… we helped the group on the air track to set up the time gates.”

You move over to the group on the air track and ask what they are doing.
“Well, yesterday we were *disproving* Newton’s Law, not intentionally, but today we think we might have overcome the flaws in our design and might be able to see if it is true”
A girl opens her lab book, “See how the graph goes here, it is supposed to be a straight line, not this curve.”
You notice how messy the book is and ask about it.
“Oh, yeah, Sue has asked us to think of our lab book as a log book… that we record what we do as we do it, like real scientists”
“In the first investigation we wrote our data on a scrap of paper and Sue scrunched it up. She was making a point. She said put it in a book and sketch results as we did them to see what they were while we had the equipment set up in case we wanted change anything… not wait weeks to do a formal write up.”
“Yeah, my book now is really messy, but that is OK and it certainly saved us time; if we had waited to do a proper graph when we wrote it up properly we wouldn’t have spotted the flaw. Anyway, Sue says I can hand it in as it is… that she doesn’t require us to write a proper science report for this experiment … as long as we include a good written discussion.”
“Well, that is not going to be hard, we have certainly got lots to discuss.”
“It is interesting that you can take accurate results but still get the wrong result just because you haven’t understood the theory behind what you are doing.”

You notice something out of the window… a girl hanging off a balcony by a rope. Is it safe?
“Oh, that’s Lauren…don’t worry it looks like she has got a proper harness on – she knows her stuff. I think they are looking at what happens if an astronaut hits his space ship with a

hammer versus a screw driver… see the other piece of wood hanging… that must be the spaceship."

"She is swinging too much, that rope is not going to really simulate freefall!"

"I think her video crew have worked it out… look they have lowered her a bit."

"But I really wonder at whether that is the best way to look at it… you need to have a frictionless, forceless environment."

"Like what then?"

"Well the air track."

"But how could you simulate hammering a nail."

"I'll have to think about that."

You move on just as a group of three girls enter the room quite flushed, one carrying a bathroom scale. Well we did it… thanks for suggesting the commonwealth building, Andrew, the lift is amazing!"

"Yes, I lost 5 kg going down."

"We went up and down so many times… we got some really strange looks."

"I can't believe how it felt though… you really do feel lighter when you start to go down, and heavier when you come to a stop."

"It really made me think - as we were walking back I could almost feel the same thing in the way I walked."

"Better get to it, and calculate those forces."

And here is another group. What are they making?

"Oh hi, this is our demonstration of Newton's 3rd law… see we are going to strap this bear on this wheel which we are then going to propel using soda bulbs."

"Yeah, we hit the bulbs and they release gas one way and that forces the wheel around the other way."

"It's a kind of Ferris wheel… you see we have even made a little ticket booth for the bear."

"We were thinking of a flying fox, but another group were looking at that and we noticed they were having problems banging the tack into the soda bulb… we wanted to use a soda bulb."

"Yeah they are cool…"

"But we needed to think of a way of making our set-up more rigid so we could counterbalance the force of the hammer…"

"Because then it would be the hammer making it go forward, not the gas."

"So we came up with this…"

“We know we are using a similar situation to Alex’s group but we’ve done some research on rockets and we hope our explanation to the class will take a different slant on it.”
“Do you want us to demonstrate? We just need to get the tape and strap the bear in.”
“Don’t forget he needs to buy his ticket first!”

Epistemological Pause

Well, that took a lot longer than I thought and I didn't get very far in my story.

I have tried to write by projecting myself back into the time, tuning into the fairly modernist and sometimes strident voice of my 'gung ho' past self as well as remembering the significant events or questions of the time. But here, sitting in front of my computer, I am also in my present - writing peacefully and reflectively. Did I really think like that then? Was I so reflective and questioning? I must have been reflecting in some way because I moved in understanding and practice … but it wasn't using this nice gentle reflective voice… it was one that bounced around exuberantly very much like Tigger from 'Winnie the Pooh'.

I bounced my way into learning about the teaching of science; my experience moved through me often straight into action, in the same way as an artist might allow experience to be expressed in their art and then become an observer of the possibilities of meaning that emerge. I don't think I stayed still long enough to unpack an experience with depth… if I saw one thing emerging I would leap on it and take off again on this wild ride of exploration. I also need to acknowledge that this growth in perspective was not done in a vacuum; many of my state-wide colleagues were moving in thinking as well and that interactivity played an important part in my changing perspectives and understandings.

Between 1990 and 1996 I wasn't seeing myself as doing action research - it was prior to commencing my doctorate – but here we see a simple action research cycle of observe, reflect, plan, do, feedback. Sounds a little bit like the scientific inquiry cycle. I guess I was bringing my scientific self to the process of my teaching. Once a scientist, always a scientist?

Only with hindsight and perhaps a higher perspective can I piece together the meaning, make the connections and see the significance. And I remind myself that this is a construct, albeit one which I have tried to make as honest and authentic as possible. Perhaps I need to try harder?

Why is it so long? Well I went back in and added bits to better paint a picture of my thinking about science and science inquiry at the time, because I realize how problematic mere words are if you don't give examples of what they mean. How someone with a different value system may see *inquiry* or *questioning* in a different way. I needed to give examples of the types of questions I was asking then (I now ask different ones) because it reveals the pragmatic place that I was coming from which is perhaps representative of someone living in the world of *trivial constructivism*.

Needing to explicate this is the result of watching a documentary two nights ago called "*The root of all evil*" where Richard Dawkins (the gene scientist) critiques *all* Religion and especially Fundamental perspectives of Religion; not seeming to differentiate between various perspectives within Religion. He denies any other experience or understanding of the world that is not based on empirical evidence. He sees science as the only choice for rational people. Science he says is based on careful moderation between many scientists, bringing a sceptical eye to what they are doing, prepared to change ideas when evidence to the contrary is found. It sounds very civilized.

But the documentary was not and it was painful to watch a scientist expose himself as someone who was as firmly entrenched in his own belief system as those people he was arguing with and trying to ridicule. He saw science from within it, did not see it as one valuable epistemology within a larger range of epistemologies, nor was he able to critique the assumptions underpinning the construction of science. He also had no sense of the different cultural perspectives (vMemes) that might be evident and how we cannot lump all religion in one box, neither all scientists.

So listening to this helped me contextualize better my experiences during the first five years of my teaching – where I had come from and where I was moving to. My notions of science inquiry that I started out with were in fact very similar to Dawkin's views about what happens in the scientific community. Which is no surprise because I was a real scientist for over three years and had been exposed not just to my own scientific inquiry within an organization, but also involved in the mediation of findings with other scientists on our team and through conferences with outside scientists.

What is interesting, is that although I had this experience in my own scientific inquiry I could not initially teach science *as inquiry.* From a spiral dynamic point of view (Beck & Cowan 1996), perhaps as a *scientist* I was operating in the **orange vmeme** (self authoring) but as a *teacher of science* I was operating in the **blue vmeme** (authority, right answers). By explicating who I was as a scientist I could then teach from my own experiences of science inquiry, breaking out of the traditional experimental straightjacket that many science teachers were wearing at the time.

However, because of needing to get 'right answers' for the exam I could not let go of me needing to *direct* the students to inquire…. If they had their own projects how could I guarantee *what* it might be that they would learn, and then how would they pass the exam? My experience of inquiry as a scientist was that you start with something no one knows and you aim to find it, rather than inquiring into something that is already known and coming up with the conventional understanding. You have no idea what you might learn along the way. So while I was thinking students were being scientists, it really was within a very small context of just bringing a sceptical and discerning eye to what they were looking at. There was no true creation of knowledge that is the aim of most scientists.

I was firmly entrenched in *Teaching for Understanding*. What comes after that? *Teaching for innovation? Teaching for action? Teaching for Wisdom?*

Towards the end of this time I was beginning to helicopter out and see science from a wider view; beginning to see it more than an inquiry cycle but also as a community of construction. It would take a few more years for me to fully explicate this to myself.

Now I don't want to pre-empt myself too much by this analysis from my 2006 standpoint. I need to get on with the story and see where science goes from here. We need now to bring in Holistic perspectives and see how those sensitivities interact with this thing called science and this thing called Sue. Can I begin to see out of this box called science, to see it with a different perspective, to see my teaching with a different perspective?

How does one start to get out of a box?