Chapter 8

The significant classroom - 1995 – 1999

Questions:

What does it mean for something to be significant?

How is physics significant?

What are the various ways that physics can be significant to students?

Introduction

So far in my story I have come a long way in my teaching of physics. I am helping my students to understand the physics better, I am beginning to look for greater plausibility and give what I do meaning and enchantment, linking to students' questions and passions. But is this enough? Have I really made physics *significant*? I soon discover the answer to that – not enough. But I will get there in a minute.

What makes something significant? Perhaps when it has a direct impact on us, when it is related to our own goals, when we see how it is connected within a bigger whole helping us to see in new ways, when it helps us to solve issues in our lives, or when movement or change happens.

How might physics be significant for me? How might it be significant for my students? How do I even begin to think about this?

Students' goals for doing physics

- To understand physics.
- To be challenged.
- To boggle other people's minds with lots of facts.
- To find out some interesting things.
- To be more aware of the world around me.
- To get into my course at university.
- I want to know the things around me… I want to be able to talk to myself and think about how it happens.
- To widen my personal knowledge of physics and apply them to my own applications.
- To do something good for the world.
- To enjoy and learn.
- To enjoy, enjoy and ENJOY!
- I am intrigued by Einstein and his theories on quantum mechanics and I want to understand more about them.
- Strengthen my strong interest in it, provide a science side to my thinking to equal out my ideological side, hope to be able to join the two sides when needed.
- To acquire a thorough understanding of the physical world/universe and the changes that take place in it.
- To learn a whole lot of new things and meet new people.
- To pass and decide whether or not science is something I am really interested in.
- To use the wind tunnel that I saw in the prep room.

(written in second lesson of the year from 1998 and 1999 classes)

Fig 8.1

Students' goals for physics are mainly based on how it can help them understand the world better. Does physics have any more significance for my students beyond that? Can it help them understand themselves better? Can it help them grow and change? Are they only thinking of understanding the physical world, or can physics help them understand the world of constructed meaning as well?

Let me ponder this for a while. Perhaps all the ingredients are there and I just need to wait until somewhere in the nether regions of my mind a cake is baked. Hopefully the oven temperature is on the right setting…

Ingredient 1 – the collapse of plausibility

It is 1995. I have a small class of 12 students. It is the end of the year and we have just finished exploring Quantum Theory over four weeks. One boy, Benjamin, is really interested in Michelson and Morley's alternative view of Quantum Theory which he had been reading about and sharing with us during the topic. It was creating a lot of debate in class, as he was taking the stance that Quantum Theory is wrong, so I suggest that we put Quantum Theory on trial.

So students choose their roles in the trial – some taking the roles of the key scientists of the time, others of prosecutors (Benjamin) and lawyers for the defence. I give them time to research their roles, and they now come to the 'courthouse' in role - some with wigs and lab coats. The room is set up with a jury of some students from my Year 11 Physical Sciences class sitting in chairs high up on one table and I am the judge on the other side of the room sitting in my elevated chair with my look-a-like gavel. We start.

Each quantum scientist is brought to the stand, and is examined by both prosecuting and defending lawyers. They are trying very hard to answer the questions and explain why their ideas are feasible. Einstein, played by a cheeky boy who has a matt of white cotton wool on his head, is questioned mercilessly about the veracity of his theories. He finally gives up justifying them and says in a deep European accent – "It is my job to come up with the theories and your job to test them!" pointing at Benjamin accusingly. Yes, it is very funny and we are all laughing, but now we move into a greater debate where it seems that even science and truth are being put on trial - what constitutes proof, is it 'science' when Einstein comes up with a theory that is yet to be tested?

Planck (Courtney) is now called to the stand. She falters under Benjamin's cross-examination, unable to justify the development of the idea of *discrete wavelengths*, the underpinning concept of Quantum Theory. The jury of Year 11 students are looking on with amazement (and say to me at the end of the trial that they can't wait to do Physics next year), but it seems they are unconvinced of the case for Quantum Theory. Is it because Quantum Theory is really that unconvincing, or just that my students didn't understand it enough to justify it under the agile questioning of Benjamin?

At the end of the role play Courtney, who played Planck, comes up to me quite upset. "I looked at the text book and based my defence on that," she says. "It seemed reasonable when I was reading it, but as soon as I was cross-examined I could not see the logical reason why it had to be… it just did not seem plausible."

I look at the textbook with new eyes. "You are so right. It doesn't really explain why Planck had to make that paradigm shift in thinking. What could make it plausible?"

We then discuss what she might have needed to know. It wasn't so much that she needed the text to be plausible and coherent (which it wasn't), but also she really needed to know which bits were significant. What were the key things that required the shift in thinking that Planck made?

I go back to my university texts and realize that even here the significant moments are not made clear. I remember at university I was just trying to understand the complex ideas and didn't even look at it from this point of view. Now I am looking at it with another lens.

Ingredient 2 - The Day the Universe Changed – a documentary series

1996. I am quite taken by a series on television called *The day the universe changed.* It is looking at key moments in history which created major shifts in thinking. Quite a few examples from science are being used and I am amazed to see the far reaching consequences in social and cultural structures. I hadn't really thought about physics in this way before, but I can see the possibilities.

I am interested in how the authors determined that these moments were significant and how they deduced all the effects coming from them. Was this a 'true' representation of history or

a construction to make a nice story? I remember when I was 14 years old asking my father, an historian, how the first world war started and it took him weeks to explain it. Mainly because he started back in Ancient Greece. To understand the intricacies of Balkan and European politics you had to go back to that time. How can you tell then which events were more important than others if it is an interconnected web?

Quite by chance I have discovered a book by Asimov at a second hand bookshop. It is a history of scientists and what is really interesting is that it has a number system (similar to web hyper linking) that interconnects scientists and their discoveries with other scientists so you can trace lines of experimental thinking. It really is an interconnected web, with scientists in one area actually being influenced by thinking in other areas. The more I read, the more fascinated I become with the historical construction of science. Books on famous scientists don't really get across this interconnectivity of science. There is also a lot of politics going on with ideas accepted because of who you are and how much power or respect you have. I wonder what our society might be like now if the photovoltaic effect was discovered before the steam engine…. Would we have bypassed completely the need for fossil fuels? Hmmm. How can I use this?

Ingredient 3 – Concept Challenge Theory

1996. I have just completed a workshop on **Concept Challenge Theory** which comes from *Trivial Constructivism* (see Chapter 5). Basically the theory says that there are three stages students go through to change their current theory to a new one.

1. Is the new theory understandable and clear?
2. Is it plausible?
3. Is it fruitful? Does it explain my world any better?

Students may understand a theory or even see that it is plausible but unless it actually does something for them why should they replace or value-add an old theory which has worked very well up to now?

Hmmm. Activities like roles plays have moved us beyond *understanding* phenomena and theory into being concerned by the *plausibility* of those ideas. Do I need to now to move to the next step? Is fruitfulness really about significance? Is this what Chris was looking for…and is this search for significance a natural progression if you go deep enough into an idea or a topic? Can you see the significance of something if you don't understand it?

I thought I was going deep before, but now I wonder. What is the difference between being *meaningful* and being *significant*?

Ingredient 4 – Egan's development stages

1997. I have just got hold of a book by Keiren Egan (1986). Egan suggests that we need to ask not just what student's *know* (the constructivist concern) but also *who they are* and what are their native ways of *being* in the world. I like this slant, as *being* is something that is emphasized in the Holistic Education literature.

Egan has a development model of 4 stages, nominally every 7 years, wherein he suggests that at each stage students have a different way of experiencing and processing their understanding of the world. He says that we should teach according to how the student experiences the world, providing the appropriate cognitive tools for each stage.

Each subsequent stage encompasses the ones below and just because a student might be at one stage doesn't mean they can't be stimulated by techniques of earlier stages.

I am struck by his examples of how we can use stories which speak to the **mythic mind**. What are the grand narratives of science? What might be the story of the beginnings of science… *Human beings searching for security from a wild world?* What are the grand narratives now? Does *physics* have a grand narrative? And if these stories also include transformational heroes, can they then speak to the **romantic mind**? Do my students already have a grand narrative of science? Who are their heroes in science? Einstein? Hawking?

Egan's Stages

1. **mythic** - binary opposites and metaphor stories
2. **romantic** - inspired by transformational heroes, immersing yourself in depth and exploring the edges, feelings
3. **philosophic** - constructing meaning making frameworks… perturbed by anomalies or paradox into more complex and richer understandings
4. **ironic** - being able to deal with big picture *and* particular…. an understanding of the limitations of generalizing models

Egan (1986)

Fig 8.2

How am I helping my students move beyond the **romantic** stage into the **philosophic** stage? Are they seeing physics (and their other subjects) as disconnected bits or are they connecting the parts together in larger knowledge frameworks? How might I be perturbing these and helping them to create richer and more complex structures… am I seeing a moving from

'black and white' thinking into shades of grey? How have my past activities, such as exploring paradigms, helped in growing these frameworks?

In the past I have looked at creating activities which have contexts that students can relate to, or are relevant to their daily lives. But now, Egan's model has given me a new way to ask what might be relevant to students. I wonder at the success of the Crop Circle Mystery …did it speak to the Romantic mind of exploring the weird and the edges of science? I wonder how I can now use activities I already have in my pedagogical toolkit much more deliberately… metaphor, concept mapping, paradox, anomalies, stories. What other activities can I bring in?

And in doing all this am I touching something deeper within my students, because I am starting with *how they be* and not only with *what they know*?

Ingredient 5 – Visit to South Western College, New Mexico, USA

1997. I have just visited a holistic university and met with one of the directors, Greg Cajete (author of *Look Towards the Mountain* 1994). The university is very small, providing a *Masters in Art Therapies*, but has gained a very good reputation. It is a two year course which uses a lot of experiential pedagogies similar to what I have been using across all my classes but in a much more purposeful way. They are all geared to help create, support and debrief student transformation.

In the first year of the course students are encouraged to experience transformation for themselves in order for them to be able to understand deeply the transformation issues of their future clients. They do this through remembering their past journeys and transformation passages. They then embark on a journey of self exploration. They choose a transformative 'hero' from the past, taking on the persona of that person for one month where they try to live their lives through the eyes/heart of this person's perspective. They have to imagine how they would see, do and be. It is a way of calling to the 'highest thought' and fostering deeper understanding. Journals are an important part of recording experiences, thinking and change.

What might it be like, I wonder, for students to experience perspectives of different scientists… to be an Einstein or a Newton? Hmmm. Do they need to live as that person for one month? How else could I do it? Can I simultaneously foster students' connection to the stories of science as well as use these stories to foster changes in perception or perspective? Hmmm. I wish I could do more than that.

Ingredient 6 – My perennial concern about wholeness

1997. My perennial concern is one relating to wholeness. I am teaching physics bit by bit. Physics looks at the world bit by bit. What does it mean to teach physics as a whole?

Does wholeness lie in the interconnections we make?

Does wholeness lie in the stories we tell and the way we see the significance of the parts to the whole?

Does wholeness lie in the wholeness within us …. the integration we make as human beings living in the world …and the ripples we send out in the world as a result of this being?

Is asking the question *how to teach physics as a whole?* problematic, because physics itself is actually a construct? What does it mean to see nature as a whole, then? Do I have to take things apart to understand them or can I understand them through another way of knowing? Does wholeness lie in the nature of the questions we ask and the way we choose to try and answer them?

Creating Grand narratives

Creating the physics story

How can I see physics in a new way? How can I move in perspective so I am not just seeing the parts, but also can see the whole? What are the big themes in physics? Is there a chronological story to be told? Why did one thing follow from another? What are the significant moments?

I now look at my notes for the whole course and wonder how I might construct it better. What topics lend themselves to development according to history, what ones lend themselves to engaging directly with the contemporary understanding? What could particular historical anecdotes reveal about the *nature* of conducting science? And what about my experiences as a scientist? Do they have a place in this story as well? Can I put myself in this physics story?

Can I make better connections between what I do? How might topics flow from one to the other by using key questions? How might topics be replaced by significant investigations or

concerns that are likely to uncover the big ideas of the topics? What are the big ideas anyway?

Concept mapping now becomes an important tool for me in not just brainstorming questions leading into a topic, but also in linking together concepts, showing their relationships, significance and limitations across topics. I have now moved from just teaching ***for*** understanding of the concepts to teaching ***how*** they came about, ***why*** they came about and their claims to validity.

What were their claims to validity? Why are some discoveries more significant than others? How do different discoveries or theories become accepted while others do not?

From being uninterested in the history of science I begin to read more about it. The more you read, the more you begin to see patterns. I begin to move out of seeing science as this dry objective act of investigating the material world into seeing it within a context of human endeavor which is not objective at all. And I begin to realize that there are many places in the course where I can bring in this grand story of human endeavor, the nature of science revolutions, the impact on the political and social landscape of the time and the political and social construction of science.

An example of an essay topic

The space race

During the cold war of the 1950's to 80's both Russia and the US spent trillions of dollars on space missions. What were some of the key missions and their claim to fame or importance? What was learnt?

Why was it so important to be first to the moon? What affect did it have on the nations' psychology, economics etc?

What are the costs and the benefits of space missions? Can we justify the cost of such scientific research when people are starving in the world? Who should decide what research is funded? What sort of research do you think is important and why?

Fig 8.3

Lets go back to Quantum Theory. How can I teach it now? What are the morals to be learnt? Can I help my students get into the eyes of the scientists at the time and walk through their journey?

I try to do so and I am astonished with what happens. Not only do some students come up with Planck's theory for themselves, but we begin to explore the nature of anomalies which push us to new understandings. We discuss how contingent science is and how one system of understanding carefully built up over centuries can be torn apart in paradigm breaking

research. There is a fragility to scientific knowledge as well as a door opening to our own participation. Perhaps we too can challenge the foundations and look for new ways of conceptualizing phenomena. Perhaps we can be *creators* of science by just thinking outside the box?

So now, are we beginning to gain an *intimacy* with the subject through inhabiting scientists' minds as they come up with their discoveries? This is the intimacy with a subject that Parker Palmer (1998) suggests is needed to go deep…. being able to inhabit what it is we are coming to know. There is a sense of inhabiting which is direct physical, emotional or spiritual experience, another which is about inhabiting the perspectives of others, another which is getting inside the concepts through playing them out as in a role play or hypothetical. What might be happening here? How can I use this more intentionally?

How do I see science now? I now see myself as a teacher not just of physics concepts, but also of a physics story. I am not just teaching my students to think scientifically, but to also think historically – where they are beginning to see the political, social and historical construction of science and realize how difficult it is to step outside of a paradigm.

Science now feels open rather than closed down… open to sudden changes in perspective as well as the usual building on what we already have. It seems more open now for students to *be scientists*, not just in terms of *thinking* scientifically, but in participating in the collective *creation* of science understanding. What do I mean by this? Before, students were creating their own meaning with the aim of *understanding* the physics or questioning its *plausibility*; now some are looking at theories and their anomalies with a great interest in solving the issues. Apparently now their other teachers cannot stop them talking about physics in their classes. I have created a monster! Or have I? Perhaps creating solutions to anomalies is actually something students do in their lives but just haven't had the permission to do it in science… or if they did, I didn't notice it before, because it was off topic.

This view of science knowledge as open to new perspectives is freeing for me. Whereas before I had felt science was closed down, resulting in me wishing to explore the Kosmos through another perspective (the spiritual one) now I am feeling science might have some potential after all for moving out of the materialistic. Yes, Einstein and Planck have inspired me with Quantum Theory. I wonder whether the next paradigm shift in science might be one where it might integrate subtle realities with physical reality? Would this then be called science? What role might I have in being a creator of such new paradigms?

However, as usual, there is a downside to my new approaches and attitudes. With all this connecting between ideas it is not so clear when a topic starts and ends – students need to know this for the exam. And what about the history… some ask what bits do they need to know for the exam – "These historical stories are interesting but will they be tested?" So I am trying, sometimes unsuccessfully, to balance the needs of the exams with a deep development of the course. I try to make things clearer. I never seem to get it right for every student at once. Perhaps that is OK; they all have different learning styles and not everything will work for everyone.

But is there a bigger narrative of physics?

Now that I see the stories *within* physics, can I see grander themes? What really is physics? I now develop a metaphor of physics where I see it as a foot which moves us forward in understanding and predicting how our world works. The toes each represent the different lenses we bring to seeing the world. But we are just looking at one foot of possibilities – waves, energy, forces, fields and quantization… what might be on the other physics foot? (It is a little play on TOE (Theory of Everything)).

Fig 8.4

I put a poster of the foot at the front of the class, continually referring to it, asking what lens we are using now and what lenses are appropriate, what are their limitations in bringing one particular lens to a phenomenon compared to another one? For example, forces is a good lens to use when we are interested in looking at the mechanics of something, but breaks down when you look at the *very big* (cosmology), *very small* (quantum), *very fast* (relativity) and *very complex* (chaos theory).

This seems to make a big impact on students… physics isn't just a list of things to be learnt, or a confusing concept map… but clear tools which can be applied and which have limitations. Students become used to asking what lens might be useful to apply now and the problems with using the wrong one.

And where does the 'physics foot' sit within the bigger context of human knowledge? Are my students integrating what they learn in physics with what they are learning in other subjects or experiencing in life? Do they see where the physics lens is useful and where it isn't? How can I help them think about the connections?

In 1997 I am introduced to Wilber's 4 quadrant model from *Eye of the Spirit*. I see that physics is part of a greater whole… and my spirituality and physics dichotomy seems to be solved in one foul swoop. It seems the answer is to recognize they are different lenses and to agree to a demarcation. Hmmmph! Here have I been concerned about making physics whole, when obviously I can't! I have been trying to bring **I** perspectives into physics when physics is really an **IT**. Perhaps by trying to integrate the two I am in fact causing more problems? But in trying to make the links between the whole and the parts am I in fact engaged in an exercise within the **ITS** quadrant?

I Spiritual Interior	**IT** Empirical Physics
WE Shared meaning	**ITS** How it fits together Significance

Fig 8.5

Despite my angst, at the end of 1997 I decide to introduce the quadrant model to my class, asking them how they organize all their different bits of knowledge. How useful is it to think about knowledge using the quadrants? We discuss different metaphors for knowledge and I realize that many see their different knowledge as separate unrelated boxes, some see them as a jigsaw puzzle. We also remember the metaphor of the blind men trying to understand an elephant and getting it wrong because each can only feel one part. Some students say to me how they have never thought about this before and how useful it is. Even though I present integral theory on the board and think I might be pushing it too much, students do not feel I am forcing them to take it on … it is one of several knowledge metaphors.

This intrigues me now. The notion of helping students to reflect on how they construct, demarcate and integrate knowledge through exploring and playing with a number of metaphors. (see Chapter 2). It is the play between the metaphors that appears to perturb students out of their pre-conceived ideas of knowledge. It seems to be a very fluid process. I wonder how I can use this more deliberately. Is this helping them gain a more *ironic* understanding of their *philosophic* state of being? What meta-cognitive tools could I help in this process?

And what about significance to the students?

We seem to have gone beyond significance that is based on ideas being relevant to students' daily lives (e.g. not a good idea to lean your forehead on the microwave oven while watching popcorn pop.), or related to their goal to understand the world (physical as well as constructed). We have now moved to something that perhaps has significance for their

growth as human beings. They seem to be developing greater meta-cognitive capacity, they seem to be moving from *romantic* to *philosophic* to *ironic* stages. What is causing this? My deliberate activities or the very story and nature of science which is percolating in the background?

What am I teaching now? Physics or philosophy? Do we need to cater to the students' own growth in the style of our subjects – as they move from the detail of the **romantic** stage (taking stuff apart, interested in submarines and bucky balls) to the **philosophic** stage (needing overarching frameworks to make sense of the profusion of detail) do we need to move into a different style of subject teaching?

If someone now said to me "Sue, you need to remove content from the course", I would be really anxious, because now I see the significance and potential in all the physics concepts for greater learning about self , the universe, the nature of science, the particular physics lenses that we apply to the world and the construction of knowledge. What could I take out?

I need to have electrostatics because I need to ask them the question *"How do you know an electron truly exists?"* I want to perturb their romantic view of knowledge, for them to question where their knowledge comes from and what they truly can know. I want to support them in their process of painful deconstruction and help them learn to deal with uncertainty. No, I certainly can't get rid of electrostatics.

I can't get rid of light or Quantum Theory either. I need my students to experience a true paradox that will challenge their logical thinking and cause them to move towards more dialectical reasoning.

But there really is a problem now. Seeing all this significance has filled up my course so much that there is really now no space for something that might emerge out of students' interests…. Like the Quantum Theory trial back in 1995, which we were able to do because we had time. No time for anything like that now, I am sorry. No time for students to **inquire into** their own new science creation, only time to **think about it**.

If someone said to me, "Physics should no longer exist.... we should move to interdisciplinary inquiry based on issues in the real world", what would I do? I believe that such open ended problem based inquiry is important in experiencing agency as scientists… yet I am in love with the beauty of my subject… not the exams… but the meaning to be found it. I feel that there is so much to be learnt from it. Can we do both?

I have even mapped out next to each topic what aspects lend themselves to revealing the morals of science inquiry, the philosophy of science, the wonder of the universe, the different lenses of physics, the political construction of science or the development of the self. I wonder if this can be applied to other subjects as well. Could each discipline teacher find aspects within their discipline that speak about their discipline as well as to the stage of growth that students are at?

Lenses to apply to a subject

In what way might particular topics in your subject reveal your discipline's:

- Inquiry processes
- Lenses and constructs
- Epistemology
- Nature and purpose
- Political construction
- Philosophy
- Sense of Wonder

In what way might these help in students' development?

Fig 8.6

I now wonder if the story of science resonates with students' own journeys. How might I map these journeys and see how they overlap?

Nature of Science	Personal Story
Science knowledge is constructed from experience, observation, experimentation – theories are best fit and tentative.	The construction of personal knowledge is an ongoing process which is contingent and is expected to change.
Anomalies, enigmas and paradoxes force us to question current theories and come up with better ones – sometimes these are just extensions, other times completely new ways of thinking.	Challenges to our beliefs are opportunities to review these beliefs and test their currency and worthwhileness. Paradox forces us to think outside of 2 dimensions and into other perspectives.
Science is a journey involving many processes in an iterative cycle. All processes are valuable parts of the whole, but by only doing one part may give you a skewed understanding.	We are on our own personal journeys which we expect to be a continuing iterative process. We value all aspects and look for ways to integrate our whole experience into meaningful understandings.
The purpose of science is to move society forward – better understanding, better quality of life, solving problems.	Where do we see our own purposes? What is the meaning of our lives? Are we aiming to move forward?
All knowledge is constructed within a paradigm. We need to be aware of the paradigm, its limitations and the privileged perspectives it is enabling. We need to look beyond the paradigm and explore other perspectives and use discernment and selectivity. (eg. By designing an experiment with a particular theory in mind, can get skewed results.)	How are our own views of the world modified or influenced by the media, society, parents, school? What do we take for granted that we should question and challenge? What do we believe for ourselves? How much of our actions are our own? What might it mean to think and act being totally aware of the paradigm we are in?

Science is a collective human endeavour with controversies, serendipitous discoveries, heroes, villains, competition, collaboration, wrong turns, painstaking investigations. It is done in context with the world and society, not just for the pursuit of absolute truth – it has an ethical dimension and human failings. To understand the ethical consequences we may need to change from our scientific experimental perspective/process into others – systems thinking, qualitative research.	The process of inquiry can be done by anyone. We are not alone and can use others and other knowledge in our own pursuit for meaning. However, what we do has ethical ramifications – we are not an island and need to think about the consequences of our actions. How can we know what these might be? What ways of viewing the world can help us?
Science has a privileged status in our society. Often other ways of looking at thinking about the world have been given less credence in decision making. How do we reconcile different ways of knowing?	How do we think about all the different types of things we do and learn – how are they organized – what value do we give them? Consider meta-cognitive tools for thinking about organizing different ways of knowing.

Fig 8.7

Where is the soul in all this?

Is it in the enhanced sense of meaning the students are making which goes beyond understanding individual concepts into seeing the connections within a larger whole? In the increased intimacy they have with the subject? In their expectation that there is deeper significance to be found in things… meaning to be extracted. Is it in the resonance between their selves and this thing called science?

Am I being seduced now by the meaning I am making into this construct called physics? Am I seeing significance in everything? Am I imposing my view that life is significant and interconnected (not chaos) on my students? Am I leading them into seeing significance without asking them to critique the assumptions behind such constructions? Is seeing significance a spiritual belief? While seeing significance in something might make it more meaningful and enhance our experience, might it also limit what we perceive from experience? Am I too much in my head, in a world of constructed stories?

What stories am I missing in my grand narrative of science? Other cultural perspectives? Hmmm. They aren't in Asimov's book of science… maybe I need other resources to help me understand Western science in context with sciences from other cultures? I just don't have a big enough picture to see how I can fit these alternative narratives into my teaching of physics. But wait, am I expecting to have understood significance and connections between things before I teach them… how can I let go of that need and just play with the parts again,

and see what emerges. Is this need to find significance me being trapped in the *philosophic mind*… wanting to have meaningful frameworks all the time? How can I move to the equanimity of the ironist, and the openness of Zen master?

Am I allowing my students the space to find significance for themselves?

> "The Tao is like the emptiness of a vessel; and in our employment of it we must be on our guard against all fullness."
>
> **Lao-Tzu**

My understanding of learning now is well and truly moving to the rainforest metaphor where we can't predict in a linear or even a systems way what is going to happen… mushrooms might just pop up in a totally unpredictable way. I become very interested in Bateson (1972) who suggests that educators need to create a variety of experiences - some with dissonance some with resonance, that we need to speak to many levels of being through multiple forms of expression - metaphor, dialogue, lecture, experience, rational, dance, poetic - and then we allow the meaning to be made by the person experiencing it. Allow them to live their way into the meaning, not seeing it as something that happens then and there with a fixed view of the needed outcome.

Yes, but I have a point to make haven't I? I have particular things for students to learn? But what do I really know what my students take from experiences? What do my students' 'I wonder' journals tell me about their learning? It percolates, pops up, is mulled over, it goes to one extreme and then another, different ideas in tension held at the same time from their physics world and outside life act to propel them to new insight. Ummm. Where is my role in all this? I no longer *facilitate* their learning but perhaps now I am *occasioning* their learning? Do I really matter in all of this?

And in this focus on significance am I forgetting that wholeness is a whole lot more? Or is this process of looking for significance and stories enabling myself to experience and immerse myself in another way of being? Where might it lead in my own flourishing of self? What new questions might emerge?

How am I feeling now? Stimulated. A sense of activism or agency. Political. Ready to stir up my colleagues. Watch out, here I come!

Interlude 1: What are students' beliefs about science? How can these be transformed? A reflection…

In 1997 I began to listen to students' questions and issues in a new way, realising that behind these were certain assumptions about the nature of science. I became very interested in my students' beliefs, wondering where they came from. I was shocked at the beginning of the year when some students' views of science were the notion that anything that is based on measurement must be true, that the scientist plays no part in the truth of the discovery, that science is unassailable fact. Many had no sense of where science comes from, the rich history of construction and development, nor the sense of contingency. It was as if science is a body of knowledge floating on air with no foundations. I was very keen to use my pedagogical toolkit to challenge these views and designed many multi-purpose tasks that could simultaneously encourage critical thinking about the concepts as well as about the nature of science itself.

As a result of doing this all through 1997 I was amazed at how the students had grown. It seemed that making *what science is* explicit also assisted in empowering students to think for themselves, to make their own decisions, to choose what they do and don't believe, to be comfortable with dualities and uncertainties, to ask questions and to be very critical about answers they find.

A big claim, I know. I surveyed and interviewed different students in my class at the end of the year and it was interesting hearing how they pinpointed key things that made them change their understanding of *what science is*… a particular teacher, or the way they were allowed to investigate something for themselves… but most often they said it was only since they were in my class did they begin to really question and understand what science is.

When I met my 1998 class, the difference between their perspectives and attitudes and those of my previous class was really brought home to me. Whereas my previous class would enter into activities of any sort with assurance, curiosity, criticality and creativity, this very passive class seemed to only want notes on the board and prescriptive experiments, not the open ended investigations that I was wanting them to do. Many seemed to have no sense of what it meant to act as a scientist or to think for themselves.

What could I do? What was the issue here? I assumed that part of this passivity was a limited view of what science is and what their role might be as student/scientists. I also thought that

perhaps they were in Egan's *romantic* stage as compared to my previous class, which by the end of the year had moved through the *philosophic* stage and into the *ironic*, as far as I could see. Yes I really had underestimated the journey that the class of 1997 had come on. Now I had to vision the journey that I could take this very different class on.

How could Egan help me? Egan recommends perturbing students from one stage to another by moving into their current stage and using the ways that they relate to in that stage with appropriate challenges to their thinking. Romantics love detail, are inspired by heroes, are affected by emotion and the personal and are still close to the mythic love of a good story with binary elements, plots and morals. Hmmm. Let me think….

I designed a performance/role play called *Isaac Newton - This is your life*, relying very heavily on Asimov's book on Scientists as my guide. This book enables the reader to connect concepts and scientists across the centuries, seeing how different experiments and ideas influenced others, and best of all it includes all the juicy bits - the controversies and the infighting.

I asked one student (Richard) to play Isaac Newton and I was the compère taking 'Isaac' through his life, introducing him to other scientists who influenced him, from the past and his current life, as well as scientists from the future who were effected by his theories (e.g. Huygens wave model of light took 100 years to replace Newton's model because of the stature of Newton). I set up artefacts around the room belonging to key scientists (e.g. Galileo's telescope, Aristotle's angels pushing the earth, Boyle's colour chart) and asked students to play these scientists. Some had words to read or had to improvise. It was interactive, yet obviously I was guiding the story.

Newton's development of his theories is very interesting with many examples of how he built on other scientist's ideas, perhaps only slightly modifying rather than creating new theories out of thin air. He put his Theory of Gravity aside when it didn't seem to work because of inaccurate measurements of the radius of the earth. He then brought it out again many years later with the encouragement and financing of Halley (of Halley's comet fame) when better

> "I do not know what I may appear to the world, but to myself I seem to have been only a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay undiscovered before me."
>
> Isaac Newton

measurements were made, only to embark on major fighting with Hooke (Head of the Royal Academy of Science) who was trying to get his own version accepted. And then there is Newton as alchemist, mystic, and head of the Royal Mint. What a life! The student playing Newton read out some of his famous quotes at different stages including "If I have seen further than other men, it was because I was standing on the shoulders of giants."

What did the students think? They were mesmerised, amazed. So many said to me it was the best lesson of their life. So many were stunned at this man Newton. Many said to me how amazed they were at how many scientists it took to help Newton get to where he got. They had just thought it was one man who had come up with these things out of nothing. I wondered then if science had been seen by them as something you only do if you are brilliant… that ordinary people don't do inventive science.

Immediately afterwards I saw a change in their attitudes to their experiments. A complete turn around. A willingness to experiment for themselves, to be creative and work with others to share knowledge. Perhaps science was now something they felt they had permission to do and could do. There was so much enthusiasm in the class and they continued to talk about the Isaac Newton experience. Even months later one girl wrote an *Isaac Newton, this is your life* spoof in her journal, a complete surprise.

Why have I spent so much time relating this? I guess this is an example of a grounded approach to challenging perceptions about science… not through philosophy, but through an experiential activity. It was very interesting to me at the time that I could take what I understood about the nature of science and Egan's development levels and design such an activity for the direct purpose of challenging perceptions. The fact that it had such a big and immediate impact stunned me, but also encouraged me to believe that my thinking about pedagogy and science had some value. Does the effectiveness of an activity justify the reasoning behind it? If I continued to use that reasoning in activity design could I build further evidence of its usefulness through the resulting growth in student capability and perspectives?

How would I really know students' perspectives? That year (1998) I decided to ask an independent researcher to interview a focus group of my students. She had been interviewing Year 11 science students as part of a study being conducted in the state to look at why students dropped out of Year 11 science. She was amazed by my class… the way they worked together as a group, their sophisticated attitudes towards science, their confidence in dealing with uncertainties and their ability to articulate their views. Her interview notes (see

Appendix 6) and the video footage give ample examples of students' ease in discussing paradigms, contextualising and qualifying their knowledge as well as their own self understanding and reflectivity.

What is more difficult to determine from this is what assisted in this transformation, but this was one question that she didn't ask them, unfortunately…. It certainly would have been interesting hearing their take on it. (The reason she didn't ask many of the meta-questions I had provided for her was that she herself was certain the students weren't capable of answering these, which was obviously not the case.)

At the end of 1998, having spent two years explicitly designing a range of activities to perturb students' beliefs about science I now wondered whether I could also challenge teachers' beliefs about science. I had my own preconceptions of what these must be, based on my interactions with teachers in the past, and seeing their best practice.

Interlude 2: December 1998 - Beliefs about Science Workshop for teachers

I am standing up here in a large room in the University Chemistry Department. There are about 30 physics and chemistry teachers and lecturers sitting around tables with about six people per table. It is the last major session of our annual two day end of year conference. I am running it. I have invited seven students from my 1998 class to be part of the discussions.

I am passionate about it. I tell the audience the story of Lauren in my 1997 class who was keen to have a class T-shirt. We were discussing what should go on it and she says to me "We have to have *Imagination is more important than knowledge*". "Oh, why?" I ask. "Come on Sue, she replies, "Einstein said it… it is on the poster in our room."

Yes, it is… As I put notes on the board and explain them to my class I am looking directly at it. A bit ironic that, me telling students *bits of knowledge*, while Lauren obviously has a sense that science is imagination.

Where do our students get their beliefs about what science is? From posters, from the way we teach, the type of experiments we do, the stories we tell? What messages might we be inadvertently giving them? Are we really aware of how *we* think about science? Are we explicit about saying what science really is? Might we be giving conflicting messages? What notions about science would we like our students to take away with them after studying our courses?

So what is this seminar about today? It is about making explicit what beliefs we have about science and looking at the implications for our teaching.

I now ask teachers to pick up a survey on their tables and to have a go at filling it in. It is the *Beliefs and Assumptions in Science Questionnaire* developed by Peter Taylor at Curtin University. Teachers start looking at it warily.

I would not have dared to run a seminar like this two years ago, but my reading of post-modern critiques of science (Guba and Lincoln 1994) has made me a lot more confident that my own 'subversive' beliefs about science have a rational and legitimate base, solidly backed by postmodern discourses. I believe I can do this with this group of science teachers

because I have built up some goodwill in running other sessions in previous years which people have said to me that they value.

What is my agenda here? I am keen to challenge science teachers' world views of science. I want to move them from seeing science as a fixed body of knowledge to seeing it as tentative, socially constructed, value laden, relying as much on intuition from scientists as it does on rationalism and empiricism. I am hoping that if science teachers shift their beliefs in science then they might shift the way they teach it and what they value in the syllabus.

I am not sure that what I have planned will help transform perspectives that people have. I have brought in seven of my 1998 students who have developed quite sophisticated views of the validity issues of science as a result of our discussions throughout the year and I hope this might challenge participants to realise how capable our students are at thinking at this meta-cognitive level.

But now a group at one table waves me over.
"Sue what do you mean about *beliefs* about science?" asks one person shaking their head over the title of the questionnaire. The rest are looking at me attentively and puzzled.
"Yes," says another teacher. "Are you asking us for something like our *spiritual beliefs*?"
I am absolutely floored. "No, no, nothing like that…. It is just asking what you *think* about science and what science is."
"Not what we *believe in*, then?" asks one person.
"No, how you *see* science… the nature of science."
"Well that word *belief* just shouldn't be put in the same sentence as science then! It just isn't appropriate."

My heart plummets and I think this is just not going to work … haven't they ever thought about science at this level before? I go around all the tables and field questions until people settle down and fill out the questionnaire. The body language is not good and obviously there is a high level of discomfort. People do not look as if they would be willing to share and discuss any of the questions they have answered. The questionnaire probably gives the impression that there is a right and wrong answer and teachers are probably afraid of being seen as a wrongheaded. Not a good climate for emergent discussions. Shit. Have I blown it?

I pull them together and say, "OK, I have given you a questionnaire which has forced you to think analytically about how you think about science. Now I would like to get you to think about it using the other side of your brain and see what happens." They look at me, some

with puzzlement, but the goodwill is back. “How do you really think of science? Can you put that in a picture, or a symbol or a cartoon? There is no right or wrong… just let your intuition speak.”

I get a few looks with eyes narrowed, but people start taking paper and coloured textures. And soon conversation arises as one person sees what another is drawing and asks questions. I formalise this by encouraging them to share and explain their pictures. There is laughter, tentativeness and it seems real listening is happening.

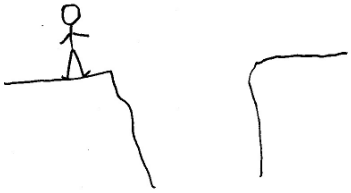


Fig 8.8

One university chemistry lecturer has drawn a person standing on one side of a chasm looking to cross it. The people at her table are intrigued at this picture and ask her to explain it. She describes how when she starts investigating something she has no idea what she might find, she feels nervous and uncertain. How does she leap across this huge gulf? She says how she has to work out appropriate methodology and questions that might help her start to bridge the gap. But she might be on the wrong track… she doesn’t know if her choices will actually get her across the chasm and sometimes you just have to take a leap of faith and go with it. The table erupts in conversation.

I think what a wonderful perspective to hear from a *real* scientist… as teachers we are not doing that… crossing a chasm into something we don’t know…. Because we are teaching what we know… and perhaps forgetting that the act of doing science is about leaping into the unknown.

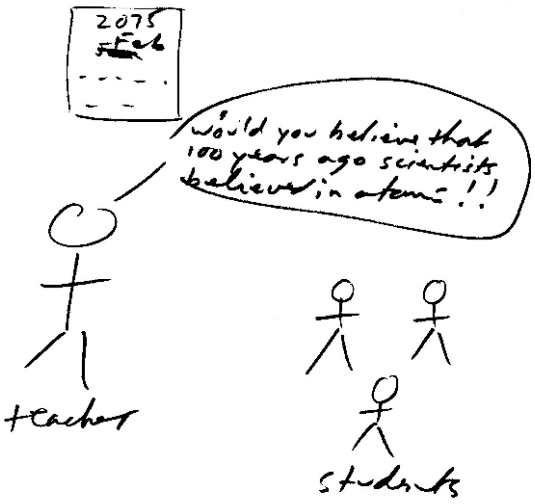


Fig 8.9

I listen into another table where a teacher has drawn a cartoon of a teacher saying to his students while laughing “A hundred years ago, people used to believe in atoms!!”
A discussion then arises about whether atoms could ever be disproved and teachers are giving examples of complete turn-arounds in knowledge in the history of science. One person says, “Well perhaps we shouldn’t be teaching things so much as facts, perhaps we should be upfront about how tentative it is.” Another

person argues that there are degrees of tentativeness and really we are pretty certain about some things. Other people look uncertain about that.

At another table a person is explaining the infinity sign he has drawn.

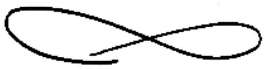


Fig 8.10

"Why did I do this? Partly I think because I feel the more you look the more there is to find. Science is never going to run out of things to look at or questions to ask. We haven't touched the surface yet."

"Yes that's what I think too," says another teacher showing the group his question marks that he has drawn.

"And the question of infinity also opens up a whole lot of questions for me… it is a concept which intrigues me and puzzles me whenever I try to get my head around it."

"Yes, I think that science has that effect on me too," says another person, "there is so much to be in awe about."

"How do you keep that fresh when you are teaching the same thing year after year though?" another wonders.

Fig 8.11

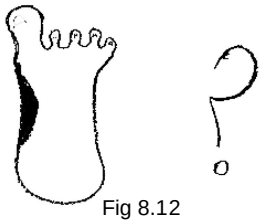


Fig 8.12

At another table a group of teachers are asking one of my students to explain her picture which is a big foot. She explains "the foot represents physics which is trying to understand the world better to move it forward… that's why it is a foot. And these toes here are the different ways physics chooses to investigate and explain the world… through an energy lens, or forces, or waves, or fields… but then that is just one foot…. There are lots more toes and other ways of looking at the world. You need to choose which toe to use based on the system you are looking at."

I can see the teachers' faces, eyes open, leaning towards her, some shaking their heads and asking her how she came up with it. I think to myself, "Oh, oh… I have indoctrinated her into my view of science… one which is subversive and not generally accepted." But no, it seems that they are shaking their heads with appreciation and amazement. Perhaps they underestimate the interest students have in understanding science as an epistemology in context with other epistemologies.

At another table a teacher is leaning towards one of my students who is wearing the 1998 class physics T-shirt along with his other peers in the room.

"I just have to ask… why have you got *we don't give a rat's arse* on your T-shirt?"

Scott replies "It represents how we think about physics … We don't give a rat's arse about whether it is really true or not, we just really enjoy the process of finding out."

The table is momentarily speechless.

I continue to move around the room. It is upbeat, with lots of discussion. I feel that people are intrigued and surprised by their colleagues' views and ways of representing them. "Thank god," I think, "that I got them to draw a picture." The questionnaires just sit desolate on the tables.

I pull the groups together and ask each table to summarise the essence of their discussions. A common theme is the surprise they have about the fact that their views of science are so open with such a sense of awe and sense of possibility. Like me, I think many have felt that their own views might not be the party line of science and have kept them to themselves. They are surprised to find many others thinking the same. This session was almost a confessional. One young science teacher stands up and says to the whole group. "Well if we value imagination and possibilities, sense of awe and the unknown in science why aren't we teaching it that way?"

Yes, a very good question. I expected to come here and perhaps challenge science teachers to move to a state where they might begin to see science differently. But most teachers here seemed to already have aspects of a critical constructivist view of science. Why wasn't that being articulated into practice? Habit? Perpetuating teaching methods that had been *done on them* as science students? Not realising that it was OK to articulate their views into the way they taught? Not seeing how it was possible? Being constrained by the curriculum and syllabi structures? Not believing students were capable of discourse on the nature of science?

We had some time for groups to brainstorm ideas and write them up on the board and butchers' paper to share. It seemed very vibrant, purposeful and open with lots if interesting ideas. One person even mentioned using poetry, saying how interested he was in the way our picture opened up discussion whereas the questionnaire closed it down. What other teaching approaches open us up to intuition and insight?

I was feeling really excited. Perhaps all we needed was the stimulus to talk openly about our beliefs?

The workshop was over. People still milled around, chatting animatedly. The convenor of the conference came up to me and said that he had just been asked not to let me run a session again as I was too progressive and that that this workshop was a waste of time. My heart plummeted. I could not believe it and then I could. I asked him who had said this. A couple

of teachers and yes I know who…. Two very conservative, yet influential physics teachers (males). I was astonished that he would pay so much attention to them given the feeling of the workshop and what I thought were some very positive outcomes.

They had obviously been sitting silent during the excitement of the others. I collected the *Beliefs about science questionnaire* and had a look at what people had said. It was clear that there were a number of individuals there whose notion of science was very positivistic. Perhaps these were the detractors. How naïve of me to think I could challenge anyone's view of science. The role I ended up taking was just to help the group, who already had constructivist science views, to explicate them, while the others were possibly marginalised. Hmmm. How could I have dealt with it better?

What would you do?

Beliefs About Science and School Science Questionnaire

(results of a survey of 22 year 11/12 physical science teachers and 6 university lecturers from Chemistry and Physics – Dec 1998)

Process of Scientific Inquiry

percentage

	Seldom	Sometimes	Often
1. Scientific observations depend on what scientists set to find out.	4	32	68
2. Scientific inquiry involves challenging other scientists' ideas.	4	42	54
3. Scientific observations are affected by scientists' values and beliefs.	14	36	50
4. Scientific inquiry involves thinking critically about one's existing knowledge.	4	8	88
5. Intuition plays a role in scientific inquiry.	4	23	73
6. When making observations, scientists eliminate their beliefs and values.	36	24	40
7. Scientific observations are guided by theories.	8	62	30
8. Scientific inquiry starts with observations of nature.	0	26	74
9. Scientific investigation follows a well-defined method.	7	37	56
10. Scientific ideas come from both scientific and non-scientific sources.	8	29	63

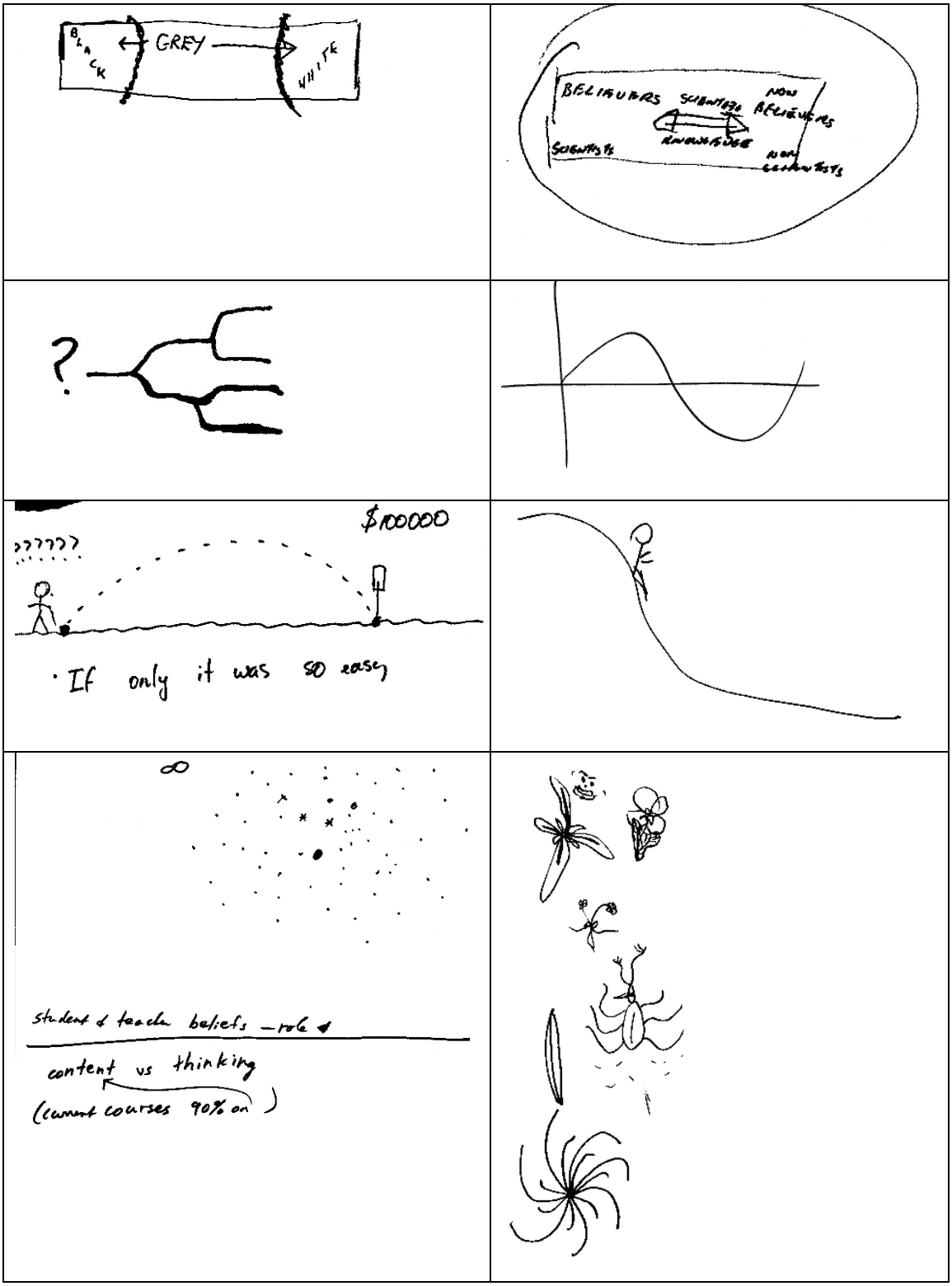
Certainty of Scientific Knowledge

	Seldom	Sometimes	Often
11. Scientific knowledge gives a true account of the natural world.	12	46	42
12. Scientific knowledge is tentative.	4	38	58
13. Scientific knowledge is relative to the social context in which it is generated.	31	19	50
14. Scientific knowledge can be proven.	31	31	38
15. The evaluation of scientific knowledge varies with changes in situations.	15	31	54
16. The accuracy of current scientific knowledge is beyond question.	63	18	18
17. Currently accepted scientific knowledge will be modified in the future.	7	7	86
18. Scientific knowledge is influenced by cultural and social attitudes.	15	23	62
19. Scientific knowledge is free of human perspectives.	73	15	12
20. Scientific knowledge is influenced by myths.	50	42	8

Fig 8.13

Beliefs about Science – Teacher's pictures

(Teacher responses to asking "How do you see science?" Draw a picture, a symbol or a metaphor to represent your view.)



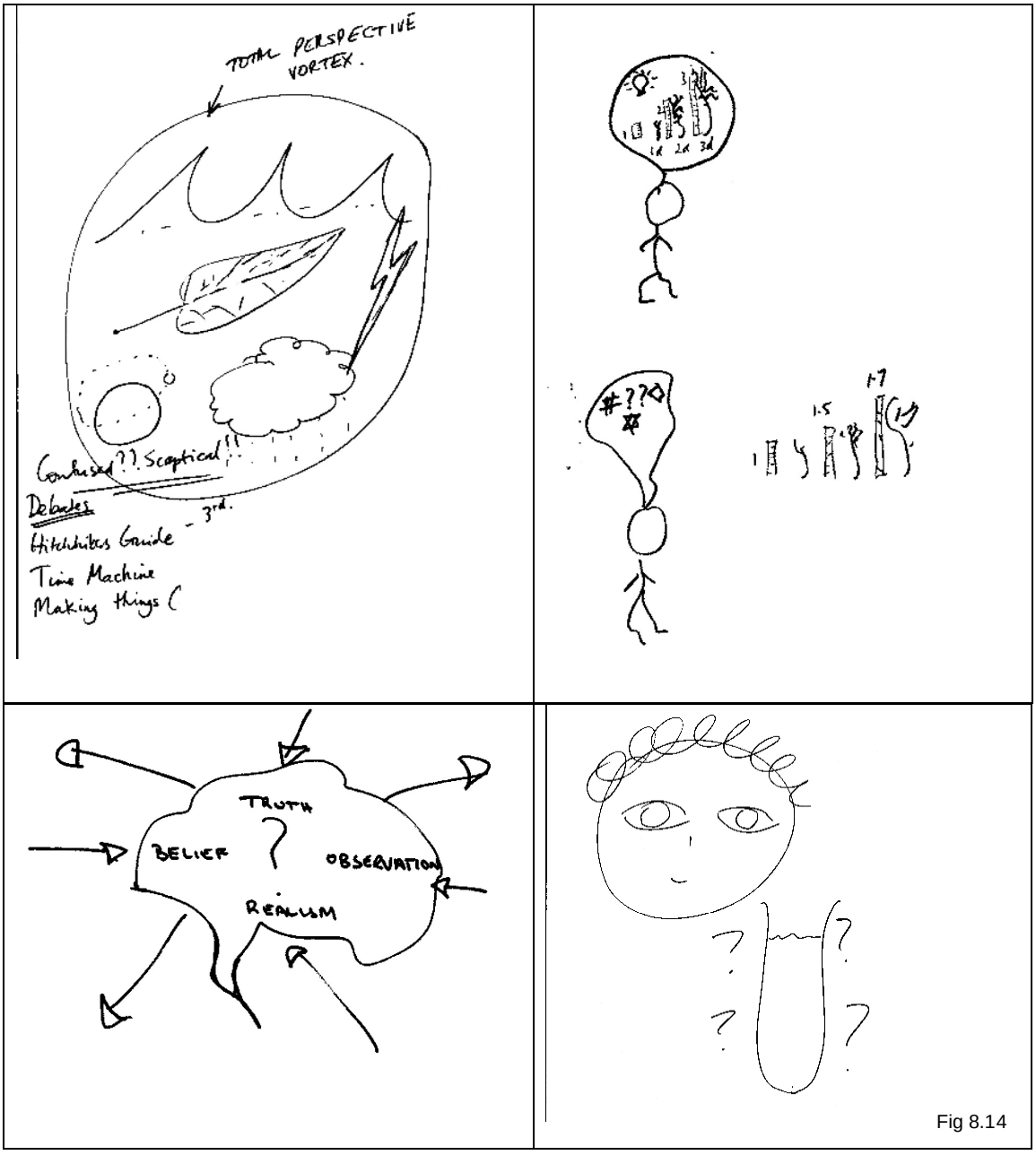


Fig 8.14

What do these pictures reveal about teacher's beliefs about the role and nature of science?

What do these pictures reveal about how teachers see nature?

What do these pictures reveal about how teachers see the relationship between scientists and nature?

What picture might you have drawn?

What picture might an American Indian have drawn?

What inhibits teachers from fully being able to articulate their beliefs about science into their teaching practice?

Interlude 3: An extract from a student's journal

Isaac Newton - This is Your life!

Mike Munroe (MM): So Isaac, how does it feel to be here tonight?

Isaac Newton (IN): Well actually, I'd rather be back in heaven.

(Nervous laugh from MM)

MM: So Sir Isaac, you were born on the January 4th, 1643 at Woolsthorpe, near Grantham in Lincolnshire. You had a very disrupted early life, with your widowed mother remarrying when you were three, leaving you in the care of your grandmother….

IN: (interrupting) Yes, Mummy was like that, always leaving me in the care of someone else.

MM: (continuing) You were sent to grammar school in Grantham and then, in the summer of 1661, you went to Trinity College, University of Cambridge. There you met your long time friend (perhaps your only friend) and he has a few words to say…

Voice over: Isaac, old pal. Gee, you look better than you did when you were alive. Well, anyway, you have a good night tonight, through this séance. You probably thought no-one would ever call you up, right? Either that or you refused to visit.

IN: Who's that?

MM: Isaac, it's your friend George Tilnay. (GT hobbles out.)

GT: Isaac, haven't you made a name for yourself! Too bad I was never remembered. Just in passing. Why weren't you at my funeral?

IN: I, er, um…

MM: So George, tell us about Isaac, what was he like at Cambridge?

GT: Well, Mike, as you can see, Isaac never cared much about his appearance. It took me ages to get him to go anywhere. I almost had to bathe him.

MM: Hmm, So Isaac, after 4 years you received your bachelors degree. You were elected into a fellowship 2 years later in 1667, and in 1668 you received your masters degree. How did you feel then?

IN: (irritated) well I felt pretty good actually.

MM: Yes, er, well. In the autumn of 1666 you developed the fluxional method, known today as calculus. This was a new and powerful instrument that carried modern mathematics above the level of Greek geometry. However you did not publish your findings. The world wants to know why?

IN: (exasperated) Well I didn't want to, OK?

MM: I heard because you were fearful of criticism.

IN: Yeah, well you didn't hear right!

MM: OK, well in 1669 you were approved as Lucasion Professor of mathematics at Cambridge University. In 1695 Gottfried Willheim Leibniz arrived independently at what he called the differential calculus. He published his method and the world of mathematics learned his notation and Leibniz's name. How did that make you feel?

IN: (heatedly) I felt quite annoyed of course…

MM: Well, you became entangled in a violent dispute with Leibniz over who developed Calculus first. This quarrel lingered nearly until your death. Well, tonight, let's put all these ill feelings to rest…

GWL voice over: So Sir Isaac Newton. I really hate you. You ruined my life, my reputation. But at least I'm remembered for Calculus, not you as you were so scared of criticism. So there! But no hard feelings, OK? I was told I had to say that.

GWL walks on…… (continued)

I don't know what inspired me to write this. Probably, I'd ask Isaac Newton all these questions like "Why were you hated so much?" like Mike Monroe did. I heard that Isaac Newton was a really horrible man who basically jumped up and down on Leibniz's grave. If he did this, it is probably no wonder he had so many enemies. He looks to be an arrogant man.

I think I wrote this because I remember that role play Richard did earlier this year. I also remember I did a "This is your life" of Martin Luther in grade 10. I still remember all this stuff about him – the 95 theses, the church in Wittenberg, his excommunication etc. Maybe more things like that will help me to step back into time and face all the difficulties and questions these people did, especially during the Renaissance, and periods of change. It makes me appreciate more how big these people's discoveries actually are.

Isaac Newton's Top 10 songs (in no particular order)

Creep – Radiohead

Charmless man – Blur

Manic Depression – Jimi Hendrix

Knockin' on Heaven's Door – Eric Clapton

People are strange – the Doors

The Boy in the Bubble – Paul Simon

Their Law – The Prodigy

Cool to Hate – The Offspring

There's nothing I won't doubt – JX

Mine – Savage Garden

(He was probably a nice man, its just history doesn't record him as being that agreeable.)

Tiffany

Intermission

A break for a cup of coffee and a piece of cake (moist poppy seed drizzled with a warm orange sauce) … a chat with some curriculum planners

Yoo-hoo curriculum planners…you can come back into the room now…. You have been waiting patiently since Chapter 4…would you like to make any comments?

"Sue, you have certainly been on a journey… taking physics from just the delivery of facts and ideas to helping students inquire into those ideas…. Then bringing in their own questions and feeling comfortable in being tentative and creative with the ideas… to then asking them to inquire into the construction of science itself."

"Yes, it seems that you are moving into a critical constructivist point of view of science teaching. I kept wanting to give you a book to read on it when I saw the dilemmas you were in but I guess at the time you were in a culture of trivial constructivism and had no exposure to postmodernist perspectives of science. What I find interesting is that you didn't just adopt someone else's say so about science… you actually worked it out for yourself… and possibly because of this you have been able to construct activities for your students that are meaningful for them. It makes me wonder about the value of 'hard won knowledge', rather than something that we might read which doesn't have an impact with us because we really need to experience it for ourselves before we can really come to know it."

"I guess there is vicarious knowing. I think Sue took *me* on a journey of asking what science is. I guess I have never thought about it that way. My experience is one of learning out of a text book and doing set experiments. I have never seen it as something tentative as the way my discipline of history is and I now wonder whether I am getting this notion across in my teaching of history! Do my students see history as tentative and politically constructed or have I enculturated them that it is a body of uncontested historical fact because we have immersed ourselves in coming to know a particular historical time period?"

“I am surprised that the students are able to engage with this level of inquiry into the political construction and epistemologies of science. It seemed that a key was giving students a real experience of a particular issue, like meeting your flat earth assertion, and then unpacking what was going on. I wonder whether we too often believe that this type of thinking only can happen at university - that our job is to lay the ground work by giving the theories and the facts rather than developing this helicopter critical thinking.”

“I am interested in the richness of what you are doing and how it stems less from the choice of activities but rather from the attitudes you are bringing to what you are doing. How important it is that you are constantly reconceptualising your notions of science … constructing something that for you which is self consistent and justified and how you are layering that within each activity.”

“There are so many layers of meaning that you are trying to construct for your students. It would take an enormous amount of energy to juggle so many different purposes in mind. I am interested in this balancing between the whole and the parts … and the whole here could be seen as whole student, whole course, whole relationships, whole of reality.”

“I too am interested in this process of reconceptualising that you are doing. It really seems to be the key in changing your practice and I am wondering about the implications for other teachers engaged in professional learning. How much is our teacher training about just applying a technique and how much of this actually shifts their view of their teaching? It seems that the tension between your science and spiritual selves is being acted out in your practice, with the students playing a critical role in giving you feedback. What tensions might other teachers bring into their teaching and how can we harness these dilemmas. They could be existential, pragmatic … it doesn’t matter… perhaps the key is finding an issue and helping them to explore it.”

“Yes, it is interesting that you design activities based on one line of thinking … but in the action of it unexpected experiences result which perturb your thinking even more. It is such an iterative process and it is interesting how your values and assumptions are shifting. Did the students realize how important they were in this process?”

"I have been listening with interest to how you are interpreting your students' experiences and am wondering how much the paradigm we are in shapes what we see in our students. You are obviously creating some very special experiences… on one hand I feel sometimes you might be over-claiming – interpreting too much through a lens *expecting* holistic outcomes – but on the other hand it makes me wonder if we close our eyes to the *immenseness of being* inherent in our students."

"Yes, it is easy to apply scientific perspectives to looking at these experiences… find one non-shifting standpoint and interpret from that perspective…. But, Sue, you are moving the lines constantly which makes that difficult."

"What are the implications for our curriculum framework?"

"Well, I am interested in the way Sue brought in students' passions. We are talking about *personal pathways* and *extended studies* as enabling students more flexibility in finding their own path according to their interests and passions. I was interested in the boy who came to class with no big questions and then ended it with "dare I say it, a desire to know more." It reminded me how students' passions need to be nurtured and revealed. So many students have no direction and we need to create an environment which is inspiring, as well as the flexibility in the curriculum for students to do their own thing."

"Yes, it reminds me of the 'means and ends' argument. Sue here seems to be meeting many ends with a particular 'mean' that we might not have seen the potential of. It makes me wonder that if we looked with new eyes at what we have already whether we could also find such rich possibilities."

"I think some subjects lend themselves to enriching but some really are not appropriate and should not exist… for example some maths classes."

"What? Can't get rid of maths."

"Perhaps we need to re-conceptualise our subjects and ask what purposes they might have in terms of student flourishing and transformation as well as what information and skills they get across?"

* * *

Hang on a minute.

Hang on a darn minute.

What have I done? Is this what I really want my curriculum planners to think?

This conversation is CANCELLED!

I have pushed the box of science so I am peeping out. I am beginning to realize its contextualization. I am beginning to be more explicit in teaching that in my classes.

Sounds terrific.

Yes, lets make our subjects more purposeful, enriched, meaningful, self critical. Yes, there is lots of room to *flourish* what we are doing. But this isn't *transforming* education! The curriculum framework is still there. We still believe in standardization, in grading, in subjects. We are just doing better within the constraints of what we have. We are not moving those constraints, we are not opening the curriculum box!

Yes, and that question about the students knowing about their importance in my process. Where are they in this story? They are still the learners, the people who I am *doing learning to*. I am learning in this relationship, but am I sharing this with my students other than thanking them and using what I have learnt *on* them? How are we sharing in the development of our learning? What is this box of teaching and being a teacher and what might it mean to re-conceptualise it?

And where is holistic in all this? I have begun to explore what holistic might look like within the box of my classroom, but what does it mean in terms of *whole of education* visioning?

Sue, Sue calm down… take a deep breath. You always tend to get into either/or rather than and/both. Just sit with the dilemma for a while and see what emerges.

Yes, I am deeply engaged with a paradox, struggling with it, but yet to find myself in a new place.

A Paradox in two parts

First part:

A Zen Koan:

> A man puts a very small gosling into a glass bottle. It grows until it fills up the bottle. The man wishes to take it out but doesn't want to kill the goose or break the bottle. How can he do it?

Koans are used in some spiritual traditions to create a dissonance in self. One tries to solve the paradox within current paradigmic thinking and fails. The only way to 'solve' a koan is to change perspective or the self. It is the engagement with it and the investment in it which helps to precipitate the person to the edge of insight. Walking away from it doesn't get you anywhere.

> "The ability to perceive or think differently is more important than the knowledge gained."
>
> **David Bohm**

Nicolescu (2002) sees paradox as an opportunity to create a third reality which enables the either/or to coexist as and/both. He calls this *the included middle*. In one reality and/both is not possible – in another it is. It might be a new physical reality or a new abstract construct of reality. But then what is the difference? The 'included middle' is now being used in exploring ethical issues.

Dialectical reasoning is a process of moving from thesis to antithesis to synthesis. Maintaining a creative tension between two polarities in any proposition or phenomena can result in progressive and qualitative change through the creation of a new entity which is more than the sum of the parts. This is the result of synthesis.

Second Part: Physics class 1996

It is the start of the third term and we have come back from a break of two weeks. A student, Will stands up in class pleading with great emotion "Sue you have to put me out of misery. *Is* light a particle *or* a wave?" I am so surprised at the angst in his voice. He goes on to explain how it has been the dinner topic of conversation for months. I am stunned. It is the first year that I explicitly pre-empted the wave particle dilemma through linking what we were doing in light with what we would be about to do in quantum theory.

It suddenly occurred to me that this was the first time a student had been so troubled by the wave –particle paradox. Why? To be concerned about it you really need to buy into the fact that light *is a wave*. And then buy into the fact it *is a particle.* Only when you were convinced of both did the paradox become alive. Perhaps finally I had actually taught well enough for the students to understand? And Will wasn't the only one. His question started a major discussion which went over many weeks about how we might find out.

What were students' responses to the paradox? Some really needed to find *one* answer. It was an *either* light was a particle *or* light was a wave. Which one? Some felt it might be something else entirely. They were even more disturbed to find that an *electron* could also be both wave and particle, because an electron was somehow more solid. But whenever you tried to test it the electron *either* behaved as a wave *or* as a particle. A group of students spent ages discussing ideas for experiments which might trick an electron into being both wave and particle simultaneously.

At the end of the topic some students became blasé about the paradox, comfortable that something could be and/both, while others still wanted one answer.

Reflection 2006. Were students engaged in dialectical reasoning? Did students move in cognitive maturity as a result? Did they experience a change in perspective about the nature of reality? Did they see the descriptors of waves and particles as just metaphors or models describing reality, rather than reality itself?

Is being comfortable with *and/both* a numbing of the potential for insight, realization and transformation? Should I be encouraging pluralistic thinking or encourage increasing angst leading to something beyond? Can I do and/both? Do I have any say in this or is it really where my students are at that dictates what happens?

What is the potential for paradox in my teaching? What creates dissonance for my students?

How do I use paradox to motivate my own growth? Tensions seem to be permanently present in me, whether my big duality of physics versus spirituality, or issues that I am facing in thinking about my students and my teaching. Am I trying to solve things by finding one right answer, by allowing both possibilities to co-exist, or by deliberately keeping the tensions alive? Perhaps sometimes I find myself seeing from new perspectives or have lived my way into a new way of being in the world.

And isn't there another way of dealing with paradox? Wilber no doubt would suggest that we look at how we can transcend and include.

Epistemological Pause

May 2006

It's about time I reflected on the epistemology I am bringing to this narrative. There are several layers.

First perhaps is the layer of epistemology I was using at the time that I was experimenting with my physics teaching. In 1996 I started using action research formally. This meant deliberately applying principles or techniques in my teaching and observing students' behaviours as well as actively seeking their feedback. Based on this I would theorise about students' learning and development. I could build up a store of anecdotes which would help me test theories I was reading and ask how do these theories apply in this situation or that. This enabled me to get inside the educational theories in the same way I was getting more inside the physics theories.

I then might ask students to give me feedback about these models I was developing to help me understand their thinking and learning. While some students found them intriguing or useful, for many others they had no relevance. So was the relevance of these models just for me as temporary scaffolding? Were they helping me to be more intentioned and reflective, resulting in being a better teacher…. the aim of action research? Did they reveal any real truth about how students learn? What was I really trying to do here?

What research should I have been doing if I wanted to find such 'truths'? How 'true' was the constructivist literature that I was reading which just focused on one lesson, or student dialogue, or some student interviews or a learning environment survey? Each of these were bringing a certain theoretical lens to

making sense of what was happening… yet in my reading of the original research data I was not necessarily seeing the same things as the researchers.

It really does depend on your underlying theories about education and learning as well as your values, worldviews and perspectival levels as to the meaning you can draw. I was astonished at how researchers confidently interpreted student dialogue, or drew conclusions from interviews and learning environment surveys without any discussion of the standpoints they might be bringing.

What did I gain out of reading all these articles? Perhaps the view that trying to understand learning is problematic and that sharing what we teachers /researchers know and think is part of an ongoing conversation enabling emergent yet individual meaning making. It is not so much about 'truth', but about opening oneself to different perspectives which can heighten self-reflectivity.

Yes, learning is rich, complex, dynamic, individual, over time…. dare I say *ineffable*. Yet here am I trying to understand it. And did my need to understand and model learning mean that I was stuck in Egan's *philosophical* stage, needing to find grand generalizing frameworks, rather than moving into the adult world of *ironic being*? Yes, I am aware of the dangers of my proclivity to model, but it does seem to have its benefits… because I find that things are working rather well. Is this a result of teaching with models in mind, or because of the flexible thinking I am bringing in the classroom – my openness to feedback from the students, to responding *in the moment* to what is happening and my deep listening? Hmmmm.

I am now doing two types of *action research*… the one which is more staged - giving time for planning, implementation, feedback and theorizing - and then

the *action inquiry* of Torbert (2004) which is action research *in the present moment* – a mindfulness in action.

Perhaps it is the play between the philosophic models, reflectivity and present moment awareness which enables the development of 'practical wisdom which is the praxis of such research. This practical wisdom is 'ironic' in that it can only be applied in the situation at hand rather than being generalized.

So now in my narrative about this process of action research and action inquiry I have to be aware of the epistemological claims I might be bringing. I am writing anecdotally, about my process of reflection, about my changing perspectives, about my many models in process (which I haven't structured as learning environment questionnaires to be statistically tested… yes, you may well shake your head over that in disappointment… but rather have 'tested' through their transient usefulness to me as a teacher).

Now this approach might be fair enough if I was just doing a self-reflective, culturally aware study with the purpose of enriching audience understanding of the life world of a science teacher, where standards of rigor might include authenticity, self-reflexivity or 'truthfulness' claims of auto-ethnography. However, I am intending to draw from my experiences, my reading and my reflections in order to come up with a grand vision for science education as a whole. It concerns me then, as a scientist, that I should make such generalizations about science from such a limited research field and mode of research.

But perhaps all I am offering is a certain insight, from my clearly stated standpoints (as well as not so clearly stated), which in itself might result in praxis for others, and opportunity for testing of the model. This is the dilemma of hindsight, because at the time of doing action research my main aim

was not to come up with the grand unified theory of science teaching but to just explore the question *"What does it mean to move towards being a holistic teacher?"* The grand vision emerged at the end as a result of this question and my need to make models of my process… and now I am scratching my head and thinking…. hmmm where is the scientific rigor? If I was starting again from where I am now, I would be offering different 'proof' other than my own process of getting there. I am getting ahead of myself. But I wanted you to see the dilemma I am facing… to be true to my process, but to meet the needs of the emergent theory for rigorous justification.

Richardson (2000) would say that when one *writes as inquiry* there is a freshness of self-reflectivity and self-reflexivity. One is capturing self at a particular time, and in the iterative process of writing one begins to see in a new way and a new self is being created. The reader is party to the creation of this self which can be quite moving, creative, insightful and inspiring. The reader can perhaps identify with the processes and be encouraged to reflect about their own experiences. When one starts writing with something to say, then one is writing from a 'science consciousness' …. writing comes from the past… the writer is merely documenting the already changed self, rather than revealing the process of change.

I am perhaps trying to do both with the result it can be merely confusing! For example, I took out my reflection based on the curriculum planners limited comments, deciding it was unimportant to the argument I was creating. But then I have decided to put it back in to reveal better this process I am taking… it is not as well defined as the words appear on the page…. I am struggling towards an understanding yet to emerge.

Back to my role as writer. I am well aware of the orchestration role that I am taking in the construction of this story. How as artist and constructivist I am

selecting anecdotes, student journal entries, and themes in order to take the reader on a journey of vicarious experience and reflection. I am aware that while in some cases I am deliberately leaving the reader to make connections and to analyse for themselves (to enable access to the inherent richness), my manipulation of text no doubt influences the possible meaning to be made. It is tricky. If only you and I could have a dialogue about the meaning you and I am making from this writing. Because most of what I write are starting points for conversations… rather than conclusions.

In the process of writing this for an audience I too am making insights… it is pushing me in perspectival understanding (another explanatory model!) and I am interpreting student data and my own experience in new ways. I see many threads I could pursue further; there are lots of questions I have and I think it would take a lifetime to research them. I am aware of how focused I was at particular times on aspects of learning and science; how it had its own inexorable momentum and direction… but now I wonder what might have happened if I had asked a slightly different question back then, or not moved so quickly from one concern to another. Writing chapters in themes has the benefit of enabling hindsight exploration along a thread (depth), whereas at the time there was far greater interactivity between each of the aspects I was exploring (enabling a sense of breadth).

Questions:
How relevant is my experience of teaching physics to the teaching of science to other age groups? What are students' needs, goals, questions? What experience of science aligns with their personal journeys?

How do teachers' beliefs inform practice in both conscious and unconscious ways? What have been various approaches in transforming science teaching practice and what are the issues with these?

Who else has had similar experiences to me and what insights have they had?

Fig 8.15

I had a dream at the time which perhaps explains the method of my journey. In my dream I found myself in a room with lots of doors, all with different aspects to explore. I opened one door and headed off down a corridor, opening

other doors into rooms where I stayed a while and played and learned. I came back into the main room and continued to go through each door and explore what it had to offer… but after a while when I opened a door I found I was on the mezzanine level looking down on the maze of corridors and connections.

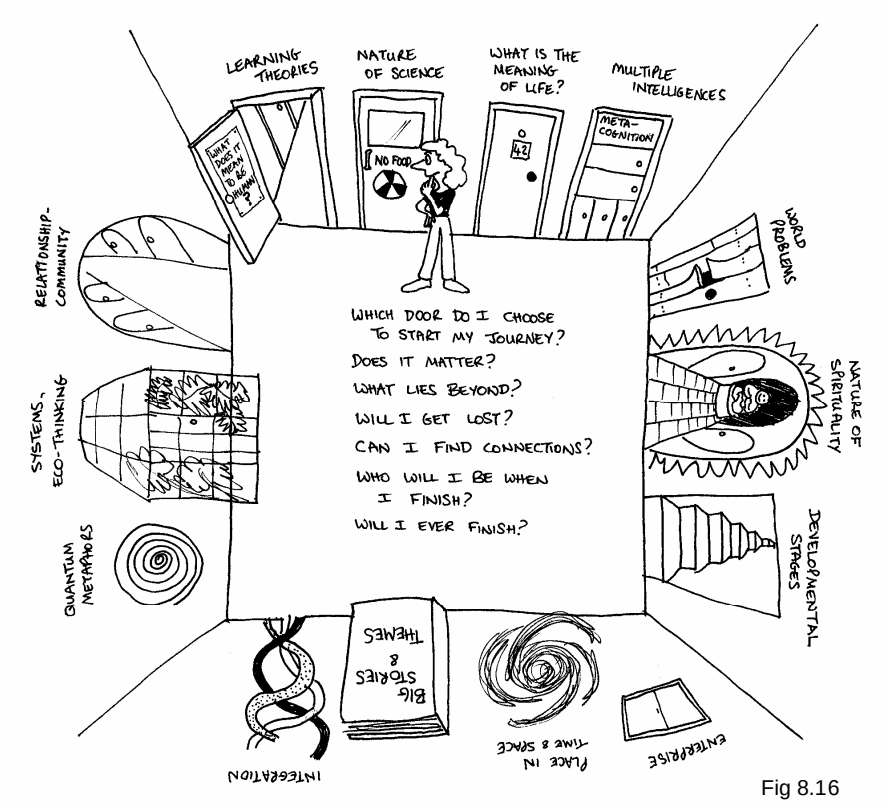


Fig 8.16

I could see my earlier self moving around at the ground level, not really understanding how each aspect linked to another one, but blithely exploring. But from this new height from the mezzanine floor it was clear how one corridor led to another and how they shared common rooms. I felt excited that I could have this perspective about the interconnectivity of what I was doing. I began to see how they all related to each other to create this ineffable thing called learning.

Then I looked up. I was in an enormous 3 dimensional maze only having covered one small part. I saw the potential of where I could go… I could follow corridors deeply, or try to cover more ground. Does the process of interconnection of my

Fig 8.16

experiences lead to greater perspectives, gaining higher floors? My dream seemed to be telling me that was the approach to take. To see how what I had learnt already interacted. And this is what begins to happen in a big way in the next few chapters.

Now there are several subplots moving through the previous chapters… I will mention two at this stage….

My own transformation.

The dialectic of physics and soul is causing me to re-conceptualise my ground of meaning. In terms of Fowler's *Stages of Faith* I have moved from **individuative** (choice in own beliefs, values) to **conjunctive** (incorporating views of others and wishing to serve others) to the beginning of **universalizing** (search for universal values, common essences). My view of spirituality has moved from an emphasis of *seeking truth and meaning* (dogma) to the *essence of being*. But this is very much still in process. My perspectival level is also moving into more pluralistic perspectives but is yet to be truly challenged and flourished.

The shift in my focus from *content* of science and *content* of spirituality to extracting the *essences* of science and essences of spirituality now enables me to marry soul and science to some extent through the nurturing of soul within a thinking classroom.

Is the process of analysing myself against such stage models helpful? For me I think it clarifies my different standpoints. Being a 'holistic teacher' who is coming from 'a spiritual paradigm' is in fact not a definitive entity. I could claim I was a holistic teacher at different stages of my journey but these would be quite different, mainly because of the perspectival stage I was in, my notion of spirituality and how I conceptualised what a holistic teacher is.

So in 1994 my focus might be caring for students and developing a sense of wonder, in 1999 it is the creation of Sue's wonderful world of physics with a truckload of innovative holistic pedagogies, and now in 2006 I have let go of the notion that holistic lies in the types of pedagogies you are using, rather I am focusing on the student and using what percolates up from my reservoir of pedagogical experience.

Yes, this change in standpoint is problematic. No wonder when I read student journals now I see new aspects to them that I didn't see in 1999.

My changing role as a teacher of physics.

This can be best explained using the metaphor of the goose in the bottle.

When I started teaching physics, the gosling (the spirit of my students) was outside the dusty bottle of physics. I was engaged in opening up the heads of my students and pouring the content of the bottle inside whether they liked it or not. I then began to discover a physics I hadn't known before… I scrubbed away the dust and in the process the bottle got bigger and more transparent. I found now that the bottle was only partially filled with physics content and there was room for the gosling inside, floating on the liquid.

I then found a sense of awe and wonder in the physics and the contents glowed with vitality which permeated the being of the gosling. It started to grow. It had its own questions and now drank deeply of the content of physics.

But then I began to see the significance of physics and I expanded the content to include philosophy and nature of science… the bottle is getting very full… with a growing gosling and no space to go.

There is a problem now. How do I get the gosling out of the bottle of physics without breaking the bottle or killing the gosling?

What is the next step for me now? What structure of curriculum could help me with my dilemma? How might I see my classroom, my students and my role as a teacher?

Am I moving from *teacher directed* to *student centered*? And what do I mean by student centered? There is a sense I already have been concerned about my students and trying to see through their perspectives, but perhaps there is more to see?

Meditations on geese