‘Re-Creating’ Science in Higher Education:
Exploring a Creativity Philosophy

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Declaration

I hereby declare that this is entirely my own work and that it has not been submitted as an exercise for the award of a degree at this or any other University. I agree that the Library may lend or copy this dissertation on request.

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Summary

There is a perception by the general public and students, as well as some scientists, that science is not creative. Views of the ‘official’ scientific method as ‘linear’ and ‘mechanical’ may be partly responsible for these views, as well as the way science is taught. Creativity, including imagination, insight and intuition are all involved in developing scientific hypotheses and theories for example, but are not necessarily acknowledged as implicit in the method. Here, a creativity philosophy for science teaching and learning in Higher Education is explored with a view to ‘re-creating’ science.

Here, the literature pertaining to creativity in science and science education is reviewed. Then a philosophical perspective of nature as being inherently creative is presented, based on developments in quantum physics and philosophy. The work of David Bohm regarding creativity in science is introduced as well as the radical views of ‘nature’ and ‘knowing’ proposed by Christian De Quincey, based in part on the process philosophy of Alfred North Whitehead. The scientific work of Johann Wolfgang von Goethe is also discussed, as a way of developing the imagination and the ability to perceive the creative dynamism and wholeness of nature.

Using a phenomenological approach, semi-structured, exploratory research interviews were also carried out with students and scientists who teach in Higher Education at Schumacher College, UK and Trinity College Dublin, Ireland. Questions focused on the participants’ interests in art and/or other creative pursuits (e.g. sports) and the extent to which these pursuits feed into their scientific work. Opinions on the ‘official’ scientific method, imagination, insight, creative scientists and creativity in nature were also solicited. Quotes from participants revealed consistent views that creativity is important for both the process of doing science and that it is inherent in nature (e.g. evolution and embryonic development).

Many creative and novel teaching methods were described. The Schumacher College lecturers and students discussed Goethe’s way of science as an effective way to develop deep observation, the imagination and also mindfulness. The use of visualisation and meditative practices in teaching and learning was also described and the benefits of alignment of
scientific and creative pursuits such as poetry, drawing, music and sport were outlined. Teaching about science from a historical perspective, including the stories of creative breakthroughs of eminent scientists was also seen as advantageous in creative science teaching. Creating a group dynamic for teaching and learning in order to instil confidence in students, and where group members are at ease, was considered important for overcoming fear of failure or fear of being creative. Moreover, small group teaching and group work in general, role-play, active and self-directed learning and inquiry-based approaches were also discussed as advantageous. Providing space and freedom and time to reflect were considered vitally important for both science lecturers and students. The advantages of an immersive educational environment as well as opportunities to discuss science with students in small informal gatherings, such as on field trips, were described. The necessity of focus, restraints and discipline for creativity in research, teaching and learning were highlighted. The ability of a lecturer to impart a feeling for the subject in students was seen as important, while open-minded and creative questioning should be encouraged. Finally, development of skills for obtaining a state of ease, relaxation or ‘flow’ was highlighted as a requirement for creativity in art and sport as well as in science. Indeed, the acquisition of skills outside academic work was seen as transferring productively into the practice of science.

A further part of this study presents comments from student self-reflective pieces obtained following a session on problem solving and creativity. The quotes from students contain real evidence of the transformative nature of this activity, particularly with regard to helping students to see the relationships between art and science, the creative process of science and in gaining skills to present their work creatively.

Science is a truly creative endeavour and creative teaching methods should reflect this. Appreciation of the historical and philosophical contexts of science and the relationships between science and art should be encouraged. Such approaches will enable students to see both nature and science as inherently creative, indicating that we are true participants in the creative and dynamic processes of nature and in the process of science.
Reflections

Well, I’m probably going against the prescribed protocol here. You see, I was going to hide this in the back of the Appendix, but then who would read it? I decided that it’s important. One of the participants I interviewed here said: “I have to remind myself sometimes how I ended up here. What inspired me to take up science?” I thought it might be worth my while to think about that and reflect on it. One of the students also said something interesting that got me thinking: “I found since studying science that we may have lost our sense of creativity somewhere along the way.”

You see, people say the most interesting things when you ask them questions. And I thoroughly enjoyed asking the questions and listening to the answers. But then again, I’ve always been asking questions. Usually, my Dad got my questions. Dad was generally patient and always tried to answer. He never really gave me any fixed answers – there were always questions within questions – reaching gently for ephemeral answers that led to more questions. “You zee me zun, nothin’ do ever stay the zame.” – the Somerset dialect, always creative.

Growing up in the country, we never saw anything as fixed in place. Winter, Spring, Summer, Autumn – always cycles and change: calves being born, chicks hatching, apples harvested, potatoes dug, broad beans picked, shallots pickled. Dad loved nature and always saw the creativity in it. He was creative too. Like the rest of the family, he played in Burtle silver band – euphonium and trombone, Aunty Grace on her cornet, Grampy on the drums – later me and my sister Sally on cornet too. Dad loved music. Told me how he couldn’t understand it the first time he heard rock and roll, but he loved it anyway! Dad built our house. He was an excellent stonemason. I helped him build walls later on and I remember getting ‘in the flow’ finding stones that would fit – we were a great team. There’s nothing more fulfilling than building a wall and making it look beautiful – working with the living stone, integrating it into the landscape.

One day Dad came home from work with a bag of sand, dug a hole for us and poured the sand in – hours of fun. Me and my matchbox cars and trucks - digging, building...wondering why the sand would get weak and the trucks would sink when I added too much water, early experiments with
liquefaction I found out years later. Sitting still and silently on the riverbank in the dark, catching eels. Then there was the old antique telescope – we studied craters on the moon. Other times on clear nights he pointed up at the stars “There’s the milky way me zun and he’s Orion. Do ‘ee zee ‘iz belt. And tha’s a pulsar?” And the twelve bore shotgun – one in a thousand model – beautiful etched hunting scene on the boss “Thees gotta hold in tight in to yer shoulder – ‘ee da kick zee!” So, I wondered about the Milky Way and the stars and Orion and pulsars and how twelve bore shotguns work. We hatched out chicks and ducks in an old paraffin heated incubator. I learned a bit about mechanics - changing the clutch in the Vauxhall Viva and always needing a creative solution to keep Dad’s old ‘Fergie’ tractor going during haymaking. Then Dad got me a subscription for Safari Cards – I waited impatiently for them to drop through the letterbox every week; cards with pictures and details about animals. I can still smell the cellophane. I would catalogue them in all sorts of different ways, alphabetical and according to Genus, Phylum, Species – hours and hours whiled away. Then to cap it all, Dad got me a microscope – it sits in my office window now – a reminder to me of “how I ended up here”. We grew brine shrimp and looked at the slides that came with it. And the most amazing thing – I went out and collected water from the pond in the next field and put a drop under there with my Pasteur pipette. And what did I see? Well, more than that, it was beautiful, a little tiny wriggling pond flea - Daphnia! And what happened? I'll never forget it! She, well she must have been a she, gave birth to a little tiny live pond flea and I witnessed it!!! Well, I actually felt like I’d participated in it! Wow! I was hooked. I’ll do something with microscopes then….years later, I’m in the lab in Canada…phoning home to Dad, so far away, on his kidney dialysis machine with Mum there keeping an eye on him …and the machine. “How be on me zun? What’ve ‘ee been up to?”… “Oh Dad, it’s going great! The experiments are finally working! I’m just looking at these patterns of protein expression in my chick embryos – they’re beautiful!”. “Ah, I’m glad for ‘ee me zun. Glad it’s all beginning to work for ‘ee.” So, in “studying science” I hope we can maintain our “sense of creativity along the way.” I hope I do my best to remember anyway.
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Dedication

To the memory of my Dad
Eric James Wride
1943-2010

Who loved nature and always encouraged me to be creative

And for my children:

Thomas, Charlotte and Samantha

That you may always see the play of creativity in nature and that your days will always be filled with the joy and love of learning
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“And an eternal, living Activity
Works to create anew what has been created
Lest it entrench itself in rigidity.
And that which has not yet been
Seeks now to come into being
As pure suns and many-coloured earths:
None of it may remain at rest.

It is intended to move, to act and create –
First to form and then to transform itself;
Its moments of immobility are only apparent.
In all that lives the eternal force works on;
For everything must dissolve into nothingness,
If it is to remain in Being.”

Johann Wolfgang von Goethe (1749-1832)

“My mind has changed during the last twenty or thirty years... Now for many years I cannot endure to read a line of poetry... I have also almost lost any taste for pictures or music... My mind seems to have become a kind of machine for grinding general laws out of large collections of facts...If I had to live my life again I would have made a rule to read some poetry and listen to some music at least once every week... The loss of these tastes is a loss of happiness, and may possibly be injurious to the intellect, and more probably to the moral character, by enfeebling the emotional part of our nature.”

Charles Darwin (1809-1882)
"In all things we learn only from those we love."

Goethe

(Zajonc, 2006)
1Chapter 1: General Introduction

1.1. The Creativity of the Embryo
I am still filled with a sense of awe and wonder when studying embryos. The gradual appearance of form of a zebrafish (*Danio rerio*) embryo is astounding. The fertilized egg begins to cleave and the first cells are formed, wrapping around the yolk sac that will provide all the food the embryo needs. The cells move and divide in an intricate dance of creative exuberance co-operating and responding with ease to the rhythms in the silent music, creating intricate, interweaving patterns that are beautiful to behold. I agree with Aristotle that there is within the embryo an inherent creativity or self-agency (Brady, 1998).

1.2. An Artist’s eye?
To understand embryonic development, is it then just a case of explaining the material interactions between the molecules and cells or is there something more at work here, something perhaps even more wondrous? Can we remind ourselves occasionally to just step back, perhaps with an artist’s eye, and admire the beauty and creativity of the process as it is? Surely, this is the way that science really works?

“The Scientist does not study nature because it is useful to do so. He (sic) studies it because he takes pleasure in it; and he takes pleasure in it because it is beautiful. If nature were not beautiful, it would not be worth knowing and life would not be worth living.” Henri Poincaré (Root-Bernstein, 1984)

The most successful and creative scientists have always been able to move beyond the ‘official’ hypothetico-deductive scientific method (Popper, 2002) into the realms of aesthetics, intuition, imagination, feeling and inspiration to gain their creative insights. Perhaps this is actually the normal mode of operation of all scientists. We need to move away from the idea that

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1 Some elements of this Chapter were previously published (Wride, 2014).
creativity is only associated with art and music, rather than science (McWilliam et al., 2008). Indeed, science is apparently not perceived by the public as a creative endeavour (Schmidt, 2011). Furthermore, there is currently a ‘battle’ for creativity at the frontiers of both science and science education (Schmidt, 2010) and it has been argued that creativity should be at the heart of biology (Medina, 2006) - art can be a science and science an art (Root-Bernstein, 1984), particularly in terms of the creative processes involved (Waddington, 1969). Can we ‘re-create’ or ‘re-vision’ science by putting a creativity philosophy at its heart?

1.3. Re-visioning Science

In a study on ‘re-visioning science’, scientists were interviewed about their motivations and every day ‘lived experience’ (Lunn & Noble, 2008). The most common theme to emerge was the relationship between science and creativity - relating to art was highly important for scientists in finding inspiration and providing a wider context for their work. The words ‘wonder’ and ‘beauty’ were often used. A wonderful quote from this study by Prof. Jeff Tallon of the University of Wellington, New Zealand stands out:

“If you have science without passion, forget it as far as I’m concerned. If you have science without creativity or without insight, well you don’t have science. It’s about extracting order out of a chaos of information, some kind of beautiful, simple, elegant theory…”

1.4. A creativity philosophy at the heart of science

For a creativity philosophy to underpin science, we may need to go as far as a fundamental change in our worldview, a ‘paradigm shift’ (Kuhn, 1962). I will argue here for a more complete science that can incorporate, but move beyond the analytical, intellectual, reductionist, mechanistic, objectivist and deterministic thinking that came out of the enlightenment (Sheldrake, 2012). A new relational ontology will be required in such a radically new view of science that will incorporate the links between science, art, and aesthetics. Therefore we will also need a new epistemology of an integrative and participative education. Such a view was called for by the physicist David
Bohm (Bohm & Nichol, 1998, 2003; Bohm & Peat, 2000), who thought deeply about creativity in science and the universe as fundamentally creative. We may also need radical new views of ‘nature’ and ‘knowing’ (De Quincey, 2005, 2010) and we may need to consider a science and a science education that actively develops the imagination and which recognises the ability to see the wholeness and dynamism of nature, as developed by the German polymath Goethe (Bortoft, 1996, 2012; Kidd, 2009).

1.5. ‘Re-creating’ science education

We will require a pedagogy that goes beyond dumping ‘factoids’ into students, towards one of relationships between student and teacher, student to student and teacher to student to subject (Palmer et al., 2010). We need a science education that tells the personal stories of scientists and the process of science and enables students to see the creativity inherent in nature. We need a science that understands its own history, for as Goethe said “The history of science is science itself” (Naydler, 1996). We need a science where wisdom, creativity and purpose are valued; a science that is integrated with philosophy again, so that deep reflection, questioning and creative thinking are encouraged and facilitated. We should emphasise that scientific research is learning and learning is research - the causes flow into the effects and the effects flow into the causes in an iterative and spiralling process of increased understanding.

There also needs to be more time in the currently busy curricula for science students and lecturers to reflect on the topics of study and on their own learning and teaching processes. Silence, contemplation and reflection are necessary to develop the kind of meditative thinking that expands the imagination and which allows the insights and intuitions that are essential for creative science learning and teaching to ‘bubble up’ to the surface (Dawson, 2003; Zajonc, 2009). It has even been determined that boredom is good for creativity (Mann & Cadman, 2014)!
Curricula should become more flexible and open, more like scaffolding than a rigid structure (perhaps just like the way the cytoskeleton remodels continuously within the cells of our developing embryo). Students and lecturers will co-create their teaching and learning experiences together as a group by utilising and playing with knowledge. We will require an integrative and participative science pedagogy (Palmer et al., 2010).

1.6. Outline of the dissertation
Here I will explore through the literature review (Chapter 2) the following:

• What is creativity? Some background on creativity in science, creativity and the brain, creativity and self-transformation (Bildung), creativity and science education.

• Some history and philosophy of science, looking at where are we now in science and the current ‘official’ scientific method.

• A radical new view of ‘nature and knowing’, based on process philosophy, which recognises the fundamental role of creativity in nature.

• Goethe’s way of science as a participatory, imaginative and creative science that enables the scientist to ‘see’ the dynamism and wholeness of the phenomenon studied.

I also used a qualitative phenomenological approach (described in Chapter 3) to carry out semi-structured interviews with practicing scientists who teach and with science postgraduate and undergraduate students in order to explore their views of science and creativity. The results of and relevant discussion of these interviews are presented in Chapter 4.1.

A further aspect to this study relates to teaching sessions I facilitated on problem solving and creativity. Students reflected on undertaking a science and creativity assignment. A selection of student quotes is presented as evidence in Chapter 4.2.

Finally, in Chapter 5, conclusions for the whole dissertation are provided.
Chapter 2: Literature Review

2.1. What is creativity?
The Oxford English Dictionary defines creativity as “The use of imagination or original ideas to create something; inventiveness”. Societal understandings of creativity have undergone changes throughout history (Runco & Albert, 2010). The ancient Greeks, along with both Chinese and Indian ancient cultures, had no word for creativity and saw creativity in art as an act of discovery, not of creation. The concept of creativity seems to have entered Western culture through the divine inspiration associated with Christianity.

Creativity ‘Guru’ Sir Ken Robinson defines creativity as “the process of developing original ideas that have value” (Robinson, 2011), but this is problematic, as it is not clear what is meant by ‘value’ - what is being ‘valued’ and who is doing the ‘valuing’? In other words, how is the ‘value’ of a creative product to be assessed? Does it always have to have ‘value’? Is this ‘value’ to be found in aesthetics, financial or economic value or all three, for example? Or, in science, how is a particular set of results, produced following a creative insight, to be ‘valued’? It may be more accurate to say that the original creative artefact produced provides a possibility for the interpretation of new meaning to emerge in the world, which may or may not have value, or may be valuable in different ways, to different observers. There is also the possibility of assembling existing artefacts in novel ways and this is also a form of creativity. Creativity is always the ability to ‘see’ or ‘feel’ the possibility of something new and to have the skills to bring this new possibility into being in the world, through linear, iterative and recursive processes (e.g. through trial and error), or by a sudden insight or quantum leap – the classic ‘eureka moment’! Creativity is also a process of evolution and evolution is characterised by both long periods of stasis and relatively short periods of rapid change.

Creativity can be divided into four separate stages: preparation, in which conscious work is carried out on a particular problem; incubation, in which a
kind of unconscious brooding is carried out or, perhaps more accurately, experienced; *illumination*, in which the new idea appears or a new set of connections is made (in other words, the existing state is transcended); and finally *verification*, in which the new idea is tested and adjusted – a second period of conscious work. To the process of *verification* maybe added *innovation* which deals with the application and utilisation of the new idea (Hammershøj, 2009).

According to Bloom’s taxonomy of learning skills (Bloom, 1956), creativity is the most complex and abstract of the higher order cognitive learning skills required to solve problems (DeHaan, 2011). While James Wisdom, in reporting on the *Imaginative Curriculum Initiative* (Wisdom, 2006), cites the work of Gibbs that factors improving the quality of students’ learning confirm that opportunities for creativity ensue when the focus of teaching changes from a knowledge-driven, personal performance approach to a student centred mode, with an explicit care for the students’ growth of understanding (Gibbs, 1992).

Thus, the development of the creative skills and interests of the student becomes paramount, and the process of learning is then associated with a creative transformation in the state of ‘Being’ (Bildung; see below) of both student and teacher. As Norman Jackson puts it, we have to “imagine a different world” – a vision of higher education in which creativity is valued alongside more traditional forms of academic achievement (Jackson, 2006).

### 2.2. Left Brain-Right Brain

The psychiatrist Iain McGilchrist argues in *The Master and his Emissary* (McGilchrist, 2010) that the modern Western world, which has been so influenced by science, has developed the left hemisphere of the brain to the detriment of the right. He argues that it is now more vital than ever that we appreciate that a re-integration of approaches to understanding the world is required that utilises both hemispheres of the brain. This will be an expanded and holistic view of the scientific method and science education that includes the logical, analytical, reductionist left side as well as the
imaginative, intuitive, artistic and connected right side. However, McGilchrist also makes clear that the situation is not as clear as a simple division between the left and right brain hemispheres:

“Certainly there is plenty of evidence that the right hemisphere is important for creativity, which given its ability to make more and wider-ranging connections between things, and to think more flexibly, is hardly surprising. But this is only part of the story. Both hemispheres are importantly involved. Creativity also depends on the union of things that are also maintained separately – the precise function of the corpus collosum, both to separate and connect; and interestingly division of the corpus collosum does impair creativity.” (McGilchrist, 2010), p 42.

### 2.3. Bildung and Creativity

Bildung is a holistic view of education developed by the German Neo-humanists concerning the relationship between the individual and the world at large (HammershØj, 2009). Specifically, it refers to the concept of self-cultivation or the formation of personality in which philosophy and education are linked to promote and support personal and cultural maturation. It can also be thought of as a unification of mind and heart and, in that sense, is a romantic or idealistic concept of education in which the ultimate outcome is a life-long commitment to the transformation or transcendence of the self – the development of ‘Being’. Thus, Bildung involves creativity as a process of formation of the self or ‘making a project of oneself’ - self-Bildung (HammershØj, 2009). In this philosophy, creativity is primarily conceived as a state of transcendence of the self or of existing paradigms of thought.

So, how can these insights be applied to creativity in science and science education? How can we develop a creative disposition within students towards learning about science and doing science? One that teaches them to be open-minded and takes them outside of and beyond their pre-conceived notions and fixed positions about what science is and how science can be understood?
2.4. Creativity in science and science teaching and learning

It has been stated that “creativity is not the antithesis of scientific rigour but the core business of scientific thinking” (McWilliam et al., 2008). However, a number of so-called ‘creativity myths’ continue to be propagated, including: creativity is ‘artiness’; creativity is individual genius and idiosyncrasy; creativity is not economically valuable; and creativity is not rigorous, systematic nor learnable.

Furthermore, little attention has been paid to creativity in science teaching and learning and science courses are often perceived as failing to reflect the reality of modern science and its contributions to society (McWilliam et al., 2008). Therefore, we need to enable science students to both think and act creatively and to be imaginative. This is not only an imperative within science, but is also the best way to empower students to meet the challenges of the future. We are, after all, in what Ron Barnett terms the age of super-complexity, which requires “an epistemology for living amid uncertainty” (Barnett, 2000a, 2000b).

The overarching problem regarding science and creativity is that both students and the public appear unable to appreciate the creativity required to extend the boundaries of scientific knowledge (Schmidt, 2010). Furthermore, although many science educators have a deep conviction that creativity should be a central focus of science education, many feel restrained by pragmatic issues related to institutional cultures and structures. Indeed, the institutional contexts in which academics find themselves have a profound influence on what might be considered legitimate and not-so-legitimate modes of ‘Being’ regarding science and science education; these internalised norms and values influence how we, as academics, engage with and teach science. Others may simply not have the pedagogical wherewithal or perceived support to enable them to teach in creative ways or simply may not have even thought about it. The tacit assumption seems to be that scientific knowledge alone is sufficient for quality teaching.

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There is evidence of declining enrolments and widespread disengagement and confusion of students in science education programmes (Schmidt, 2010). An indicator of this is the major bug-bear of lecturers the world over - lack of student engagement, epitomised by reduced student attendance of lectures (Massingham & Herrington, 2006). However, there may be good reason, since it has been said that this is “not a flight from rigour but from rigor mortis.” (McWilliam et al., 2008). Indeed, lack of student motivation is a defining problem, as well as a potential incompatibility of student and teacher learning styles. At the very least, new approaches to teaching are required (Kottasz, 2005). A ‘re-design’ of science pedagogy as a kind of “creative capacity building” that deals in dynamic rather than static sources of knowledge has been called for (McWilliam et al., 2008), since this reflects the nature of 21st century scientific knowledge – “truth for the moment.”

This also relates to questions about the very nature and purpose of the science curriculum in Higher Education. Is it only to impart a body of knowledge and to produce competent technicians, rather than to allow for the blossoming of creative scientists? Do we need to simply just tweak what we do or do we need to bring about a radical re-construction of science curricula to more truly reflect the actual process of doing science? And what form would such a curriculum take? Would this entail ‘re-creating’ science to reflect a deep philosophical viewpoint of nature and the process of science as being inherently creative? How would creative curricula follow on from this change of emphasis?

Indeed, science is a collaborative, social and interactive endeavour and scientific ‘facts’ are socially constructed, albeit within the constraints of institutional structures and norms (Latour & Woolgar, 1979) and this should feed into the way we teach and assess science. So, scientific creativity can be understood as both an individual capacity as well as being socially constructed by optimally functioning dynamic teams (McWilliam et al., 2008). It is the community, not only the individual, which should be the focus
of analysis in any exploration of how creativity gets fostered (Csikszentmihalyi, 1999).

And yet we tend to continue, on the whole, to teach and assess individual students, even where collaboration through teams and group work takes place. So, there will also need to be a fundamental re-think about how science students’ creative work is assessed (Balchin, 2006; Cowan, 2006). For example, by student self-assessment and reflection and/or by using consensual assessment, in which appropriate individual observers, who have subject-domain knowledge, independently assess the extent to which a particular piece of work is creative. Overall, there needs to be a move away from the linear principle of alignment of teaching and assessment towards a full integration of student-centred learning, which combines “outcomes and assessment and learning and teaching” (Cowan, 2006).

2.5. The ‘official’ scientific method and some history and philosophy of science

There may be a fundamental reason at the heart of the misconception by the public at large, students and significant numbers of scientists, why science is not seen as creative. It is possible that the problem is with the metaphysical basis of science itself and particularly the scientific world-view that has evolved over the last 300 years, since the enlightenment, particularly in the western hemisphere (Sheldrake, 2012).

The official hypothetico-deductive scientific method (Popper, 2002) really only begins with the hypothesis or the theory and then, so the argument goes, it is a fairly logical series of inductions and deductions that lead to the solving of the problem under investigation (Medawar, 1969). Peter Medawar was a British biologist and philosopher of science who went as far as to say that the best experiments avoid the need for thinking entirely:

“…a ‘good’ experiment is precisely that which spares us the exertion of thinking: the better it is, the less we have to worry about its interpretation, about what it ‘really’ means” (Medawar, 1969), pp14-15.
Medawar was in good company – the philosopher Heidegger, a long-term critic of science, said that “Science does not think” (Birch, 1988).

So, the hypothetico-deductive method is a rather linear, mechanical approach that does not lend itself to recognising the dynamic nature of the process of science and, more particularly, the source of the hypothesis or idea itself. Neither is it a truly evolutionary or organismic view of a dynamic, developing, evolving universe (Hirst, 2008). Indeed, mechanistic and insentient models of nature have been undermined by developments in both 20th century physics and philosophy, even though the implications have not yet, on the whole, filtered down to the way we teach science (Birch, 1988). Moreover, it has been pointed out that this particular scientific world-view has resulted in a “metaphysics of education” that does not support development of the imagination or a “reflective habit of mind” (Laura, 1981).

Furthermore, greater exposure of students to the history and philosophy of science, which is generally neglected in science teaching, would in itself help to engender a questioning and ultimately creative approach to science (Birch, 1988). The traditional approach in science teaching is an adherence to a strict materialism or at least a focus on the ‘hard science of facts’, which Rupert Sheldrake has argued is stifling creativity in science (Sheldrake, 2012).

2.6. Science and dogmas
Sheldrake has outlined what he sees as the ten dogmas of modern science (Sheldrake, 2012). These dogmas are the core beliefs or tacit assumptions that most scientists currently take for granted. From the point of view of recognising creativity in nature, the two core beliefs proposed by Sheldrake that I would like to suggest limit the ability for science and nature to be perceived as creative and for scientists to see themselves as creative are as follows:
1. Everything is essentially mechanical. Dogs and people are complex mechanisms, rather than living organisms with goals of their own.

2. All matter is unconscious. It has no inner life or subjectivity or point of view. Even human consciousness is an illusion produced by material activities of the brain.

2.7. A consistent philosophy of creativity in nature: organisms and processes

Sheldrake argues that:

“Living organisms may have an internal creativity, as we do ourselves. When we have a new idea or a new way of doing something, we do not design the idea first and put it into our own minds. New ideas just happen, and no one knows how or why. Humans have an inherent creativity; and all living organisms may have an inherent creativity that is expressed in larger or smaller ways. Machines require external designers; organisms do not.” (Sheldrake, 2012), pp 37-38.

Sheldrake goes on to describe how the backlash against the view of the universe and biological systems as machines was provided by the Romantic Movement to which both Johann Wolfgang von Goethe and Samuel Taylor Coleridge belonged:

“Followers of the enlightenment put their faith in mechanistic science, reason and human progress. ‘Enlightened’ ideas or values still have a major influence on our educational, social, and political systems today. But from around 1780-1830 in the Romantic Movement, there was a widespread reaction against the Enlightenment faith, expressed mainly in the arts and literature. Romantics […] saw nature as alive, rather than mechanical […]. [and] portrayed nature as a dynamic interplay of opposing forces and polarities through which matter is ‘brought to life.’” (Sheldrake, 2012), pp 38-39.
I outline Goethe’s contributions to an alternative or complementary approach to science below. Moreover, when Coleridge wrote that matter should be contemplated as “a product in time”, this anticipated the process philosophy of Alfred North Whitehead (1861-1947) in which change or ‘becoming’ is the cornerstone of reality (Whitehead, 1929b). The fundamental constituents of reality are ‘actual occasions’ that are in essence pure creative acts that result from ‘moments of experience’ (De Quincey, 2010), p 136.

2.8. Creativity and quantum physics
Furthermore, in the early 20th century, along came a new way of viewing the universe – Quantum physics, initiated by Max Planck (1858-1947) and Albert Einstein (1879-1955). Quantum physics emphasises that we exist in an energetic universe of potential and possibility in which, to quote Nobel Prize winning physicist John Wheeler (1911-2008), “we are shapers and creators living in a participatory universe” (Folger, 2002). In other words, we are co-creators, not passive, powerless and separate from the rest of reality. This insight has profound implications for the way we view the world and our place in it, how we comprehend the nature of creativity and how we teach students to understand their innate potential to be creative. The Quantum Physicist Amit Goswami puts it this way:

“Consciousness is the ground of being and matter, mind, all these things, are possibilities within consciousness. And that gives us a fairly new way of looking at it where creativity becomes possible because with every collapse of possibility into actuality, consciousness has a new beginning, has the possibility of a new beginning. So, at every moment, we have the possibility of choosing the new and therefore creativity.” (Goswami, 2010).

2.9. David Bohm on creativity
One of the greatest scientists turned philosophers of the 20th century was David Bohm. Bohm was a theoretical physicist who worked alongside Oppenheimer and Einstein (Bohm & Nichol, 2003). Bohm explored deeply the role of creativity in science (Bohm et al., 1999; Bohm & Nichol, 1998;
Bohm also became fascinated about the relationship between art and science and the role of creativity in them both. Bohm explored extensively in various books and dialogues the idea that the work of the visual artist is remarkably similar to that of the scientist. He also thought about the latent creativity in the human mind and the presence of creativity in nature and the universe at large:

“Bohm [...] links mind to the realm of natural processes, ultimately suggesting that manifestations of creativity in humankind are not merely similar to the creative process in nature. Rather they are of the same intrinsic nature as the creative forces in the universe at large.” (Bohm & Nichol, 1998), p vii.
Bohm saw the human being as having a unique position of perceiving the
dynamism and movement (he called it the holomovement) of the world
around him, while realising that perception itself can be considered to be an
equivalent order of creativity and that it participates intimately with the world
it observes. Thus, there is a non-sensory organising activity required by
observer-participants, which is essential for creating meaning (Figure 1).

Figure 1: “More to seeing than meets the eye” - the non-sensory factor in
perception (Bortoft, 1996) (image designed by Jackie Bortoft – retrieved

At first sight, this appears to the observer to be a random pattern of black
and white areas. However, sooner or later a recognisable figure suddenly
emerges from the seeming chaos in a creative leap of perception:

“Meaning about the world through science is obtained through an act of
creative imagination in the mind.” (Bohm & Peat, 2000), p 67.

Furthermore, Bohm and Peat propose that the crucial factor for a new
creative vision is to break out of old patterns of thought. This, I believe, is a
crucial and defining statement about teaching and learning. Indeed, it
influences the relationship between the way students learn and the way
scientific research is conducted as well as how students see the similarities and differences between material provided on related topics in different modules. They cannot appreciate the similarities and differences when they are caught in a mechanical and fixed, shall we say, ‘text-book of facts’ mode of thought. They require development of new modes (or organs) of perception (this will be discussed further below in the section on Goethe):

“Initially of course scientists may fail to recognise the essential similarity between different things, for this requires a creative act of perception. But once the perception has been achieved, science may fail to see the essential differences that are also inherent within the metaphor. Clearly, the problem with thought is that it often fails to be perceptively sensitive to similarities and differences and instead applies mechanical habits of seeing similarities and differences.” (Bohm & Peat, 2000), p 32.

Bohm and Peat also point out that a narrowness of vision has developed in science owing to specialisation and fragmentation, which is a practical division of knowledge into ever-more separate disciplines. However, they also point out that creativity can be maintained if the specialisation remains flexible and dynamic (i.e. is seen as a process) rather then something rigid, since there can be no creativity in rigidity. This means that Bohm and Peat disagree somewhat with Kuhn in that they believe that there is the potential for a continuously creative approach to science, so that any abrupt discontinuity (Kuhn’s paradigm shift) is not inevitable. Indeed, they state that “paradigms interfere with the free play of creativity.” Ibid, p52.

Bohm and Peat also discuss the idea of ‘the play of thought’ as creative:

“It is the very nature of play that nothing is taken for granted as being absolutely unalterable and that its outcomes and conclusions cannot be known beforehand.” (Bohm & Peat, 2000), p 51.
They go on, in a positive vain, suggesting that science can move in a new direction in which greater freedom for the ‘play of thought’ is permitted and in which creativity can work at all times. This should also be our aim for a true creative philosophy of science teaching and learning, which is more playful and less rigid. Indeed, there is a positive correlation between playfulness, ideas and creativity (Bateson & Nettle, 2014), while Vygotsky described play as “imagination in action” and outlines how a creative process develops in play as new and unfamiliar meanings emerge (Lindqvist, 2003). I always felt when I was working in the laboratory that I was at play and I always felt playful in my approaches to learning about new things and making new connections between them. But, my own experience is that most students are very serious and earnest about their education - fun and play are not natural bedfellows with the ‘serious business’ of passing the exams!

The above brief review of Bohm and creativity has tremendous implications for our educational practices. We have to recognise the participatory nature of the student-teacher relationship in manifesting an educational experience that is truly creative:

“…any search for absolute, fixed knowledge is illusory since all knowledge arises out of the shifting, changing activity of creative perception, free play, unfoldment into action and its return into experience.” (Bohm & Peat, 2000), pp 55-56.

2.10. Radical nature and radical knowing: creative participation
In Radical Nature – the soul of matter, Christain De Quincey, Professor of philosophy and consciousness studies at John F Kennedy University, explores how a full appreciation of nature requires a view of reality in which consciousness is intrinsic to matter all the way down to its deepest levels (De Quincey, 2010). De Quincey demonstrates that the idea that matter is ‘dead’ is actually a relatively recent aberration in Western thought and traces the history of intrinsically sentient matter (‘panpsychism’ or ‘panexperientialism’) all the way back to the earliest days of Western
philosophy from Thales (585-525 BCE), to Plotinus (205-270 BCE), Bruno (1548-1600), Leibniz (1646-1716), Spinoza (1632-1677), Goethe (1749-1832), and Coleridge (1772-1834) who, as mentioned above, anticipated Whitehead’s process philosophy.

I would like to suggest that this worldview truly sees nature as creative and, since humans are part of nature, it also recognises that all humans (scientists and science students included!) are inherently creative; their creativity cannot be denied and they are then able to “participate creatively with nature with harmony, balance and wisdom” (De Quincey, 2010), p 78. The duality of mind and matter inherent in Descartes’ mind body dualism and the consequent ‘hard problem’ of how matter and consciousness interact is overcome in De Quincey’s ontology:

“The underlying pathology, therefore, is metaphysical: a split between matter and mind. This fragmentation runs right through our science, our education, our social and legal systems, our interpersonal relationships and our relationships with the rest of the world. It even conditions our relationships with our own selves, splitting body from mind. It is deeply ingrained in the way we think, and in what and how we know anything.” (De Quincey, 2010), p 5.

As a means to overcome this “underlying pathology” of a science without mind or subjective experience, De Quincey explores the process philosophy of Alfred North Whitehead (introduced previously). In this cosmology, creativity takes centre stage:

“For any subject-object or mind-body interaction to be possible, they must share an ontological commonality. Something about the nature of matter must be ontologically similar to the nature of mind. Whitehead proposed that both the objective mechanics of matter-energy and the subjective dynamics of consciousness derive from a deeper, ultimate ontological nature that he identified as creativity. Ultimately it is the inherent creativity of the universe
that gives rise to what we call “energy” and “consciousness”. (De Quincey, 2010), p72.

Moreover, the cosmos is experienced as:

“...a vast, perhaps infinite, network and hierarchy of interrelated events where all objects are in reality the coming into being and fading away of energetic patterns-within-patterns, self organizing cascades of creativity, converging pulses of sentient energy.” (De Quincey, 2010), p155.

Whitehead’s cosmology is summed up as follows (De Quincey, 2010), pp 54-55:

1. **Events not things** – reality is not material substance; it is organisms in process; ‘process’ not ‘substance’ is fundamental.
2. **Nature feels all the way down** – universal process is sentient; it unfolds by feeling. So, both matter and mind are derived from fundamental ‘actual events’ that are inherently experiential.
3. **Fundamental interrelatedness** – all events are mutually co-creating and inter-fuse and interpenetrate each other; there is no such thing as an isolated self-contained entity.
4. **Fundamental process is inherently experiential** – process and feelings are connected because each ‘now’ moment (duration) feels aspects of the past and gives something of itself to the next, future moment (this is the “epochal process” according to Whitehead). During this process, something novel (i.e. creative) can be added by the subject, because the subject has experience, freedom and self agency as well as intention (De Quincey, 2010), pp 232-235.

Whitehead’s worldview is challenging - our whole way of thinking requires a radical shift, since the doctrine of substance and the duality of sentience (substances that feel) and insentience (substances that don’t feel) is so ingrained in us. To sum up, De Quincey’s reading of Whitehead is a
participatory epistemology, which undermines the dominant paradigm in science of objectivity, mechanism and the insentience of matter. There is a ‘real world’ out there that is not wholly constructed by the human mind or social consensus (unlike in constructivism), a world, which constitutes us as knowers – we can know the “things in themselves”. The body literally incorporates the world experientially through acts of physical prehension:

“For we cannot know the body through our mind without at the same time knowing consciousness through our body. In a very real, literal sense: the body knows itself – it feels” (De Quincey, 2010), p258.

Furthermore, we, the subjects, can exercise voluntary, creative spontaneity. De Quincey goes so far as to say:

“This process of creative unification is the mind – it is the whole that integrates all the parts of which it is constituted, with the addition of its own injected creativity” (De Quincey, 2010), p238.

So, how can this new radical cosmology feed into our ways of knowing? In Radical Knowing – understanding consciousness through relationship (De Quincey, 2005), De Quincey argues for a transformational science that closes the gap between the beliefs of science and our own personal experience of nature. This is what William James called a “radical empiricism”, which leaves out nothing that falls within the range of human experience. De Quincey calls for a much more open and participatory science, a science in which there is:

“a shift from concept-based epistemology - models and metaphors derived from cognitive and intellectual modes of thought to more experiential modes of knowing.” (De Quincey, 2005), p 72.

Perhaps, we need a new renaissance that can meld the feelings, intuitions, imagination and inspiration of the artist with the current rational and
analytical scientific method. Someone we can look to regarding practical methods to contribute towards such a shift towards “more experiential modes of knowing” is Johann Wolfgang von Goethe (1749-1832).

2.11. Goethean Science and the imagination

Goethe was famous as a politician as well as an artist, poet and novelist (the author of *Faust*). It is not widely appreciated that Goethe also produced a large body of work in science investigating topics such as plants, colour, clouds, geology and meteorology (Bortoft, 1996; Seamon & Zajonc, 1998). Goethe used a phenomenological approach in which the scientist actively engages with the phenomenon of study using the intuitive mode of consciousness to gain creative insights (Wahl, 2005).

“Next, you must trust your senses:
They will show you nothing false
If your intelligence keeps you awake.

Keep your eyes fresh and open and joyful,
And move with sure steps, yet flexibly,
Through the fields of a world so richly endowed.”


Using this approach, for example, Goethe intuited the developmental relationship between leaves and flowers long before plant geneticists had realized the same thing (Theissen & Saedler, 2001).

Goethe’s ‘way of science’ offers a creative alternative to the mode of Kuhn’s ‘normal science’, the linear elaboration of existing paradigms, towards an acknowledgment and indeed an explanation for the “logically unscripted” moment of creative insight (Amrine, 1998). Although Goethe believed that there is no exclusively ‘right’ approach to the study of nature (Naydler, 1996), p37, Goethe’s science brings together the intuitive and imaginative
awareness of art with the rigorous observation of science and is truly experiential.

For Goethe, there were no contradictions or tensions between his art and his science, since he carried out his science with the same passion that drove him to express nature’s creativity as a writer and an artist (Wahl, 2005). Goethe’s approach rests on the development of human consciousness towards a new way of seeing in which the intrinsic organisational and creative principles in nature can be appreciated. This generates the possibility of a new science of nature that is fundamentally aesthetic and spiritual, which is beyond cause and effect and which is what Henri Bortoft (who worked on the problem of seeing wholeness with David Bohm) calls the “dynamic unity of nature” (Bortoft, 1996). It is a reverential path, not one of manipulation and control, towards a feeling and appreciation of wholeness within the scientist and an experience of nature, which opens to the sacred (Naydler, 1996).

Goethe’s science also emphasised a truly participatory approach to nature, a phenomenology of nature (Seamon, 2005), in which there transpires “an intimate firsthand encounter between the student and thing studied” (Seamon, 1998) and in which the human being is “the most exact scientific instrument” (Naydler, 1996). This approach also leads to a metamorphosis or transformation of the scientist in the process of doing science (Amrine, 1998) through self-Bildung, as described previously. Goethe called this participatory approach a “zarte Empirie” or “delicate empiricism” (science as a conversation) (Holdrege, 2005b), which legitimises and organises the role of imagination, intuition and inspiration in science and makes these qualities systematic (Wahl, 2005):

“There is a delicate empiricism that makes itself utterly identical with the object, thereby becoming true theory. But this enhancement of our mental powers belongs to a highly evolved age.” (Holdrege, 2005b).
Furthermore, Goethe’s approach was able to develop so-called “new organs of perception” that allow for an appreciation of the ‘wholeness’ of the phenomenon under study, the inter-relatedness between the parts and the dynamic processes that lead to the development (or metamorphosis) of form (Bywater, 2005). So, the three important capacities, which distinguish Goethean science from modern science, are intuitive perception (Anschauung), perceptive imagination (exact sensorial imagination), and synthesis - all of which contribute to creativity. Allowing such intuitive thinking, imagination and feeling a place in our scientific method, provided that they are deployed in conjunction with exact observation and clear thought, allow for a much fuller and more complete experience of nature (Naydler, 1996).

So, the question arises about how it might be possible to develop these “new organs of perception” in science students so as to develop their abilities of intuitive perception, perceptive imagination and ability to synthesise? One problem is that science students are generally removed from the ‘lived experience’ of being immersed in nature and when they are, such as on field trips, it is generally for a relatively short period of time.

The focus in academia is usually on textbook explanations and theoretical knowledge, such that students do not develop their skills of observation, for example through prolonged immersion in nature and drawing the objects of study. So what practical methods are required? Goethean scientist Craig Holdrege describes his experience of “a conversation with nature”, in this case skunk cabbage, in the woods where he lives in the North West United States:

“After I go out and observe, I make a point of actively re-membering the observations. With my mind’s eye I inwardly recreate the form of the leaves, I inwardly sense the colors and the smells, and so on. This process of conscious picture building is what Goethe called “exact sensorial imagination”. It entails using the faculty of imagination to experience more
vividly what I have observed. I try to be as precise as possible - and will often notice where I haven't observed carefully enough, which I try to do the next time I'm out. When you do this kind of conscious picture building, you grow more and more connected to what you’re observing.” (Holdrege, 2005a).

Daniel Wahl (Wahl, 2005) describes four stages of Goethean observation, based on the work of Goethean scientist Isis Brook:

1. **Exact Sense Perception (Perception):** Detailed observation of the object perceived through all the senses, while suspending all form of personal judgement and evaluation – drawing and/or poetry are good ways to do this.

2. **Exact sensorial imagination (imagination):** Imagination is employed as a legitimate tool of scientific investigation and as the key to entering another way of knowing in which the phenomenon under study is “entered within” and “played with” in the mind, so that “imagination is involved in the act of observation itself”, rather than the imagination being “added on, externally, to the observation” (Bortoft, 1996). Moreover, this is not a complete ‘free play’ because the practical limits on what can be imagined are also brought to bear on the object. This kind of imagination is therefore scientific rather than artistic because there are constraints on what can legitimately be imagined.

3. **Seeing is Beholding (inspiration):** Active perception is suspended and as much as possible the scientist ‘receives’ from the object. The phenomenon is ‘seen’ in the dynamic awareness reached through the use of the imagination to allow the ‘thing’ to express itself through the observer.

4. **Being One with the Object (intuition):** Being one with the object of study, which allows the content or meaning of the object to be appreciated, as well as the form itself. So, the outer appearance of the ‘thing’ and its inner content are combined by conceptualisation.
Thus, this approach is a practical methodology for developing students’ faculties of perception, imagination, inspiration and intuition where these qualities are intrinsic to the process of science, rather than ‘add-ons’ prior to or post analysis. However, this process is not without its challenges - moving into new modes of perception and knowing can be disorientating for the student, who is trained through their prior education to expect, strive towards or look for a specific ‘outcome’ (see interview below, p41).

Maura Flannery describes a Goethean approach to the analysis of proteins (Flannery, 2005) and points out that this is a method that scientists routinely use, even though it is unlikely that most would label it as such. Moreover, the following has been said about the Nobel Prize winning plant geneticist Barbara McClintock (1902-1992), so this approach is by no means limited to the distant past:

“[she] gained valuable knowledge by empathizing with her corn plants, submerging herself in their world and dissolving the boundary between object and observer” (Palmer et al., 2010), p28.

Thus, the ‘official’ scientific method appears not to be the true or complete scientific method that scientists practice day by day. Goethean science is at work in modern science, though it will take pointing this out and discussing it with science students to truly bring it out into the open and to expand students’ perceptions about what science really is or at least has the potential to be.

2.12. Summary of the literature review

In Chapter 2, an overview of the literature related to creativity, including definitions of creativity, was provided. Then some of the work of the UK Imaginative Curriculum Initiative was described, which was an in depth analyses of creativity in Higher Education. Then the role of the two hemispheres of the brain in creativity was considered as well as creativity as an opportunity for self-cultivation of both teacher and learner through
Bildung. Creativity in science teaching and learning was then addressed, including current limitations on both students and practicing scientists in perceiving science as a creative pursuit. Following this, some background thoughts and considerations regarding the ‘official’ hypothetico-deductive scientific method were provided and why imagination, intuition and creativity are apparently not fully acknowledged in this method. This was followed by a discussion of the possible restrictions on creativity in science as a consequence of dogmas and mechanistic and dualistic views of the universe. It was then proposed that to truly perceive nature as creative, we need a different approach. Support for this view was then provided from insights from philosophy and quantum physics, including the observer as a participant. The work of David Bohm on creativity in science was focused on as well as that of Christian De Quincey, who argues for a ‘radical nature’ and ‘radical knowing’, which are, in part, based on Alfred North Whitehead’s philosophy of organisms and processes, ‘actual occasions’ of pure creative acts. Finally, an introduction to Goethean science was provided, which allows for and develops the faculties of imagination, inspiration and intuition. It was proposed that this approach would enable science students to gain a ‘lived experience’ of nature and to see and experience its dynamism and inherent creativity.

In Chapters 3 and 4 the methodology, findings and discussions of interviews and reflections of practicing scientists and science students are presented, regarding creativity in science, focusing on science teaching and learning. An attempt is made to explore their ‘lived experience’ in relation to some of the philosophical and theoretical background provided in this chapter as well as in additional emergent themes. The reflections presented comprise a case study of creativity in science and science education with two embedded cases: TCD (a traditional University setting) and Schumacher College (where creativity is embedded in the institutional norms).
Chapter 3: Methodology

3.1. Research Interviews about creativity in science

Research interviews were undertaken between April and June 2014 using a qualitative phenomenological approach. Phenomenology is a design of enquiry coming from philosophy and psychology in which the researcher describes the ‘lived experience’ of individuals about a phenomenon (Creswell, 2014). Phenomenology is as an appropriate approach for study of the creative process as it is well suited to the study of the immediate ordinary human experience (‘lived experience’) (Bindeman, 1998). The study was exploratory as there remains a lack of a commonly agreed framework for interpreting perceptions of creativity (Oliver et al., 2006).

The method of participant recruitment was purposeful in that ‘information rich’ staff and students were approached initially by email. At this time, the list of questions (either for staff or students; Appendix I), the project information sheet (Appendix II), and the consent form (Appendix III) were provided. This ensured that participants who were enthusiastic about and at ease with the topic were recruited (Lunn & Noble, 2008). Ethical approval for the study was obtained from the Trinity College School of Education ethics committee.

Each interview took between 34 mins and 78 mins, equating to a total of 9 hours and 51 minutes. Notes were taken and interviews recorded using a LiveScribe pen (http://www.livescribe.com) and transcribed. Two published studies investigating creativity in Higher Education, as part of the UK Imaginative Curriculum Initiative, have previously utilised a similar exploratory approach, but did not focus specifically on science (Edwards et al., 2006; Oliver et al., 2006).

To provide consistency, a semi-structured approach was adopted. The questions were open-ended and flexible and were designed to allow the participants to reflect, elaborate and to develop their thoughts and to
encourage themes to emerge during the course of the interview. The interviewer asked relevant follow-up questions where appropriate.

The research process began with asking each participant to provide a brief autobiography. Questions then focused on the perspectives of the participants on the relationships between art and science research, teaching and learning, their own interests in art and/or other creative pursuits (e.g. sports), whether these pursuits feed into their scientific work or whether they compartmentalise them, their opinions on creativity in science, particularly regarding to the ‘official’ scientific method, imagination, insight and creative scientists and creativity in nature. Thus, an attempt was made to develop a holistic picture of the opinions of each participant and the ways in which other aspects of their lives informed their scientific research and/or study. This was a similar approach to that utilized in the study of Re-Visioning Science (Lunn & Noble, 2008).

Interviews were carried out at the following sites: Trinity College Dublin, Faculty of Science, School of Natural Sciences (4 academic staff – one additional staff member provided written responses only and was not interviewed; 3 students – 2 undergraduate students, 1 PhD student) and Schumacher College, Totnes, Devon, UK (2 academic staff; 2 MSc students). The biographies, inspirations and creative hobbies from the interview transcripts of all those interviewed can be found in Appendix IV.

Trinity College Dublin is a traditional ‘mainstream’ academic setting, where it could be argued that students come across the concept of creativity in science by chance via individual interested academics. On the other hand, at Schumacher College, creative teaching and learning approaches to science are implicit within the institutional norms. The author of this study is also a visiting lecturer at Schumacher College on the Holistic Science MSc Complexity Module and thus has direct experience of this more open and less rigid way of teaching and learning about science.
Details of the Schumacher College MSc Holistic Science course are at http://www.schumachercollege.org.uk/about/msc-holistic-science-programme and information about the overall ethos of the College is at http://www.schumachercollege.org.uk/about/schumacher. The MSc in Holistic Science at Schumacher College is a full-time one-year programme, the student group is less than 20 students and the focus is on interactive, experiential and participatory learning. Various non-traditional teaching formats, learning experiences and assessments are facilitated. A nice summary of the kind of approaches that are utilised and encouraged can be seen in this quote from the Holistic Science web site, specifically regarding the dissertation component of the MSc:

“As a new type of masters degree which encourages novel approaches to scientific investigation, students' holistic investigations for the dissertation often result in different outcomes to traditional styles of research and reporting. The dissertation can involve the use of alternative creative formats such as personal narrative, artwork and experiential material alongside those normally used in scientific writing in order to integrate intuitive insights and feelings that arise during the course of the work. Students are encouraged to blend the analytic-synthetic and the narrative-experiential as extensions and complements of each other in a coherent, holistic manner.”

Following transcription, interviews were read and re-read so that the researcher could become familiar with the material obtained and relate it to the theoretical and philosophical underpinnings of the study outlined in the literature review (Chapter 2). The transcripts were then analysed by constant and iterative comparative categorisation and collated into themes using MSExcel®. Quotes from selected themes are presented in Chapter 4.1. Abbreviations used are as follows: SSF: Schumacher College Staff; SST: Schumacher College Student; TSF: Trinity College Staff; TST: Trinity College Student. Wordle™ analysis (http://www.wordle.net) was also carried out on transcripts to depict visually the word use of participants.
3.2. Student reflections on problem solving and creativity sessions
A second part of this study entailed collating comments from student self-reflective pieces obtained following a session on problem solving and creativity in the tutorial series of Junior Sophister (third year) Functional Biology and Plant Science students at Trinity College Dublin. This session built on previous sessions involving ‘getting to know each other’, ‘facilitating group work’, and ‘philosophy and history of science’, and ‘animal research and stem cell ethics’ that were held by the author.

Although this session had been introduced in the previous academic year, it was modified and developed following the micro-teaching session held as part of Module 4 of the MEd. Peer feedback suggested that the student assignments should be more creative and so these suggestions were incorporated into the teaching and assessment of this session during the 2013-2014 academic year. The assignment information and assessment criteria are provided in Appendix V.

Abbreviated reflections are presented in Chapter 4.2, while a selection of complete student reflections is presented in Appendix VI. The reflections allowed a wide perspective of student opinions to be obtained. The comments also provide further evidence for the efficacy of implementing creativity through both assessment of creativity and creative assignments into the undergraduate science curriculum. Briefly, the assignment involved students working in small groups to research a scientific problem from history, including what motivated the scientists, how they come to recognise the problem, and the fundamental creative insight(s) that changed the way the scientists looked at the problem and led to the solution. Topics researched were Watson and Crick and DNA, Calvin and photosynthesis, Niels Bohr and the atom, William Harvey and the circulation of blood, Alfred Russell Wallace and evolution, the accidental discovery of viagra, the discovery of graphene, and Marie Curie and radioactivity.
Presentations were of ten minutes duration each, including a question period. The students were asked to avoid use of passive and one-way presentations using Power Point, but to present their chosen topic creatively “in an interesting and alternative way”. Suggestions were given, including producing a film or a play and the use of artistic approaches to supplement their presentation, such as poetry, sculpture, music or art work. The first part of the assignment comprised an essay on the topic, while the second part consisted of a short reflective piece by each student on their attitudes and feelings towards the assignment and what they had learned about themselves regarding their creativity, as well as the pros and cons of the group dynamic and about their attitudes about creativity in science.
Chapter 4: Research Findings and Discussion

4.1. Findings from Interviews

A number of themes in to which participant comments could be categorised (or coded) emerged during the course of the interviews, as follows:


Owing to space restraints, quotes from all the above themes could not be included here. In Figure 2, a Wordle™ is presented of all the participant discussions related to Question 3, regarding creative hobbies.

Figure 2: A Wordle™ of the 75 most common words mentioned in the discussions of all participants relating to Question 3: hobbies and interests (more details are provided regarding hobbies in Appendix IV).
Quotes are presented from the various participants within selected themes considered most relevant to concepts of creativity in nature, science, science education and the creativity of the individual scientist or science student. Themes are related to each other and are discussed in the context of the relevant literature.

The selected themes are: Creativity in nature; Imagination, intuition, drawing, visualisation, perception and Goethean science; Creative teaching and learning; and Skills, embodiment, wholeness and flow.

4.1.1. Creativity in the ‘official’ scientific method and in nature
Participants were asked to reflect on whether the ‘official’ scientific method recognises the role of creativity. The general consensus was that the ‘official’ method does not reflect the true method, which incorporates creativity, particularly during the early phase of using the imagination to gain insights for hypothesis development:

SSF1: No, I really don't think it does. I mean, I just think the massive role that subjective observation, imagination play in biology. I mean it's just completely ignored and yet [....] you just couldn't be a good biologist without those two things.

TSF3: We are locked into this method, this scientific procedure. It is a retrospective snap shot of the whole thing and yeah there is an awful lot more behind the scenes.

SSF2: It's really weird that in the history of science all of the scientists will refer to this creative process [....] The way understandings are arrived at is not from the effort itself, but by some kind of other creative leap that they can't quite explain and to me this is where the emphasis of science should be. It's where science is really happening in that creative leap. So what's happening at that creative leap and how does it build on what's happened before?
SST1 describes how it is vital for creativity in science for scientists to become aware of the dialogue occurring between their analytical mode of thinking and the artistic mode:

SST1: I think the key is to be mindfully aware of when they're coming together, what dialogue is happening between them as it’s happening? You know, what’s the louder voice? What's going on within you at the time? And cultivating that mindfulness [...]. So, if we think about entering into a relationship with your right and left hemispheres [of the brain], with your analytical side and your artistic side. That for me has a totally different energy about it and being aware of that and seeing how they relate to each other, in that sense, I think that's where creativity is born.

SST1 also talked about how science education should highlight the aliveness and dynamism inherent in nature and the process of science, rather than focusing on conveying static, ‘dead’ products. She also described how her earlier educational experiences had stifled her creativity and how the Schumacher approach to teaching and learning had opened it up again:

SST1: What's alive for me, what's dead for me? I think my whole life everything around me has been dead because I've not been able to access or have my creative side fed [...]. For me, things have to move, they can't be static and in the way that I was taught physics, biology, chemistry it was static, it was dry. There wasn't anything that could be grounded in personal experience because all the feeling was taken out of it and for me creativity is feeling, so when I wasn't allowed to ask the questions my creativity just dived.

Participants were also asked about the perceptions of creativity in nature: is nature creative? SST2 equates resilience in biodiversity with health and about how a healthy system can respond creatively to changing conditions:
SST2: I think if diversity is a reflection of creativity, then it's clear that currently our science isn't generating or participating in landscapes that are diverse, in cultures that are diverse. And yet, at the same time, holds those things as a measure of life - diversity, biodiversity as a measure of resilience [...]. Does it fit into that understanding of health? And by health I just mean life that is vital, resilient, creative in its response to changing conditions.

TST3, a Trinity undergraduate student, clearly sees nature as creative and even implies that nature is thinking or exhibits some sort of mind-like property that is actively and forcefully exploring the various possibilities available in solving problems during evolution:

TST3: I think nature is [...] creative in a way, because if creativity is thinking of different ways to solve a problem [...] - like there's D and L glucose and the body picked one over the other. So, it just went, “Well, let’s try this and if it works sure, we’ll go with that”. It’s like nature will keep trying things, like permutations and it’ll just keep throwing balls at pins until something clicks. So that’s creative because it tries different things, almost as if it’s a force.

Trinity staff member TSF5 recognised the inherent creativity of nature in response to a dynamic environment, but was also wary to qualify what she said in making clear that she didn’t believe that there is a plan for evolution:

TSF5: I think there is creativity [in nature]. So, you always struggle with the right kind of language to use when you talk about evolution ‘cos you don’t want to make it sound like there’s any kind of plan. But, it is trying to solve a problem, so it’s not conscious of solving a problem, but it is finding a way, nature is finding a way to make things work [...] in the face of a changing world I suppose.

TSF1 also recognised that there is an evolutionary benefit to creativity in terms of its response to the environment:
TSF1: The fact that [creativity] exists means that there's a benefit to [....] having it. I mean, in a time of crisis when there is change, say a storm or bad weather or a crop failure or a fire or anything, you need somebody to have a good idea about how to get over it. You do need creativity. You can't be doing the same thing if there is a change in your environment.

And TSF4 extends this analogy even further in talking about genetic algorithms as modelling creative leaps during evolution and being inspired by the creative process of evolution:

TSF4: So, we use genetic algorithms often, which start finding solutions in various different areas of the problem space and they get progressively better like evolution [....]. So, the genetic algorithms were inspired by evolutionary processes.

TST2 discussed evolution as being the best example of creativity in nature and she also highlighted the dynamism of ever-changing nature and the process of creative change inherent in evolution:

TST2: I keep going back to this module of evolution because it was so mindboggling to me. From what I had learned there was a pattern - it went from A to B to C to D. But, there are all these different species, these hybrids that came from this creative combination and this ever-changing world, the ever-changing habitat around that led to this explosion of creativity.

So, the scientists and students quoted recognise the role of creativity in nature the limits of their educational experience in seeing this creativity and in recognising their own creativity.
4.1.2. Imagination, intuition, drawing, visualisation, perception and Goethean science

Several of the scientists and students interviewed, both at Schumacher College and Trinity College, recognised the vital role of imagination, intuition and deep observation in science and they also discussed this in the context of art (e.g. poetry and drawing) and artists and the development and use of an artistic (right brain) mode of thinking, which can be developed using Goethean science, though there are challenges associated with this.

The first Schumacher student mentioned Einstein on imagination:

“Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand.” (Einstein, 1931)

SST1: Einstein said that imagination was more important [...] and he imagined when he came up with his theory of the speed of light (actually special relativity) he imagined himself travelling on a light beam through the universe.

SSF2 related skills of deep observation, intuition and imagination in science to those of an artist:

SSF1: I always tell anyone I talk to about science, friends that are non scientists and so on, how important a creative ability is for a scientist and that it can be a very creative discipline and, particularly, if you are doing research you use imagination and conceptualisation [...]. I always say, as a biologist, the most important skill is the deep observation, very objective observation and imagination. And I think that often that is underplayed in the life sciences. [...] Very mindful observation is also important for an artist to have, particularly a visual artist. Mindful observation is often a precursor to artistic activity and then imagination. So particularly say, if you're observing a plant at a particular time of year, then you're imagining how that is at the rest of the year.
The second Schumacher College staff member went on to describe how the development of the imagination using the Goethean methodology described in Chapter 2 is the primary focus of the entire Schumacher College educational approach. The deepest insight here is that the imagination looks forward into possibilities, whereas the analytical mind can only process what has already come into being or already exists:

SSF2: Of course, the work we're doing here is very different to the work that typically happens in a lab where you have to be very disciplined and you're working with living data. So, here it's much more about developing the imagination and so the Goethean method is specifically to use the imagination as a kind of tool, which allows the plant or the phenomenon to reveal itself. And so, in that sense, it is very similar to an artist in that [...] you're becoming an antenna for something to reveal itself, rather than setting up a kind of analysis. They are very different ways of approaching the world because imagination takes you forward into what something can be and [...] it doesn't really tally with that analytical way of looking of what way things have been.

In other words, the imagination allows one to see the thing as it is developing, emerging, becoming or coming into being (upstream; Vernunft), rather than analysing a fixed, static end product (downstream; Verstand) that was created in the past and no longer has any potential for change (Bortoft, 1996; Naydler, 1996). So, students are led to believe that the fixed knowledge is ‘fact’ when it becomes reified in a textbook, whereas ongoing research and learning is always a process of becoming. Thus, the students don’t see or appreciate the dynamic nature of scientific progress or indeed the dynamism that is inherent in nature or the process of learning. Thus, the ability to see or perceive the world dynamically can be developed by Goethean science.
SST2 talked about developing Goethe’s “new organs of perception” and a feeling of being embedded within nature and participating with it, as well as a change in perception in perceiving dynamic, differentiating ‘fields’, rather than discrete and separate ‘finished’ objects. This fits well with the work of Bohm, Whitehead, and De Quincey reviewed in Chapter 2:

SST2: Perception is what we ignore generally in both the humanities and in science [....] And [it] is an extremely complex process that [....] has to be fully engaged in all the time. And that has driven my creative interaction with the world, that understanding of reciprocity in perception. And [it] has equally driven [my] scientific interests. [....] And [....] is part of what has made a bridge for me away from thinking of the world in discrete objects [....] to perceiving the world as a whole field continuously in process that is differentiated, but not separated. And so, a person becomes not an object separate from other objects, but a location of activity within that field. And that changes everything.

There was also a recognition by SST2 that a creative scientist can integrate science with artistic pursuits. In this case, to enhance their powers of perception and observation by combing the analytical mode of perception with the feelings experienced at the time of the observations:

SST2: My creative pursuits and scientific interests have always been joined. I mean, most of my scientific pursuits have been more in the tradition of a naturalist. So, I can't separate my observations that I'm making of creatures and of a particular ecology and say a poem I write later that day. In fact, those are often what make my observations more reliable [....]. It also brings [....] out things about the feelings that are going in to my perception. Obviously I'm never noticing all of what's there. So, when I write a poem, a lot of how I came to see what I see and observe what I observed becomes clearer because I spend time with a particular image and then understand my feelings around it and why I took such strong notice of that image.
So, SST2 sees the challenge as one of integration of the whole person and that all activities, such as poetry or painting for example, are conducive in making observations as a scientist and this fits into the ideas of Bildung and the metamorphosis of the scientist introduced in Chapter 2 (Amrine, 1998; Hammershøj, 2009):

SST2: The activities that you do in one area, say painting, will be carried into how you make observations as a scientist. How you think critically about a problem or a context. And in that way I think students can follow their interests and they'll always be relevant to all of their other interests as a whole person.

A quote by Goethe comes to mind in this context “Nowhere would anyone grant that science and poetry can be united. They forgot that science arose from poetry, and failed to see that a change of times might beneficially reunite the two as friends, at a higher level and to mutual advantage.” (Goethe, 1817).

SST1 also described the challenges of how to integrate this new way of knowing using techniques of Goethean science to develop a way of seeing nature as dynamic and as a creative process, rather than seeing the world in a mechanical way, as a machine or mechanism. But she also outlined the challenges of integrating this new way of seeing into her ‘Being’:

SST1: I had the most profound experience with the groundsel plant when I did Goethean science. …I was sat there in front of this plant thinking “Oh my God! What the hell am I doing? I'm not supposed to be doing this! If my Dad saw me doing this? And if my friends saw me doing this, they'd think I'd gone off my rocker!” I was trying to let this plant talk to me or see it differently….to go upstream and be with it outside of labels or pre-judgements…. And I dropped into this chasm, this void for a week where I couldn’t say anything. It was like this whole silence thing - it freaked me out, it really, really freaked me out. And I didn't know what was happening to
me….I was in a completely different relationship with the plant – allowing - not coming to it with any preconceived ideas and not knowing what to do with that. Not knowing how to be with it. And I was just totally overwhelmed. I felt energetically that something was happening, but I had no words. And I remember saying to [my teacher] "I've got no words, I don't know what I'm supposed to be doing". He says, "You're not supposed to be doing anything". Because I wanted... “this is what you do”...and you can't do that with phenomenology or Goethean science. You just have to ‘notice’ and ‘be with’ and I don't think I'd ever ‘noticed’ or ‘been with’ (in relationship with) anything before in that way. So, I was in a place of the unknown and quite fearful I think because I kept dropping into "I've got to justify this“ and I couldn't justify it.....Even though I was spiritual and I had a spiritual way of understanding, I was only understanding in the mechanistic way.....I have been exposed to the opposite of what mechanistic thinking and the mechanistic paradigm I've been brought up in is. I can see that now. I can look at it, but also this is like this brand new way of viewing the world.

There was a also a recognition that **drawing or doodling** to depict structures and using visualisation to imagine and to solve problems, including mathematical or quantitative problems, is also an important creative skill that scientists should have. But, there was also some lack of confidence with the ability to draw well and effectively and it was felt that this is a skill that could be more developed in scientists:

**TSF3:** I've never been much of an artist. Certainly I have no artistic skills for drawing, but I have instead enjoyed drawing geometrical shapes. I have always enjoyed playing with a compass or playing with rulers and angles and doing trigonometry and geometry. So I think definitely that aspect has helped greatly with me visualising patterns and visualising data representations and visualising numbers, so for sure that’s helped.

**TSF4** also elaborated on the role of **visualising and drawing** and the advantages for a scientist of having artistic abilities:
TSF4: I think in pictures a lot, so if I’m trying to work out a problem, I’ll visualise it and that’s how I solve my maths problems and my logic problems is by visualizing […]. Being able to picture and hold in your head a lot of components and be able to see your way through a problem is creative I think. […] So visualising it in my head is a bit like me drawing a picture of it and working it out. So, I do a lot of that as well. I’ll draw pictures and graphs and I need whiteboards basically in order to be able to think. So, it’s like an extension of my visualisation process.

4.1.3. Creative teaching and learning
The recognition of the role of imagination and visualisation in science, through guided meditations for example, was also discussed regarding creative approaches to teaching and learning. Goethean science was discussed as a method for developing the imagination.

TSF4 discussed how students often don’t visualise in their minds or draw as a method of study for “internalisation of knowledge.”:

TSF4: Some of them are very good at regurgitating things back to you, but ask them to draw a picture or a graph that really tests their internalisation of the knowledge. They’re able to take it in, mix it about in their heads and think about how it relates to other concepts, visually in their heads, and you can test that by asking them to draw the graph or whatever. I think you have to teach them how to do that too. I think you have to make them draw stuff and build up that skill.

The reluctance or inability of students to draw as a means of developing skills of observation and perception was also highlighted by TSF5.

TSF5: I make them draw embryos and they don’t like it […] and some say to me “I can’t see anything” and they draw a little squiggle and I say “But that’s a little squiggle” and they say, “But that’s what I can see when I look down the microscope”.

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The creative ability to use the imagination to synthesise and integrate information from different aspects of the course by building mental pictures was also reflected upon by the undergraduate student TST3.

TST3: It's almost like my head twists inside because it's like you're reading something and it's being referred to either in another course or in a different way and I'm like trying to relate it to itself. It's almost like you're trying to build a 3D picture in your head, like if you're reading one course and it's mentioning this thing on a couple of slides and then in a different course it's mentioning different aspects. If you can put it together then you can understand it better and that happened to me using different approaches and then I can bring in the information from either in the exam or whatever - it's weird. How did this relate to this? And then you make sure you really understand it I guess. So, you bring in different aspects of it, bringing neuroscience into genetics or embryology or something like that.

SST1 described how she had begun to perceive bird song differently through a creative approach to learning that involved listening to bird song put to music:

SST1: I now listen to bird song so totally differently [...]. It was incredible, that was fantastic [...] I didn't hear it before. So, that has connected me into birdsong and into nature in a way that I could never have imagined.

TSF4 discussed student’s views of themselves and their perceptions of how scientists are or how they should be seen or behave (similar to the points made regarding art and science previously (Lunn & Noble, 2008)) and a way of overcoming this by suggesting that more artistic activities should be incorporated into science teaching and learning:

TSF4: Students are quite worried about appearing scientifically logical and completely rational and non-creative. They think that that’s what a scientist...
looks like and they’re trying to be what a scientist is [....] So, maybe encouraging a bit more creativity in our students would be a good thing [....] by giving them the opportunities to do improvisation or artistic works and design and things like that. That might actually be helpful.

In support of this statement, a recent study reported on a collaboration between scientist and sculptors in which science students fabricated steel protein sculptures with the aim of emphasising the importance of imagination and metaphor in understanding and communicating science (Gurnon et al., 2013). Indeed, study of the relationship between creativity and metaphors can lead to insight into the scientific process and science education (Sanchez-Ruiz et al., 2013).

TST3 described how important it is to learn about the **process of science** from a **historical perspective** and gave a specific example:

*TST3: I think it is nice to hear about creative scientists because you think, “Oh yeah! I could do that” or to think about a problem [....]. We get a lot of the stories. One that you keep coming back to is Rosalyn Franklin. My leaving cert biology teacher - at the time we didn’t really appreciate her off-loading extra knowledge because [....] we felt like we had enough and she’d go off and say “Now you don’t need this for the exam, but......” ...ten minute lecture and we’d be like Aaaaagghhh! But it was interesting to know [....]. especially for women in science - it made me think."

TSF5 outlined that her approach includes stories of **creative breakthroughs** and overcoming the rigid thinking that students can develop:

*TSF5: I do try to tell them about discoveries that are inspirational and are accidental. To try and show that it's not all linear and moving from one question to the next. It's amazing, no matter how much you try to tell them that things are on-going how up to about the end of third year they think*
everything is already discovered and why don’t you know the answer to a question? Because I think that’s how textbooks present it really.

Thus it is important to tell the stories of creative breakthroughs in science and the insights of creative scientists, rather than solely purveying what is in textbooks. Indeed, textbooks often present science as a set of finished ‘facts’ or ‘truths’ and this is actually counter-productive to creative learning, since it fails to stimulate the process by which educational experience unfolds as lived meaning (Benhur Oral, 2013).

SSF1, the first Schumacher College staff member interviewed had particularly interesting things to say about her approaches to teaching creatively, particularly the use of guided meditations to develop the imagination using a Goethean approach. This not only breaks up the information being conveyed, but also enables an experiential and embodied approach to learning, which enhances comprehension (Macintyre Latta & Buck, 2008):

SSF1: So, quite a few of the guided meditations I do will be around taking the attention onto phenomena and then moving out to different spatial scales - something that you get with plants - while first considering the tissues, organs inside the plant and considering the whole organism. And then, you know, its immediate neighbours and then the kind of surrounding ecosystem and so on. So, it's kind of using a mixture of focusing on what's in front of you and then bringing imagination in to fill in the gaps. [...] So, things like a guided meditation with an apple tree in winter where the students imagine what it’s like to be that apple tree at different times of the year and kind of imagine how it is to experience that environment. And sometimes they'll actually lie on the ground or kind of put their hands in the soil. And they'll do things that you know actually kind of help them to “think like a plant” (Holdrege, 2013). I think that’s particularly valuable with botany because it's all quite abstract and the plant kingdom is so different from us and it can all get all very dry, very factual and very detached. [...] and so it
kind of lightens the information. Because, to be honest, some of the creative practice is as much about breaking up the information-rich material and having time for it to sink in and just to kind of relax and have a different way of knowing, rather than just constant bombardment with information.

This participant also highlighted the potential for the students to see science as a story, thereby emphasising the creative aspects of storytelling, including for a dissertation for example:

SSF1: And we have a resident storyteller at the college [...] and he's going to be teaching my students on the next module [...] around developing their own story and the idea of the dissertation, or any inquiry, as a story. And I suppose that's something we're always really keen on is the importance that postgraduate study, so much of it, is about writing or other forms of expression, but the fact that you need to develop a narrative and that it is so like story telling that even the driest scientific paper is having to develop a story and tell the story so that's really important for us.

The role of teaching as a story was also mentioned by the other Schumacher College staff member. This is also associated with the creation of a space for the creative leap in understanding (as the story) to appear in the student, rather than the imposition of the knowledge on or in to the student. This is relevant to Popper’s theory of learning, which claims that there is no transfer of knowledge from outside the individual (Wride, 2015):

SSF2: The way I teach is very much to try to allow something to come into the student, something’s happening with the student, not through my telling them something, but by allowing a space of inference in which the teaching becomes a kind of a story that initiates a kind of transformative jump into something new, a new realisation.

Role-play was also highlighted as an advantageous method employed for creative teaching and learning. Indeed, role play is a potentially beneficial
active learning strategy for Higher Education (Rao & Stupans, 2012), for science teaching and learning (Elliot, 2010) through which students gain a ‘felt understanding’ of learning material (O’Sullivan, 2011):

SSF1: And then I teach soil science as well and I experiment quite a bit with teaching chemistry through creative methods. Because lots of my students don’t have chemistry A level. Soil science has some quite heavy chemistry. We do role-play where […] we’ll have little pictures of different molecules in physical states and the students have to act out that chemical process that’s going on in the soil.

This issue of the extent to which these innovative teaching practices could push students outside of their ‘comfort zones’ and how the lecturer also has to feel confident and comfortable was also discussed:

SSF1: Some of them really love it and some of them, it will challenge their comfort zone and I think it’s very much how you present it as well. I think they much prefer something where they are, say moving pictures around, rather than actual role-playing. So, I think it’s really important not to push comfort zones because I think that can really impede the learning. But, then some of the stuff at the College does kind of push people out of their comfort zones and I think that's productive too, but my own style is playing it safe with people’s comfort zones. I don't like making people kind of be uncomfortable or be in places that they'd rather not be. Or, let's say, I think you can do that if you're the kind of person that can pull it off, but I'm not […]. There is a certain personality that can push people out of comfort zones and to make it productive for them.

The advantage of active and self-directed learning was highlighted as well as a means to learn creatively by both Schumacher and Trinity lecturers:
SSF1: The other thing that we do actually, which is really productive, is rather than feeding the information to people is about getting them to find out for themselves. So, rather than telling them to find out what the characteristics of different plant families are, actually just giving them a load of plants and saying “Right, group these by shared characteristics”.

TSF3 stressed the importance of teaching students about the history and process of the development of an idea and knowledge generation:

TSF3: We’re showing them how to learn. We’re showing them how to generate new knowledge. We’re not just telling them the knowledge, that’s sort of easy, but to give them somehow the sense of how that knowledge is derived and the process. The history of how ideas are formed is really useful in a broader context for them and then things like research projects and things like sitting and talking with senior academics about their latest paper I would hope will give them insight.

TSF3 went on to describe a highly innovative, participatory and transformative approach to teaching students about the emergence of order from chaos:

TSF3: I use them [the students] as human crowding animals. So they basically walk around interacting with one another and I film them from above and they don’t know what’s going on, but from above you can see patterns emerge. And in the lecture I can show them starling flocks and fish shoals and I can also show them the videos of them self organising and the patterns emerging in their own behaviour that they couldn’t see from their vantage point within the crowd. So, I think that is an interesting moment when you see something emerge from apparently nothing.

A student centred approach and the allowance for space and freedom and the right kind of immersive educational environment in teaching
and learning was also highlighted by the Schumacher College staff and students:

SSF1: I think coming to the College actually is really beneficial to mainstream scientists. [...] I think it's easier to be creative in an immersive educational community because it's not so 9 to 5. It's like you've got space for creativity. You've got space to fit it round the other stuff. You're in the right environment. You're not just in the classroom. You're outside and or having lunch together.

SSF2 added to this as follows:

SSF2: The context of many people being creative and cooking together and having these grounds does lead to a different type of insight than if you're working in a more formal academic structure because [...] that whole process of creativity is more like a gestation of something and it doesn't happen if you're continually prodding it, asking for funding. It needs that kind of long period of being able to go round in circles, of being completely lost and frustrating everybody, including yourself. And if you look at Newton coming to calculus, he was alone for long periods and he had plenty of time to get it wrong and without anyone becoming upset.

Regarding this immersive environment at Schumacher College, in which academic staff and students can mingle freely, the statement of Whitehead (in his book The Function of Reason) is relevant here - the justification for a university is that it “preserves the connection between knowledge and the zest for life, by uniting the young and the old in the imaginative consideration of learning.” (Birch, 1988). Furthermore, it also brings to mind the ideal, again espoused by Whitehead, of the Benedictine ideal of ora (meditative reading) and labora (work) (Caranfa, 2012).

The second Schumacher student commented on the importance of an inquiry-based and student-centred pedagogy and the space and
freedom for creativity to flourish, rather than on a traditional rigid subject-based curriculum, which brings about a fragmentation of knowledge, as emphasised by Whitehead (Birch, 1988; Whitehead, 1929a) and Bohm (Bohm & Peat, 2000):

SST2: You can't plan the path of dozens of individuals [.....] their interests have a particular coherence that can't be predicted and where they go next with that also can't be predicted. So while the programme provides you with both the expectation of rigour in what you do from your peers and from your tutors, it doesn't dictate what you do. [.....] I think maybe the way forward in scientific education is to move beyond disciplines to have learning be inquiry based, to be led [.....] by the way that [students] find coherence in all of their complementary skills and proclivities and that providing the space, the freedom to do that, is the only approach that I can imagine.

A lovely quote from W.B. Honey in Science and the Creative Arts is relevant to the requirement for freedom for creativity to flourish:

“Rebellious opinion and intellectual activity, the boldest scientific speculation, and the most adventurous creative art, all spring from the same ground of freedom.” (Honey, 1945), p75.

At Trinity, TSF3 also commented on the advantages for creative teaching of small groups and learning in an immersive educational situation such as field trips:

TSF3: We're not ever really formally having brainstorming sessions with undergraduates [.....]. But, I think you could almost emulate the pub style chat, which is small group [teaching], which is sitting around the table. It happens on field trips I find. When you're on the field course with students, you've got time over lunch or coffee or a bus drive somewhere and you can just have kind of semi-daft discussions where you're just wondering and
pondering asking each other their thoughts, but it’s informal and it’s not assessed or rewarded directly.

However, there are practical limitations and restraints on implementing such teaching and learning strategies at University level owing to the existing academic structures:

SSF1: But it all kind of takes more time. I suppose that's the downside of creative teaching […]. If you've got a very heavy curriculum, it's very difficult to do. I mean we've not got a very different curriculum, so that's what allows us to do it. But, certainly, I struggle to see how you could integrate that into a university course, because you have a much higher number of students […] and the sheer amount of information you've got to get through.

TSF3 also talked about the importance of freedom for teaching and learning creatively and restraints:

TSF3: I think actually here in Trinity I have a huge amount of opportunity for freedom at least to teach in any way that I want, within reason […]. I think that freedom is important to try out new things and if you're trusted to do it and you're a sensible person you're not gonna keep banging on with something that’s not working, you're gonna reflect on it and you're gonna deal with it. […] But it requires the usual – smaller class sizes and more freedom from bureaucracy. But how you solve that – more staff, less students really. […] And yes the current academic structures hinder creativity – definitely, I think there's ever more administrative jobs, there's ever more bureaucracy.

TST1, a Trinity PhD student reflected on freedom and creativity in her research work in the laboratory:

TST1: Here I would see myself as very free, but I know a lot of people who wouldn't. So, it depends on your supervisor. It depends on how the lab
structure works. I would presume […]. if I continued on and went into industry, [I] probably wouldn’t be as free as I am now. But I think that’s the nature of the PhD and how it evolves.

Co-teaching and teaching collaboratively was also highlighted as an ideal for creative teaching:

SSF1: We do a lot of co-teaching. Most of the postgraduate teaching at the college is two teachers in a room […]. But I suppose a lot of the format would be more that one teacher would facilitate and the other one would teach. But I’d have to say that where we have literally co-taught it’s worked well and I think it’s preferable to the kind of more rigid facilitative teacher combination.

Collaborative and group learning as well as building a coherent group dynamic were also highlighted as effective creative approaches to learning. A wonderful description of the advantages of group learning was described by the one of the Trinity undergraduate students:

TST2: I think group work is fantastic. I mean it only takes one person to ask a question that will trigger an unbelievable response in another, which then I think brings about this domino effect of people asking more questions and answering more questions and coming out of their shell and opening this little bit of creativity.

She goes on to outline the advantage of having a relatively small number of students on a course (in this case, fifteen in Functional Biology).

TST2: So I think putting us in a group straight off the bat, it allows people to instantly relax […]. I think that group work and collaborative work is essential for creativity because people are too afraid to be creative by themselves, but when they challenge one another on thoughts and ideas that opens (sic) up these doors […]. I think it allows people to release from
their rigid structure even just the smallest bit. If you’ve had the experience with the group where you’re questioned, I feel as though you can go into anything from an interview to an assessment with more ideas.

TST2 also highlighted a perceived fear regarding opportunities or support for writing creatively in science:

TST2: You’re kind of pointed in a certain direction and you’re kind of asked to adhere to the system […]. People my age find it difficult enough to come out of the shell anyway. People find it hard not to be a sheep. So, when you’re dealing with grades, a graduating degree, people are afraid to go off the track because [they are] in fear that people will laugh and mock and so I believe that the opportunity is there. I mean if you’re given an essay title you can do with it want you want, but I think people are just afraid to. They don’t know how to unlock their creativity.

Overcoming fear is also important for creative teaching and learning. TST2 points out that the creation of the group dynamic can overcome fear:

TST2: It was because we were made relax from the word go. There was no pressure, there was no fear I think. I think there’s always a littler bit of fear when you first walk through that door. It was smiles and laughs and it just immediately put everyone at ease, it made everyone want to communicate and to be calm and enjoy.

TST1 talked about overcoming fear of failure in order to try new things with regard to her Laboratory based PhD research:

TST1: Just an acceptance to fail and an understanding that that’s a part of the process - that it’s not the end of the world if something doesn’t work…you just have to take something from it, learn from it and move on and carry on from it.
TST2 described the possible reasons for the undergraduate fear of being creative and how this might be overcome:

* TST2: *I think it almost depends on a little bit of hand-holding in the beginning to say, “It’s OK to be creative – you will not lose marks for being creative”, because that’s all students care about when they come in initially. I feel as though they don’t start asking questions until they know they have a good result, that they won’t be ostracised for being a bit different, for being a bit quirky. [....] People need to be told that it’s OK to go off on a tangent, to branch off away. That it’s OK to be an individual. You don’t have to be a sheep. You don’t have to adhere to the system so rigidly. Do your work, but get creative with it and I mean people are scared of that.*

The second Schumacher student reflected on the nature of fear and its possible wider causes and effects:

* SSF2: *In addition to fear, it’s each individual. If each individual, if their life hinges on them making their immediate conditions predictable, then that means making the conditions of other people, their students, all of that, predictable and I think there’s more than fear going on there, more than fear of uncertainty. It’s also [....] the effects of things like time restraints, of resource restraints, of the skill that people have in being sensitive to each other and to what's going on and trusting order to emerge out of that and to balance that approach with the approach of planning. Yes, I think the fear of uncertainty is huge, but I don't think that describes necessarily where that fear comes from.*

This idea of trust rather than fear fits in with the point that some constraints are necessary for the creative emergence of order from chaos (Tosey, 2006) and is related to the idea of a requirement for discipline to be creative, which was elaborated on by TST1 regarding her lab-based research.
TST1: I'm not an airy-fairy creative! Everything would be timetabled on my Google calendar as to what I'm doing…even if I just start to do it during the day, I'll put it in there so I know I've done it, so there's no blank spaces, which could be seen as not being creative at all!

So, a major challenge in encouraging lecturers to teach creatively is in the overcoming of the fear of failure, a certain reluctance to try new approaches, but to stick with the known and trusted, rather than to try to use more creative approaches to teaching and learning. However, it is acknowledged that some structures and discipline are advantageous for creativity. Students, on the other hand, will benefit greatly from the creation of a group dynamic at the beginning of their course as well as the opportunity to get to know each other and become relaxed with each other through fun activities, team building and group work.

TSF5 also talked about her approaches to creative teaching and trying to connect with the students emotionally and instilling a “feeling” for the material being taught:

TSF5: I suppose quite a bit of my teaching up to third year […] is to try and give them a framework of knowledge that they can build on, but I do try to connect with them. In first year by I suppose telling them the relevance of what I’m teaching them to other things that they might know about and to other parts of the course…[…]. It’s not exactly creative, but it’s getting them away from teaching them about facts in a linear way and showing them movies and little video clips so that they engage with it, not just as words on a page in a text book, but have some sort of feeling for it as well […] To learn something you have to have an emotional response. If you don’t have an emotional response, you don’t learn.

So, for this lecturer it is necessary to inspire students by creative teaching, to engage them emotionally in the material and to provide them with a reason or purpose to motivate them towards learning. Indeed, Whitehead
said “The first thing that a teacher has to do when he (sic) enters the classroom is to make his class glad to be there” (Birch, 1988). In fact, Birch points out that the literal meaning of the word ‘education’ is “to lead out by genial encouragement” in order to engender “imaginative zest” in students. Moreover, Arthur Zajonc outlines the importance of the relationship between love and knowledge for deep learning (Zajonc, 2006).

The second Trinity student also talked about this requirement for the generation of an emotional response and feelings for learning and reflected on the session on problem solving and creativity in science that I facilitated:

TST2: After that session, I remember it opened us all up to not only discussing College aspects [of our lives], but all other [aspects]. It seemed to kind of once again unlock this order that everyone had. Everyone kind of discussed possibilities of what could happen, what might happen, what may have happened in order to lead up to this moment. So it kind of allowed people to get that little bit creative […]. I mean there are scientific minds that have trained themselves to believe that they are solely scientific, whereas we kind of ended up being able to discuss the creative aspects. Be it how that feeling is when you play sport. Be it what people read, what people watched, what people discuss among other groups that aren’t this one College group that we only know of each other.

Encouraging students to overcome fear of questioning and using creative questioning to help maintain the “curiosity of finding out” was also highlighted, particularly by TST2 who recognised the essential role of creative questioning by scientists. Indeed, students should be encouraged to constantly question assumptions, so that questioning is part of the daily exchange so that students learn what questions to ask and how to ask them, rather than simply looking to learn the answers (DeHaan, 2009):

TST2: The learning aspect is difficult because it doesn’t [….] encourage you to question. So, I always found things like exams more difficult than when I did project work because it feels as though they ask you a question, but they
want an answer in particular – there’s no room for manoeuvring there. And it doesn’t make it enjoyable then because you feel under pressure to say what they want to hear, whereas what I want to say is possibly not want they want to hear, so it has this little fear factor within you [...]. So, what is a student meant to do when it’s a ‘yes’ or ‘no’ question and all you want to say is ‘maybe’ and there’s no such option? [...] I believe that all the questions should start with ‘What if?’

TST3 described her experience regarding effective questioning by a lecturer and how this helped in participation and building her confidence:

TST3: M asked a question in one of his lectures. It was like an exam question. But what I love about the way he lectures is, he said in one of the early ones, “I know when you’re being silent that you don’t know what’s happening or you don’t know what’s going on.” Whereas other lecturers either don’t want questions or they’re just fine to just keep going, whereas he’s like “If you don’t ask me questions”… he’ll just stand there, so you have to ask questions and participate, which is great - it makes you really focus on it. I’m just waiting there and I answered it and I got it right. So later when I was studying I had this question and I thought I was able to do that and it just gives you that confidence.

TST2 described the necessity for students to continually question the material provided by the lecturer and her frustrations with what she sees as simplistic or inadequate answers, with regard to evolution in this case:

TST2: I have all these questions. People explain these situations to you, these differences in species, these different habits that they have and mechanisms of evolution and you just say well then why this? Why that? Not all of it can be explained and I feel as though a lot of the time people just kind of give a sigh, an exhale [and say] “Well, it’s because of this…” and that’s not good enough for me! It’s not as simple as that. I’m a very grey person, it’s not all black and white for me.
4.1.4. Skills, embodiment, wholeness and flow

Several of the participants talked about experiencing feelings of wholeness when being creative and of a ‘spiritual’ feeling or of being in a trance like, hypnotic or open state of consciousness – a state of ease that has been termed ‘flow’. There were also descriptions of experiencing a moment of insight or inspiration associated with participant’s creative pursuits such as playing chess, music, riding a horse and playing cricket. The participants equated these embodied feelings to those they might experience in their scientific work. Indeed, the relationship between creativity and flow has been well documented (Csikszentmihalyi, 1996). This is important because it shows that students need time to consolidate their skills before they can learn creatively and be creative in their work:

SSF2 talked about playing chess:

SSF2: When I used to play chess, I remember playing in a tournament and […] I was playing this good player and then somehow without really thinking about it I did this move and completely put him in an impossible situation and it was like I didn't realise what the move was until after having made it. It's that thing where in a way your kind of hard work, which may have seemed to have got nowhere, suddenly opens up to show you something that's already there. It's not that you've understood something new - the thing has kind of shown itself to you.

TSF1 spoke about her experiences of being a musician:

TSF1: I also play the flute - with that you're almost in a trance if you know what I mean […]. When you're playing at your best [….] you're almost drifting.

She equated this experience of drifting in this meditative/contemplative/reflective state with the times when she gains
insights and inspirations relevant to her work, while relaxing or reading, rather than when she is working in the laboratory:

TSF1: The times that I drift, that I think of things, new things I guess are not the times when I'm pipetting, they're the times when I'm maybe lying in bed and thinking about things and I am drifting in my head. I mean it's also when you're reading things when you make links. I don't know if that's creative or not? You make the links because of your background and of what you're reading and what you're seeing at the time and what you know.

A recent Scientific American article referred to this as “The inspiration paradox: your best creative time is not when you think”, leading to solving non-analytical or ‘insight problems’ (May, 2012).

TSF4 described the necessity for the development of embodied knowledge as a precursor to creativity and she related this to sports and learning to drive:

TSF4: You have to train your muscles to do things, and it's often not the physical training, but the mental training. If you do something often enough it kind of gets hard-wired in your brain and you don't have to think about it any more. Like driving […]. But as you get more practiced - thinking, statistics, mathematics, knitting whatever you like and then as you get more practiced you don't think about it and then you can start to get creative.

And TSF5 describes beautifully a feeling of being in the flow or in a state of wholeness, while using a dissecting microscope to study embryos:

TSF5: When I sit down at a microscope […], I've never tested it, I must test it some day, I think my heart rate drops. I can feel myself relax, which is a very strange thing when you're sitting at a microscope like that, but I can just feel myself calm, and there can be things going on around me in the lab, but
I’m in that dish and I love it. When you just get inserted into something that you just have a feeling for because you know it so well.

And she goes on to describe the problems that a novice has in being creative before the skills are mastered so that the process of flow occurs in which new ideas can appear:

TSF5: And you’re struggling to think “Am I doing it right?” And you don’t know what you’re looking at totally; you’re trying to figure out what you’re looking at. But when you get to a certain stage, you know what you’re looking at and you can go further in your thinking when you’re in the middle of something that is fairly routine for you, but is stimulating at the same time.

TST2 described the feelings of relaxation and flow associated with her work on her final year project:

TST2: Well, I also found in the lab, it was a relaxation. It was a setting of pure enjoyment for me, but maybe also because it was quiet. It was like my own little bubble and, once again, it’s that numbness, of people were around me, I wouldn’t even notice to be honest.

And this was in relation to a previous description by this student regarding horse riding and a feeling of flow and connection:

TST2: I’ve had my horse for six years and we’ve built up this bond. In a sense, it’s a relaxation for me to go out. It also numbs everything else around you - it’s just this unity, this spirit – we’re one body. So, for me, it’s so creative because every touch, every movement I take she’ll respond too, whether it’ll be positively or negatively and it will also make me wonder why? Why has she done this when I have done this? And it’s not just training, because she has her own personality, her own being, her own form when I’m not riding her and when I’m riding her. It’s so creative because it’s like an art; it’s not just training it’s a spiritual connection.
TST1 plays cricket at a very high level and related this to her PhD research in terms of **experimentation and the acquisition of skills and creativity**:

*TST1*: It [cricket] can be very experimental. I wouldn’t be afraid of trying things because they could potentially fail. I know lot of people would, but I’d be the same in here [in the lab]. I’d try something even if it had a 2% chance of working because, if I didn’t, I wouldn’t know. And I suppose I do that as well in my game in cricket […]. To compare it to the lab, even if you learn something and you have your technique, everybody does it slightly differently. What works for one person, it might not work for another and you’ll find comfort in the way it works for you, [….] that you’ve got the skills to do it. […] I know how to do things inherently now that I wouldn’t even have to think about and I wouldn’t be afraid of it.

TST1 also reflected on common themes of learning to be creative in both cricket and in her work in the lab:

*TST1*: I suppose it would depend on the person. I don’t know if it [creativity] could be taught because you have to have an open mindset to do it. There would be a lot of girls who I play [cricket] with who would just do what they’re told, but that isn’t necessarily going to make them successful, but it’ll make the coach happy. It’s the same with a teacher student. If the student is just going to continue do what the teacher says, it’s not them pushing the boundaries or learning for themselves.

**4.2. Case study: creativity in science teaching session and student reflections**

The following brief quotes are selected from the student self-reflective pieces provided for the Junior Sophister (3rd year) Functional Biology and Plant Science students (2013-2014) problem solving and creativity assignment. The comments provide support for the efficacy of the session in opening up the students’ minds to creativity in science and presenting
material in creative ways (a selection of full student reflections is presented in Appendix VI).

The comments throughout often demonstrate the surprise of the students that learning and presenting science can be fun and creative. There is a sense of liberation from traditional structures and the perceived rigid approach to science education. There is also evidence for this assignment being transformative: in instilling increased confidence in the students’ creative abilities, in engendering new skills and also in connecting their artistic interests with science. There is also a recognition that this activity was fun and that there was a sense of “a different spirit” or feeling in the group when engaged in this activity.

**Student 3:** This exercise was honestly one of my favourite assignments I have completed in college. I found since studying science that we may have lost our sense of creativity somewhere along the way but this assignment has shown me that science can actually be creative and enjoyable.

**Student 4:** Science and art are at a first glance totally different fields. We are made to believe so by years of education, where our minds are squeezed into tight fitting boxes of lay-outs, marking schemes and past exam papers. After years of following sheepishly what I have been told, I can honestly say I feel less clever, and certainly less creative than before.

**Student 5:** I noticed a change in the spirit of the group. People have an interesting response to being creative or ‘playing’. I think it is very healthy and it has opened my eyes to the fact that not all of the best work is done staring at a computer screen. I particularly enjoyed how Watson and Crick were using Cardboard cut outs of nucleotides to attempt to identify the way they’re assembled. The fact that a method like that can win a Nobel prize assures me that there’s hope for us all.

**Student 7:** Overall this assignment was interesting as it was different to a general scientific presentation the creativity aspect was a good new addition to a scientific skill set as creative presentation can be useful for presenting
scientific findings in a novel way that could arose more interest and attention in the audience.

**Student 8:** I really enjoyed watching the rest of the groups’ presentations. It was interesting to see the different methods that people apply to their work when they are given minimal instructions and creative freedom.

**Student 10:** This module opened my mind to the idea that science can be creative. As an artist, I would have never put the two together, but I have realised the same principles can be applied to both.

**Student 13:** From our research topic and our presentation I realised how easy it is to become creative if we open our mind. As science students we rarely get to be creative in our writing or presenting, as everything is very black and white. I found this exercise extremely helpful as I now know it’s easier to learn things if we move away from the books and it’s also easier to work as a team when we are making it fun.

A example of one of the assignments carried out – a black and white silent movie made by one group of students about the life of Marie Curie, is linked here on the Functional Biology blogspot:

http://functionalbiologytcd.blogspot.ie/2013/12/marie-curie-and-radioactivity-silent.html
Chapter 5: Conclusions

5.1. The EU Creativity Project
An investigation of creativity in European Higher Education was carried out by the European Universities Association (EUA) - *The EU Creativity Project* (EUA, 2007), incorporating input from higher education institutions, governments and external partners. The overall conclusions were that Higher Education Institutions (HEIs) should promote a culture that is tolerant of failure, question established ideas, go beyond conventional knowledge and strive towards originality. They also pointed out that quality processes have the potential to strengthen creativity and innovation if they focus on the capacity for change, while at the same time providing a supportive infrastructure. This fits in with an emergent perspective on creativity in Higher Education, and that some constraints are important for focusing creativity (Tosey, 2006).

The EUA also recognised the following, which really refers to the ability to overcome existing dogmas:

“The complex questions of the future will not be solved “by the book”, but by creative, forward looking individuals and groups who are not afraid to question established ideas and are able to cope with the insecurity and uncertainty this entails.” (EUA, 2007), p6.

Further, the report recognised the points made here about the requirement to overcome ‘old’ world-views of linearity and mechanistic thinking:

“If Europe should not succeed in strengthening creativity in higher education, the very goal of a European knowledge society would be at stake. Purely mechanistic approaches geared towards reaching predefined targets will certainly not allow European Higher Education institutions to contribute adequately towards this ambitious objective.” Ibid
In terms of actually obtaining these objectives, the report also that it is necessary to transcend the traditional approach of one-way teaching, passive listening and hierarchical relationships. The results of the interviews and student self-reflections presented here would seem to agree with these conclusions, in presenting ways forward compatible with the EUA report.

5.2. Methods for enhancing creativity in science teaching
Explicit teaching strategies have been suggested, several of which were mentioned in the interviews, that can be incorporated into science teaching to enhance creative problem solving and to enhance interactivity (DeHaan, 2009):

• **Model creativity** - students develop creativity when instructors model creative thinking and inventiveness.

• **Idea generation** – students generate ideas and solutions to problems repeatedly in an open environment.

• **Constantly questioning assumptions** – teachers use questioning regularly as it is vital that students learn the kinds of questions to ask more so than the answers.

• **Imagine other viewpoints** – student perspectives are broadened by reflecting on ideas and concepts from different points of view.

• **Think-pair-share-create** – the possible answers to an open-ended question or small problem are initially thought about individually, then discussed in pairs then shared with the class

• **Brainstorming** – the instructor poses a problem and the students work together in small group to develop solutions (facilitates associative thinking – relating different ideas to each other).

5.3. Final comments
A creativity philosophy should be at the heart of science. However, this will not be achieved by implementing academic structures and curricula focusing only on efficiency and control (Neumann, 2007) including standardisation of the student ‘experience’, constant ‘performance measurement’ and excessive ‘accountability’. Furthermore, creativity
teaching and learning can benefit from smaller classes and collaborative group work - there should be more ‘sit down, observe and draw’ immersion-style practicals for example. But this ideal is not easy to achieve in a climate of reduced staff to student ratios, rigid timetabling and condensed and intensive modules allowing no time for consolidation of knowledge, space for reflection or time for students to engage in creative assignments. Science should be promoted as a truly creative endeavour. This may be achieved partly through adopting creative teaching methods, many of which have been mentioned here. This may go some way to overcoming the “cult of mediocrity” which it has been argued, pervades science (Greener, 2005).

There is also a need to appreciate the historical and philosophical contexts of science and the relationships between science and art. For example, having students read and then discuss recent articles in Nature about scientists who are also artists and musicians could be beneficial in opening up students’ minds to a wider view of science and scientists (Gewin, 2013; Kaplan, 2014). Also, discussing common themes regarding creativity in both research and learning is important. A recent paper for cultivating creativity in conservation science describes cycles of learning, struggle and reflection that are as applicable to education as they are to research (Aslan et al., 2014).

Engaging science students in considering new developments in physics and philosophy, such as those discussed here, is very important. They may allow students to see both nature and science as inherently creative, and will help pave the way towards seeing how we can ‘re-create’ science, through a recognition that we are truly creative participants in the creative and dynamic processes of nature.

To conclude, this study has provided an overview of the philosophical and theoretical background to creativity in both science and in nature in general. The argument has been made that views of the ‘official’ scientific method as linear and mechanical inhibit the ability of scientists and science students to
'see' nature as creative. An organismic and process philosophy view of nature, based on the scientific and philosophical perspectives of David Bohm, Alfred North Whitehead and Christian De Quincey, has been presented, as a means to overcome this kind of thinking. Furthermore, the way of seeing dynamic wholeness in nature and using the imagination, developed by Johann Wolfgang von Goethe, was presented and discussed.

It is apparent from the interviews that scientists, despite the 'official' scientific method, view the process of science as being creative and utilise numerous creativity techniques and practices in 'doing' and teaching science. Furthermore, the students interviewed prefer dynamic, collaborative and interactive modes of learning and see these as creative. Through the evidence of their reflective pieces, students also benefited from a creative assignment that enabled them to explore both their own creativity and their views of science as creative.

Personally, I am heartened by the views of the scientists and students presented here. They have re-invigorated me regarding “how I got here” – I’ve always appreciated the creativity of nature instilled in me by my Dad and by my other teachers and mentors. Having completed this dissertation, I feel better about the future of science and science education. It needs a bit of tweaking perhaps, but it won’t take much to ensure that we can avoid that sad indictment of science education expressed by one of the students “I found since studying science that we may have lost our sense of creativity somewhere along the way.”

…..we really don’t need to lose “our sense of creativity somewhere along the way” after all.
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Appendix 1: Question sheets

Appendix 1.1: Student Question Sheet

1. Describe briefly your educational background, current course and primary scientific interest(s).
2. Describe what inspired you to take up a course in science. This could involve a particular early formative event, or an inspiring teacher, parent etc
3. Do you have creative hobbies/interests in art away from your studies e.g. creative writing, poetry, painting, drawing, music, dancing? Do you socialise with arts students?
4. Do you feel that your ‘creative pursuits’ feed into and/or complement your scientific studies? Or, do you keep them separate; i.e. compartmentalise them? Are you open about your creative pursuits with your science student peers? If not, why not?
5. What generic and particular creative skills/abilities do you believe that a scientist should have and/or cultivate? Are these similar or different to those that an artist might utilise?
6. Do you feel that you are (or have the potential to be) a creative scientist? Can you provide example(s) from your own scientific studies/research so far where you have had a creative insight, used your imagination or intuition to solve a problem or develop a hypothesis or theory?
7. Do you feel that you are able to express your creativity in your scientific education/research in your current position? Do current scientific/academic structures help or hinder creative expression in science? How do scientific research groups and/or collaborators synergise for creativity?
8. Do you have opportunities to learn creatively? In your experience, are science students taught about creative breakthroughs in science? If so, how is this done?
9. Can you model creative teaching on nature in general, or scientists in particular, as being fundamentally creative?
10. Do you think that the current ‘official’ scientific method recognises the role of creativity in science? How could science be made more creative? How could scientists develop their creativity? For example, how could creativity be embedded at a fundamental level in scientific research and teaching/learning? Do, we need a more flexible model/method/process for carrying out scientific research.

Appendix 1.2: Staff Question Sheet

1. Describe briefly your academic background, current position and primary research interest(s) as well as your current teaching areas.
2. Describe what inspired you to take up science. This could involve a particular early formative event, or an inspiring teacher, parent etc
3. Do you have creative hobbies/interests in art away from your scientific work/teaching e.g. creative writing, poetry, painting, drawing, music, dancing? Do you socialise with artists?

4. Do you feel that your ‘creative pursuits’ feed into and/or complement your professional scientific work? Or, do you keep them separate; i.e. compartmentalize them? Are you open about your creative pursuits with scientific colleagues? If not, why not?

5. What generic and particular creative skills/abilities do you believe that a scientist should have and/or cultivate? Are these similar or different to those that an artist might utilise?

6. Do you feel that you are a creative scientist? Can you provide example(s) from your own career in scientific research where you have had a creative insight, used your imagination or intuition to solve a problem or develop a hypothesis or theory?

7. Do you feel that you are able to express your creativity in your scientific research in your current position? Do current scientific/academic structures help or hinder creative expression in science? How do scientific research groups and/or collaborators synergise for creativity?

8. Do you have opportunities to teach creatively and to teach students about creative breakthroughs in science? If so, how do you do this? Does your teaching include examples from your own experience/research of the creative process in science?

9. Can you model creative teaching on nature in general or scientists in particular as being fundamentally creative?

10. Do you think that the current ‘official’ scientific method recognises the role of creativity in science? How could science be made more creative? How could scientists develop their creativity? For example, how could creativity be embedded at a fundamental level in scientific research and teaching/learning? Do, we need a more flexible model/method/process for carrying out scientific research.
Appendix II: Project information sheet

PARTICIPANT INFORMATION SHEET: March 2014

Project title: Re-Creating Science: Creativity in Science Education

Principal Investigator: Michael Wride, Zoology Dept, School of Natural Sciences, TCD

To: Interview subjects

You are invited to participate in a research study for my MEd in Higher Education Teaching and Learning aimed at exploring the role of creativity in science and science education. I plan to conduct semi-structured interviews with academics and students regarding their attitudes towards creativity in science and creativity in science education. My findings will be presented in my MEd dissertation and may also be presented in conference papers, peer-reviewed articles, and/or a published book. The study is part funded by a TCD Centre for Academic Practice and Student Learning (CAPSL) Writing Grant: Writing for Publication in Teaching and Learning initiative.

Your participation in this study is entirely voluntary, and you may ask to withdraw your consent at any time up until 10 days following the interview. The interview will take place in your office or another venue of your choice and is expected to last 60 minutes. A list of possible interview questions is attached; you are also welcome to suggest your own.

The interview is anonymous; that is, your real name will NOT be used in my dissertation or any published books or articles that arise from the interviews. I will ensure that direct quotes and other information are used in such a way that you cannot be identified as the source.

The interview will be digitally recorded and later transcribed by me or a research assistant who has signed a confidentiality agreement. You will be sent a copy of the digital recording and will be given the opportunity to read the transcript and request changes within 10 days of receipt. The interview data (digital recording and transcript) will be stored electronically on a password-protected server to which only I will have access. The data will be destroyed/deleted after 6 years.

Thank you for your help. If you have any questions, please do not hesitate to contact me.

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<th>Researcher name and contact info</th>
<th>Supervisor name and contact info</th>
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<td>Prof Michael A Wride</td>
<td>Prof Aidan Seery</td>
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For any ethical concerns contact: The Chair, The School of Education Research Ethics Committee (REC) http://www.tcd.ie/Education/ethics/

Approved by Trinity College Dublin School of Education Research Ethics Committee March 24th, 2014
Appendix III: Consent form

CONSENT FORM

This consent form will be stored electronically for a period of six years.

Project title: **Re-Creating Science: Creativity in Science Education**

Researcher: **Michael Wride, Zoology Dept, School of Natural Sciences, TCD**

To: Interview subjects

I agree to take part in this research. I have read and understood the Participant Information Sheet and have had the opportunity to ask questions and have them answered.

In understand that:

- My participation in this study is entirely voluntary.
- I may ask to have my interview data withdrawn at any time up until 10 days following the interview.
- The interview will be digitally recorded and transcribed by the researcher (MAW) or a research assistant who has signed a confidentiality agreement.
- I will be sent a transcription of the interview and given 10 days to request changes.
- My interview data may be quoted in the MEd dissertation of the researcher (MAW) a book, conference paper, and/or published article.
- My interview is anonymous; I understand that my real name will NOT be used in the MEd dissertation of the researcher (MAW) or any published books or articles that arise from the interviews.
- My data will be stored electronically on a password-protected server to which only the researcher has access.
- The data will be destroyed and/or deleted after 6 years.

Name (print):___________________________________________________

Date:_________________________________________________________

Signature:_____________________________________________________
Appendix IV: Biographies of Participants, Inspiration and Artistic Interests and Hobbies

Schumacher Staff 1 (SSF1):

I did a degree in biology when I left school. And then I did an MSc in ecology about 8 years ago and now I'm doing a PhD in biological education and I'm a lecturer in ecology effectively on the sustainable horticulture programme. And, my research interest is around biological education. It's basically around people's relationships with plants. My teaching is soil science, ecology and horticulture.

Well, I had a passion for plants from a young child, probably from about as young as 4 or 5. I was very fascinated by plants and both growing plants and also learning about native plants, so I did a lot of 'botanizing' in the countryside. And I suppose, early formative events, I had some very good, three very good books on plants for children and they were very kind of important in my development. My parents, my father was a biochemist, he was a patent examiner in biochemistry, so he certainly inspired me a lot about science.

I've probably got less creative hobbies at the moment than I do usually. I've played quite a lot of music in the past. I learned the trumpet for years and I was in a couple of bands. I wrote poetry for a while and certainly as a child I absolutely loved creative writing. I did a lot of that and I still write a lot. Drawing, I really love, but just botanical illustration. I've always done creative bits of botanical painting and drawing. Do I socialise with artists? I don't know if I particularly socialise with artists. I suppose some of my friends are artists. The other thing I do, well used to do, is craft, woodcraft. For a few years, before I went back to academia I worked as a craft educator, which again was linked to the plants. It was about plant-based crafts, so it was things like hedgerow basketry, wood carving using native green woods, that kind of thing.

Schumacher Staff 2 (SSF2):

For A levels I did maths, pure maths, applied maths and physical science. Went to Oxford and did maths, specialised in topology and my current position is teaching holistic science at Schumacher College. My primary research is really physics and the place of time at the moment. I've also done work in biology and in various models of genetics.

So, the event that inspired me to take up science was I was in a book shop exactly 20 years ago and I was reading a book, maybe Fritjof Kapra's Tao of Physics and that book had inspired me in the 80s and I was between the physics and theology section and I had a clear feeling of connections between theology and physics, which was a kind of very clear tangible feeling, a bodily feeling that had a sort of huge amount of wisdom in it, which I didn't possess at the time having not really understood physics. It was a sort
of telling, talking about the feeling of linking up the ages of the prophets with
the age of theories and discoveries and at the time I had been fired from my
computing job, so I had plenty of time. So, I spent the next few years just
reading physics and getting to know physics and that impelled me on a path
that eventually brought me here.

So, I've done letter press printing and had a small printing business. I play
guitar. Writing I do a lot, also poetry, more previously, not so much now, but
I do go to a poetry event here every month where you can read your own
poems and drawing. We do a lot here, drawings - Goethean science,
drawing plants and definitely I socialise with artists. So, I really enjoy that
cross over conversation with poets and artists and recognising the kind of
generic impulses that are kind of true across both art and science. And I
also bring that into my teaching

Schumacher Student 1 (SST1):

I graduated in business in 1995… then fast forward 10 years. And I was
then working at Birmingham University in the School of Electronic
Engineering, so I actually used my business degree in marketing. So I was
working my way up the ladder in marketing and then I ended up in
marketing short courses to engineers that were in work. But then I got really
interested in working with students who were on industrial placements. I
really enjoyed that. So then I re-trained as a careers consultant. So, in the
year 2000 I undertook a part time postgrad diploma in careers education
information guidance, so I became a fully fledged qualified careers
consultant and at that point my health was suffering with a lot of stress and
so I decided to take a sabbatical and I decided a couple of years later to
start up my own training school with [my partner]. I love physics, but I didn't
like the way it was taught. Biology, all of that, I just felt, you know, I wanted
to ask different questions and the questions I was asking weren't welcomed
with open arms shall I say. So, I just basically thought I was no good at
science, so I just put it to one side because it wasn't what I wanted.
And then I guess 18 months ago, Schumacher had been on my radar and I read
about the holistic science course and thought that is so me! And because of
my interests, because of the path that I'd walked, and then I had a
particularly difficult incident personally. And I just thought, no more am I
going to be subjected to what people want me to be and want me to do and
I'm actually going to do this for myself and I applied and came here and so
that's why I ended up coming here to do Holistic Science because the
course spoke to me. It's weird because people can't really explain what
holistic science is, but in my gut I knew what it was and I knew that's what
I'd always been searching for my whole life and that's why I came here. So, I
drink quantum physics. I drink anything that I can put into context in my life
and my experience. Because, to me, then the whole world comes alive - just
the way I was taught, I was learning about a dead world.
Schumacher Student 2 (SST2):

I have a BA in history and a minor in Russian. I have an educator's certificate as a wilderness ecology educator and a professional certification as a wildlife tracker with Cybertracker conservation. At the end of my history degree I started to get more and more interested in the overlap between history and evolutionary theory. Because for historians, whereas their evidence in the past was documents, more recently photographs things like that, DNA other kinds of dating all these things are becoming evidence that are as equal and as valid as a photograph and that blurs the lines between disciplines. And so, I began to question how the training for a historian or a scientist takes place. And whether it can really be trained or whether somebody has to find [or] follow their interests because there are so many sub-disciplines. You can become a historian who is particularly focused in psychoneuroimmunology or in ecological history or any of these things and there's nowhere to train for that. I think at the postgraduate level you can begin specifying an interest, but as you're going in as an undergraduate there is a dissonance because none of your courses are going to be anywhere near science. So, by the time you get to the postgraduate level most historians have no scientific literacy. I was not allowed to do that dissertation. It didn't fit within the discipline I was told. So that re-orientated my academic interest and I became much more interested in what we consider learning and what a learning path is and what it is allowed to be. At the time, I was taking anthropology courses and cognitive sciences that did include more science and none of that was allowed to go anywhere near my history thesis. And in those courses I became interested in the philosophy of how experience, direct experience has become excluded, not just from education but from work environments, from philosophy, in the philosophy of science and what was fascinating to me about that is that it is a self-fulfilling prophecy. If people don't practice their abilities of direct perception and ability to communicate with each other those abilities never develop or atrophy and then it becomes true that people are unreliable participant observers and that's how I ended up going into permaculture design initially because it's a much more experiential approach grounded in observation. Participant observation, an engaged kind of observation, where you are always within your experiment as a participant. And eventually how I ended up doing traditional, studying traditional ecological knowledge, and tracking and [I] also began doing a bit of work as an educator.

There is some creative writing, some first person reflective writing. Essay writing, I've done some journalism, which went beyond hobby too.

Trinity Staff 1 (TSF1):

So, I did an undergraduate degree, Masters degree in Leiden University, which started off as biology and specialised in molecular biology and even genetics, particularly human genetics in the last year. And once I finished that I did a PhD in Dublin in Trinity College Dublin in the Genetics Dept. and after that I stayed on as a post-doc and my main research interests I guess are gene therapy, it's very applied, it's really not basic research at all and it's
not really my interest that - basic research - either. I do like the applied research. So, we're trying to find gene therapies, in particular for hereditary retinal degenerations. So, I'm a research fellow here and I hope to remain a research fellow. I have to be honest, I'm not so interested in becoming a professor or a big wig because there is an awful lot of paperwork involved, an awful lot of admin, far less freedom and it's too much work for me, it's not what I want to do. I don't want to spend 70 hour weeks on my work because I have lots of other interests as well including children and creative ones, absolutely. And my teaching - I guess I do quite a bit of supervision in the labs for PhD students. I've just had an undergraduate student from DIT and I have a student from James' hospital who's with us for 3 months a Masters in Molecular Medicine student. So there are always students in and out. I do the odd tutorial, but not very many and I teach on the Molecular Medicine course, the Masters course in [St] James' Hospital. I teach a couple of lectures and have done for quite a few years, which is why I have the student. So that's really what I do in the lab now. So, what inspired me to take up science? Well, initially I wanted to do medicine. And I didn't get in and in Holland there's something called a numerous fixis[?] and you sign up and [your name] goes in a hat and you're either lucky or unlucky, and I was unlucky. In fact I was unlucky twice. So, I went through the list of courses that exist in Holland and scratched off the ones that I didn't like and really was only left with biology and I have lots of interests in biology, all of biology, I love ecology, botany, zoology, anything to do with biology and so it was a good choice actually and I liked the fact that it was very broad in Holland initially, so I did all the broad subjects and didn't narrow down until later than maybe some other courses, maybe in Trinity even.

So, from the artsy point of view, I don't do creative writing but I do a lot of reading I guess...not poetry or anything. I love drawing and I did a little bit of painting, but it's very time consuming, but I want to get back to it....I do quite a bit of music. I sing every Tuesday in a choir.... I also play the flute....Let me see, so I have other hobbies as well and one of my hobbies is gardening, which is a science and an art maybe. I don't know. I mean obviously you're aiming for something pretty, but it's also a science I guess. And another hobby, huge hobby that I have is we have a little cottage.... and it has 12 and half acres of lake and fields and also woodlands and I've been trying to turn it slightly into a natural nature habitat and I've been planting trees where I think they would be best suited I guess and grow and I've been picking trees that I think are right for the place, but also enhance biodiversity and all of that.

Trinity Staff 2 (TSF2):

Written responses only (not interviewed)

BSc Biology and Geography, MSc Genetics, PhD Botany (all University of Birmingham, England). Postdoc Royal Botanic Gardens Kew, England. Now Senior Lecturer in Botany TCD (starting in TCD in 1997). Primary research in plant systematics, plant population genetics and plant genetic resources including food crops and forestry but primarily grasses.
It [science] gradually grew on me - no single moment. I enjoyed biology and was offered a scholarship from the Department of Agriculture to do an MSc and then a PhD without really thinking about it too much. I was really enjoying college life at the time and it was great to stay in it for so long. I ran a disability club, was involved in Niteline (student counselling/info) and loved athletics. I also considered becoming a probation officer for some reason but thankfully settled on science and plant science in particular. Plants are fascinating things.

Gardening, geocaching, orienteering, sport, botanising/natural history. I like to be busy and don’t like to sit around too much -so pubs and dinner parties are not my thing. I do lots of arts and crafts with the kids but it is not a strength of mine. I dip in to social media from time to time but lose interest quickly.

Trinity Staff 3 (TSF3):

So my background is in…I did a degree in Zoology here at TCD. I then, after graduating, in my 4th year I realised I wanted to get into something involving computers and research involving biology and I stayed on here to work as a research assistant and I was lucky, I picked up a research position sampling lakes, which was beautiful and during that time I got some funding to go to the University of Glasgow in the UK, which I did for 3-4 years. It was theoretical ecology. Writing computer programmes to understand behaviour. And then came back here on a postdoc with the bioengineering department then built on that when my current job, which is as lecturer here in the School of Natural Sciences. My primary research interest would be the evolution and ecology of animal behaviour and how complex behaviours evolve and how animals process information and also I’m generally interested in developing quantitative tools for ecology. My current teaching areas are mostly statistics and also some animal behaviour, but not as much as I would like.

I suppose I’ve always liked biology. My father is a Dr, my mother is a nurse and there has always been a strong biological component to my up-bringing. I had toyed in school I guess with doing medicine and I always have done off and on, but I think actually probably a combination of a film and a book about Ebola virus and I decided then when I came to College that I wanted to be a virologist and/or a geneticist and then made the decision to give up on stupid leaving cert goals and just go for science. So I got into science then and I’ve loved it ever since and just taken it from there.

I have done music off and on throughout my life – a few different instruments. It sort of comes and goes. Whether I find time or not and interest to do it. I do enjoy a bit of guitar when the mood takes. Creative hobbies – not really to be honest…Music I suppose is the only one – I wish I had more time for it. I’ve always wanted to play trumpet for some reason, but I know if I went and bought one it would sit in the cupboard… clarinet and borrowing my brother’s saxophone a lot as well.
Trinity Staff 4 (TSF4):

So, my academic background is, starting now, I'm Professor [in The School of Natural Sciences]. Prior to that, I was Associate Professor at the University of Queensland from lecturer where I was appointed in 2004, to Honorary Professor, which is where I was just before I left. And prior to that I had a post doc at Imperial College London, which is the same place that I did my PhD in, so I spent in total about 5 years at Imperial at Silwood Park in the UK. Prior to that, I worked for a year with a conservation NGO and also with BP in a programme that was funded by BP funding student conservation research projects and prior to that I did my undergraduate degree at in the UK. My current teaching areas are in ecology, plant-animal interactions, and field biology. Primary research interest is population ecology and management of invasive plants, so research at the boundary between humans and the natural world.

So what inspired me to take up science? Finding out about things. So I knew I always wanted to go into a research career, not necessarily in science, that definitely came a little bit later, but I definitely knew I wanted to find out new things and so that was my primary motivating factor and synthesize knowledge, generate new things out of existing knowledge or finding out new things and integrating that knowledge into our theory of how things work and then I went through a process of deciding which area to sort of apply that research to. I started thinking about medicine, flipped back to English literature then decided I was going to do biology because I really liked and was interested in the natural world but didn’t have a good sense of what area of biology I was particularly interested in. So, my settling on ecology and probably plant ecology in particular came through my undergraduate degree where I had a very inspiring lecturer and teacher who was an expert in plants and really fuelled my interest in plants. Also, some key, key books that I read, some plant taxonomy books about the evolution of seeds and population biology of plants by John Harper were particularly interesting and inspiring because they basically had new ways of looking at plants and the environment. I was always surrounded by animals and plants and nature as I grew up in rural Ireland, so that was probably formative.

I don’t do anything particularly arty, I barely even have a chance to listen to music these days. But, I do crafts. I enjoy craft – knitting and crochet and it’s not quite as creative as I’m following recipes basically, so it’s more like recipe driven craft and that’s like my cooking as well, which is creating something and I tend to be a bit more creative with my cooking than anything else, so I think that’s creativity. Story telling is a creative art and we tell family stories around the dinner table where we all take a little piece of the story and build on it. So we’re trying to inspire our kids to be creative through story telling. So we tell them a lot of stories reading from books and making stories up. So, we’re trying to encourage them to tell stories as well, which I think is important.
Trinity Staff 5 (TSF5):

Well, science here in Trinity specialising in genetics. My current position is Senior Lecturer in Trinity with some research projects and teaching in that area. So my primary research interest is in morphogenesis really during embryonic development and I teach luckily in that area as well or in the broader area of developmental biology and developmental genetics. I suppose a formative moment during that period anyway, not earlier, that led me into developmental biology, was an internship I did between 3rd and 4th year in Cornell and it was happenchance really. I went to the Department of Genetics and Development and it was like a zing moment. This is the context in which to me made understanding genetics make sense or rather gene regulation so the regulation side of genetics was already interesting to me and now I felt like I found the aspect of biology that I wanted to look at in terms of gene regulation.

I have to remind myself sometimes how I ended up here. What inspired me to take up science? Wow, that’s interesting because I came from a small very rural area and at the time, I suppose it was a time where education was changing in Ireland and being the youngest of a family of 8, none of my brothers and sisters or my parents had ever seen anything remotely like science. My bothers would have done science up ‘til what was called the intermediate at the time, so like junior cert and it was then in primary school we had a nature table that was generally bringing in a bunch of blue bells to bring in to put in front of the statue of the blessed virgin rather than anything analytical you know. Our nature table was really more about religion than it was about science. So, when my older brother, who’s about 4 years older than me; when he started secondary school, I was dying to learn more and so he would bring home these text books and I’d be immediately opening his text books and I was just amazed and physical geography and he would like to tell me as well about what he was learning. He probably wouldn’t talk to his class-mates or his teachers like that, but he’d tell his little sister. And I remember going for walks over the fields and he would tell me about oxbow lakes and we were looking at this tiny little river and imagining it forming an oxbow lake and there were things I’d never, never ever thought of are out there and I want to learn them. So that was what inspired me to and I decided then I want to learn more about science.

I had a wonderful science teacher who wasn’t a terribly effective teacher in terms of across the classes – he had no control of the class, nobody ever listened to anything he said and except me and just I hung on every word he ever said and it was great ‘cos the rest of the class would say “You ask him to bring us for a nature walk”. So, I would ask him to bring us for a nature walk, but not too often so they’d be running to the hills and I would follow him and listen to very word he said. I remember there was a thing I used to like doing at the time. It was dandelions and splitting the stems, so if you split the stems and put them in the river they turn curly and I used to love to do that as a child and I remember doing that on what of these nature walks and he came over and said “Do you know why they do that?” and explained
about the cells and the inside being soft and the taking up water through osmosis and the ones on the outside being rigid and how that made it curl and I remember going Wow, I want to know how everything ...that’s beautiful like that works. I want to know why things do what they do! I suppose moments that I remember. And we had a geography teacher, who was a much better teacher I suppose, who also inspired me.

Do I have creative hobbies or interests? Yes and no. I certainly don’t do anything in any formal way and I don’t think I’m any good at anything artistic, but I like looking at other people’s achievements and I suppose I mess for myself only, but I wouldn’t say I have a hobby in any kind of formal way in anything artistic. It’s an appreciation rather than something I do myself and I love seeing art. I love when people do different things that to me are curious. I’m curious about why they’re doing what they’re doing in terms of modern art and sometimes I don’t get it all, but I love when you do hook onto something that’s visual but in terms of creating it myself no.

I know what was a great experience for me and helped me think more about the visual side of what I do, what that means to me, whether it’s really important in how I progress with the work or not - I’m not saying that I know it’s part of the way I work and the way I think - was when we had a resident artist in the lab and my first meeting with her and the way that was a sort of buzz there that I wasn’t, ’cos I hadn’t experienced anything like that before, I didn’t expect it necessarily. But when we first met at a social occasion and were tentatively talking to each other about what we did when I said I was a developmental biologist she said “Oh, I’ve drawn some 7 feet tall charcoal embryos” and it was instantly, I want to see them and it went from there and there were times when I think I didn’t really ... when she had her residence here she struggled a bit with what she was going to do creatively and I didn’t understand that necessarily. Not that I expected that she shouldn’t struggle but I didn’t tune in to what it was, but just having...hearing her reaction to things and her response to things was good. I think [she had a different perspective] and it just made you articulate what you were thinking sometimes as well. I remember when she showed me those two drawings that we have in the lab there and her 7 feet one and I said that one’s at stage 18 and that one’s a little older that one’s stage 20 and she was shocked because to her they were abstract they were fairly abstract, but to me I could see the embryo she’s used...she hadn’t copied it, but she’d used it as her inspiration some illustrations from a very old embryology book, so she wasn’t, in her mind, repeating exactly what was in that image, but there was the shape, the curvature of the head, the lie of the heart, the position of the heart, just things to me that were tell tale [signs] that this was a period in development, but she didn’t realise that what she was capturing was so indicative of what was going on [at those stages of development].

...to her the reason she was drawing embryos, these were chick embryos, she said to me she was drawing them because of how powerful they were and I think how we think ‘embryo’ and we have emotional responses to it as
well, so she wasn’t even realising that that picture – she knew it could be interpreted emotionally, and she didn’t realise it could be interpreted scientifically and that was a shock to her and she said really you can tell what stage the embryo’s at. We both looked at the same thing, and both had a strong response to the same thing, I mean she drew it and yet saw a completely differently thing.

And one of the things she did when she was here, she asked people to give her an image that meant something to them and in a couple of lines tell her why it meant something to them and I gave her a doodle that actually [a colleague] had drawn, something I worked closely with who is a great mentor to me. [He] and I were sitting talking about the difficulties of conceptualising mechanisms working over time and space and how difficult it is to even conceptualise that and [he] did a little doodle and that was so helpful to that conversation and I kept that doodle and so when she asked me for something that meant something to me I gave her that with [his] permission and that was good and you asked “did that make us see things differently?” I guess having to explain to her brought me back to having to explain about that. I think for myself and for most developmental biologists, I imagine, the visual helps us to grapple with the really interesting questions because things are so dynamic, temporally and spatially and it’s trying to get your head around breaking that down in a scientific way, but still trying to appreciate the complexity of it.

I think she did [get a grasp of the spatio-temporal movement of the embryo], she’s mentioned it several times because sometimes I’m with her when she’s explaining her residence to other people and she talks about it as a web as a net and actually she …the other day I met her. She’s now doing a PhD and I met her external examiner and she referred to it as like a mycelium and I hadn’t thought about it as looking like a mycelium, but it’s interesting the language you would use to describe the visual impact of something.

Trinity Student 1 (TST1):

I did a science degree here in Trinity specialising in Physiology then I did a Masters in London in UCL and specialising in physiology here I thought I wasn’t really interested in the lab at the time. I thought I’m not going to work in the lab, I’m not going to do that. And exercise and sport would be a major part of my life anyway so I thought I’d do a human based project, but it didn’t work out as easy as I thought, which was annoying. Then I thought I needed more lab-based experience so I went and did a research Masters in London in Biomedicine. From there, I did two projects in developmental biology. One in the neural development unit on pituitary gland development and the other one in the developmental biology group on eye development and rods and cones and, so that’s where I sort of got into developmental biology an then I’m currently finishing, my PhD here back in Trinity in my 4th year in Developmental biology.
Initially I did it because I wanted to do physiotherapy. And it was another way of getting in further down the line. As I was in it and I did it I realized that it was not what I wanted to do. I don’t really know why, there wasn’t anything that happened. I just thought I could do more than that.

So my family are all incredibly creative. So, my Mum’s an architect, my Dad is an artist, my older brother is a cinematographer and my older brother is studying photography, so I’m the black sheep. It even spreads further - my Mum beside her bother and sisters are textile designers. So, it didn’t come from home anyway. Maybe school, I don’t know….my biology teacher…

I’d think of myself as quite a creative person in the way I do science more than in the way I probably should. But I can’t really say that it was parents that did it. I suppose it was more my interest in sport and in understanding things than anything I think.

I would have a lot more [artistic/creative hobbies] when I was younger, because I had more free time, but I would have an interest in it and as a kid being dragged around openings and galleries.. I suppose I was always taught that as a kid from my family. So, I’d recreate a piece of furniture in the house on a weekend….something like ….I’d buy all the DIY stuff and go and do it. I wouldn’t ever get somebody else in to do it…I’d always try and do it myself. If I wanted the wall a different colour, I’d paint it a different colour. I wouldn’t get somebody else in to do it. I’d be quite creative in my garden now…and I would never see that I couldn’t do something. If I wanted to create something I’d just go and do it - it might not work and it might not stay, but I suppose it’s a place where you can switch off but where you can be creative in a different way

Trinity Student 2 (TST2):

Educational background. I went to primary school in Rathmines, in Kildare Place then I went to Alexander College for 4 years and for 5th and 6th year I went to the Institute of Education and from that I came to Trinity and I started off in first year for the first 6 weeks doing an arts degree which was a mix between Italian and History of Art and Architecture

And after 6 weeks, I was waiting to see if I went up in points, basically to see if I could get into Physio[therapy], but then when I didn’t I decided I needed to be in [a] science based [course] – because that it was just embedded in me

I’m a combination of the two [scientist and artist]. I think at the time, I felt that in order to go further after my degree that I needed something with a strong base, which is science and I just didn’t get the enjoyment, out of, honestly, the course that I was doing at the time so I changed over into science, which Trinity allowed me to do, which was amazing, to move from one end of Trinity to the other is quite unheard of and then from third year then I specialized in Functional Biology And I just graduated with a 2i!
It was by kind of pot-luck that I ended up in science. I did love science, but in terms of, I always found biology and the associated kind of biological sciences a lot easier than I did say physics or chemistry so when I got into the general science I found certain things like chemistry, math methods etc. difficult, but I loved biology and I loved things like infection and immunity and I loved all those sort of different modules and evolution things like that I really loved, but because you get only a very tiny little taste of that in secondary school, I never thought that general science would have suited me, so it was only after getting into the course, basically by chance with this idea that I needed a broader but solid base, it was only when I went in and started doing modules like that that I realized they really interested me and that it was kind of what suited me as a person, it was kind of, it asked me the right questions.

I always [had] this concept of flora and fauna and the workings of them together. The one thing that I always find baffling is that Botany and Zoology are completely separate, whereas really they are one. I mean, I grew up watching these wild life TV documentaries and the science aspect always - it helped explain so many things, but also by explaining it, it made me ask more questions, so for example this animal lives off this plant, but it’s poisonous to this animal well I’d say why? Why is it poisonous to this, how does it work and I mean that ultimately ended up driving me through the course that I did because this kind of sense of wonder, asking these questions that then got answered by one book or by one lecture just opened up another door.

I’d write - I used to write a lot more poetry. I think now that everything has calmed, I’ll start getting back to it. I like to write and I’ll write as in, not blogs, but I’ll usually write about people to be honest because it’s feelings that I get off people and I always find that if I do write about people it’s words that pop into my head, so as I’ve mentioned before this funny thing with giving people names, it’s like giving them a label, which I don’t believe, but there are certain words that I love that I think embody a person so that makes me write about them.

Trinity Student 3 (TST3):

Leaving cert I did the core subjects that was English, Irish, Maths and then I also took French and I took science obviously, so I took Biology and Chemistry and I took History, which I really enjoyed. Then first year I took 6 subjects, both biology modules both chemistry module sand I took a Maths module and a physics module. I found Physics quite difficult. And actually, it was really funny the first day the teacher went round the class to find out why the did it and one lower at the back said, I’m in Earth science and I had to do it. Second year, I took 8 Biology modules and two Chemistry modules so 10 and I found chemistry kind of difficult though I eventually cracked it and I would find some aspects interesting, but it would be when you understood it. It would be like “Oh yeah, I can do this!”
My aunty is in science. She was in California. I think she gave me a kids microscope when I was little. I think I was already interested before that because that could have been met with not the right reaction. As well, my paternal Grandad had this National Geographic collection and I think I obviously showed an interest in that and he got me a subscription and that was very connected to him I’d say and then my first secondary school teacher as well. So she had this unfortunate voice that was like a monotone, which doesn’t make it interesting, but she was really passionate about science and that showed through. I think I took an interest in it than and in TY, you go out and do work experience and I had narrowed it down to science and law and I went and did a 3 weeks work experience in a solicitors office and I walked away thinking, I’m not doing that, which sounds like I had an awful time. But I realised one day when I was in the forecourts how I guess stuck it was, it wasn’t as pliable or changeable, it was all about making an argument referring to previous cases as opposed to science, which seemed more creative and new and interesting, so I thought I’ll do that.

I was talking to R and I think it’s like a reflex to mock the arts students and I forgot that 30 seconds earlier she had said that she did film when she was a student and I had said something about arts students and I was like S@£t - it’s just like a reflex and we were talking about it and I said I think that sometimes science students get the dig in because they’re afraid of being looked down on because the arts students, just, well they dress so much better. They’re like the popular kids or something and then the science students are like, well we’re smart and she said wow well we always felt like they felt the opposite they were holding the science students up!
Appendix V: Problem solving and creativity assignment for JS Functional Biology and Plant Science - details 2013-2014

Creativity in Science: Possible topics to research, write on and Present!
Work in groups of four to research a topic - 10 Presentations, so 10 mins each, including question period!
Be creative! Can you find an interesting and alternative way to present e.g. Play/Poem/cardboard or plasticine model?
The emphasis should be on the problem and how it was solved, including the creative insights of the scientists… what was their story? What motivated them? How did they come to recognise the problem? How did they come up with the solution? How/why did they make the creative leaps that they made? What was the fundamental creative insight that changed the way they looked at the problem and led to the new insight/solution?
Hand in a summary of your topic (800 words max Plus references) and a short reflection on yourself regarding problem solving / creativity (200 words) – please bring a hard copy and also send to me as Word file By email to: wridem@tcd.ie) and Presentations – Friday Nov 29th
Assessment: 50% Presentation and 50% Summary/reflection
Please name the file you email me as follows:
“Creativity_Assignent _YourSurname”
Possible topics
Gregor Mendel: Mendelian genetics
Barbara McClintock: Transposable elements (Nobel prize)
Nikolai Vavilov: Crop genetic resources and seed banks.
Melvin Calvin (+Andrew Benson, James Bassham): Photosynthesis (Calvin cycle).
Kerry Mullis and PCR
John Sulston: programmed cell death
Alexander Fleming: insulin
August Kekule: structure of benzene
Peter Medawar: “the art of the soluble” (on creativity in science)
Watson and Crick: DNA structure
John Gurdon: amphibian cloning
William Harvey: the Circulation of blood
Linus Pauling: the structure of proteins
Alfred Russell Wallace: evolution by natural selection
James Clerk Maxwell: electromagnetism
Max Planck: quanta
Ernest Rutherford: penetrating the atomic nucleus
Mr Higgs and his Boson
Marie Curie: radioactivity
Johann Wolfgang von Goethe and his ‘Delicate empiricism
Appendix VI: Case Study: Creativity in Science Teaching Session and Student Reflections and Feedback (Detailed Comments).

Student 1: My problem solving ability used to be very poor. As a child I learnt to play the classical piano and violin, which have incredibly rigid rules and did not help me to think ‘outside the box’. Similarly in school I did not learn anything about problem solving, if anything I think it’s discouraged in formal education. The only real time I had to learn to develop any sort of problem solving ability was when I moved to Japan. I lived in Japan for three years and had to learn to contend with most information being presented in both a foreign language and traditional Chinese characters. In order to remember a small fraction of the approximately 1,900 characters that is required for literacy, I had to develop ways of breaking down and memorizing everyday kanji – I think this ‘problem’ made me more of a creative person. From this experience I learnt that I am a visual learner, rather than a kinaesthetic or audio learner and as a result I try to remember information in a series of pictures and also try to think of problems in science in a similarly visual way. [...] I find doodling and drawing very enjoyable and it can sometimes aid me in the retention of new information e.g. chemical pathways such as the Calvin cycle.

Student 2: In the beginning, my group and I found it quite difficult to think of a creative way to present our project, probably because we were so unused to having to think creatively. However, after we had researched our topic and begun discussing it, we came up with ideas more easily. We decided to use an actual horse heart when presenting the different views that were had on how the heart worked, so our audience could better visualise what we were talking about. One member of the group also dressed up as William Harvey. We felt people would remember the facts about him better this way.

Student 3: This exercise was honestly one of my favourite assignments I have completed in college. I found since studying science that we may have lost our sense of creativity somewhere along the way but this assignment has shown me that science can actually be creative and enjoyable. We decided to act out a play for our presentation and we perhaps got a little too involved in the acting and should have included more scientific information throughout. The audience would have benefitted from more information and also would have enjoyed the light-hearted entertainment in our play. [...] Watching the other group’s presentations really enlightened me for future presentations. Everyone had taken a different creative stance on their topic and you could see that everyone was having fun and enjoyed completing their presentations. Not only was this assignment creative but I found that we really wanted to get started and were eager to complete this task well. Finally I enjoyed this assignment immensely. I really felt that we were given the freedom to research anything we had an interest in and that everyone pulled together to make the presentations enjoyable, fun and also informative.
Student 4: Science and art are at a first glance totally different fields. We are made to believe so by years of education, where our minds are squeezed into tight fitting boxes of lay-outs, marking schemes and past exam papers. After years of following sheepishly what I have been told, I can honestly say I feel less clever, and certainly less creative than before. Unfortunately, many students, wanting to succeed will follow rules without questioning them, to secure the future they want. It’s a trap! Now at 20 years old I find it almost impossible to carry out a project on my own initiative, without using the helping hand of powerpoint and boring speeches. I found the presentation a challenge, and my team made it only worse. While examining us working on the project I realised, no one can let go of the science and concise facts anymore. As a result we produced a poor, boring presentation about a Danish Physicist. I feel like other groups did better, because they focused on the presentation and creativity, more than the facts. The aim of the exercise was to test out creativity and not our research skills. I don’t think the aim was to learn as much as we can about Quantum Mechanics. In the end, I feel like after this presentation, as well as after the lecture I can agree on one thing. One should not over-think! This goes for both science and art. We over-complicated the project, and it lost its meaning. Whenever I draw, I don’t think about consequences, outcomes or the meaning of the act. I wish I could do this in my field, without fear of failure. Then, I would be a successful scientist.

Student 5: The way Watson and Crick figured out the structure of DNA displayed very intelligent creativity and unparalleled problem solving. So in doing the research for this topic I did learn a lot about creativity in science. With regards to how creative we got to be, we had limited time and compromises associated with group work are always a factor. We all built our DNA model together and came up with the play. When we were making our model we were in the same room as other people who were filming or rehearsing or blowing up balloons and I noticed a change in the spirit of the group. People have an interesting response to being creative or ‘playing’. I think it is very healthy and it has opened my eyes to the fact that not all of the best work is done staring at a computer screen. I particularly enjoyed how Watson and Crick were using Cardboard cut outs of nucleotides to attempt to identify the way they’re assembled. The fact that a method like that can win a Nobel prize assures me that there’s hope for us all.

Student 6: Taking both from the presentation, and from my own experiences, Wallace to me is a true example of creativity and of problem solving. Despite the modern idea that people are born creative, that it comes to them in sole moments of true brilliance, and that science is itself cold, unfeeling, and painfully logical with no room for creativity, if more could look on the life of Wallace outlined in our presentation they might see what I feel is the truth. Creativity is something that must be worked at. Eureka moments are incredibly rare, and are themselves the product of long and arduous work. Anyone can be creative, if they are willing to work at it. What Wallace did would not be impossible for anyone to achieve. Himself a man of modest background and means, he put himself through all he did from sheer dedication: a dedication to understand and add to the world, the true union
of artistic and scientific spirit. With regards to problem solving, again I feel a scene from Wallace’s life is the perfect example of my opinion on the topic. Half way across the world from home, after spending years trying to figure out evolution, and half mad from malaria, Wallace was only then finally able to realize the answer. It was only when his mind was so busy with fever, and Wallace himself so distracted by his illness, that he could solve his problem. This shows clearly that when we are completely caught up in our problems, academic or otherwise, we can easily get mired down. It is only when we distance ourselves from them temporarily, that as Wallace would say, the answers suddenly flash upon us.

Student 7: Overall this assignment was interesting as it was different to a general scientific presentation the creativity aspect was a good new addition to a scientific skill set as creative presentation can be useful for presenting scientific findings in a novel way that could arose more interest and attention in the audience. Our assignment presentation was a play and I think the deviation from the norm by using lighting, props and acting helped to get our facts and points across. I think there is [sic] valuable cross-curricular talking points in terms of science and creative presentation. The use of creativity and problem solving in science is necessary to keep discovering as we saw in the presentations by the class that creativity helped a lot of these discoveries by these scientists occur. This assignment I think showed me that thinking “outside the box” can prove valuable and that a variety of techniques can be used in academic scientific research.

Student 8: This assignment was one of my favourites as it was interesting and exciting to study a topic that we wouldn’t normally study in an innovative way. We chose to present our project in the form of a drama, which was very enjoyable. I feel that we engaged the audience by providing an interesting and humorous presentation, although retrospectively, I feel that we could have used this platform to present more scientific information and data. […] I really enjoyed watching the rest of the groups’ presentations. It was interesting to see the different methods that people apply to their work when they are given minimal instructions and creative freedom. It was also very interesting to see the extent of my fellow classmates’ creative skills. It’s not something that we often get to show off! Overall I found this assignment very enjoyable and I feel that I gained valuable skills in both presentations and research.

Student 9: I really enjoyed this project. It gave us the opportunity to approach a presentation from a different angle and have a bit of fun with it. At first we struggled to get to grips with the concept of a creative presentation and started to research our topic as we usually do for such a project. However when we got together as a group to discuss what we discovered the creativity started flowing and we found ourselves asking a lot of questions beginning with “Wouldn’t it be fun to…” and saying “It would be cool if we could…”. It didn’t take long for us to come up with ideas as to how to make our presentation more interesting and we had to discard a few as inappropriate but, judging by some of the other presentations, maybe prematurely. We, I use the word lightly, decided that I would become William Harvey and talk a little about myself. We also decided to bring the shock
factor by bringing a heart to the presentation. D really outdid himself by
obtaining a horses heart and, judging by the crowd’s reaction, it worked.
Overall the project was great fun and I felt the session in which the projects
were presented was the most enjoyable one this semester.

Student 10: This module opened my mind to the idea that science can be
creative. As an artist, I would have never put the two together, but I have
realised the same principles can be applied to both. The problem solving
aspect also inspired me to think outside the box, and not to be intimidated
by views already depicted about different topics in science.

Student 11: Initially the problem of a creative presentation was quite
challenging, trying to break from the norm and to try something new. Also
finding a solution that was agreeable to the whole group was challenging.
Once the initial idea was proposed a series of further expansions on it
happened in quick succession, further building on and refining the idea.
This stage was the easiest as we were all very enthusiastic with the plan
and ideas and twists came thick and fast. The act of carrying out our idea
was both challenging and very rewarding. A lot of hard work was put in to
piece our final presentation together, it was also hilarious. Problems that
arose during the process were quickly talked out and solved, I think, due to
the good group dynamic we had created and the enthusiasm for the project.
Overall we had felt like we had achieved something worthwhile and were
very proud of the standard and amount of work we felt we had put into it.

Student 12: I found that this exercise was quite useful in enhancing my
presentation technique. It has taught me that you can essentially mix
science and creativity when presenting your research. Rather than just
using power point and reading off slides to try and explain a topic to an
audience, I feel I can now understand how to be more inventive and
interactive with the audience to perhaps even make learning about the topic
enjoyable. With the use of diagrams, music, props and roll plays, I can now
ensure that every future presentation I make will be a memorable one. I’ve
learnt that just because I’m studying science it doesn’t mean that I have to
leave my creativity at the door of the lecture theatre, instead it can be used
to enhance my own and others’ understanding of the topic at hand. Why
waste all your efforts on a good presentation if it’s going to be forgotten in
no time, especially when you can have a bit of fun with it and introduce
some personality.

Student 13: From our research topic and our presentation I realized how
easy it is to become creative if we open our mind. As science students we
rarely get to be creative in our writing or presenting as everything is very
black and white. I found this exercise extremely helpful as I now know it’s
easier to learn things if we move away from the books and it’s also easier to
work as a team when we are making it fun. [...] Overall I like the idea of
being creative in presentations and it made me want to work and put
something together. I also enjoyed the freedom of topic as it made it
interesting and allowed us to learn outside of our field.
A Wordle™ of the collated student reflections: