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The Implications for Science Education of Heidegger's Philosophy of Science

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Abstract

Science teaching always engages a philosophy of science. This article introduces a modern philosophy of science and indicates its implications for science education. The hermeneutic philosophy of science is the tradition of Kant, Heidegger, and Heelan. Essential to this tradition are two concepts of truth, truth as correspondence and truth as disclosure. It is these concepts that enable access to science in and of itself. Modern science forces aspects of reality to reveal themselves to human beings in events of disclosure. The achievement of each event of disclosure requires the precise manipulation of equipment, which is an activity that depends on truth as correspondence.

The implications of the hermeneutic philosophy of science for science education are profound. The article refers to Newton's early work on optics to explore what the theory implies for teaching. Modern science—as the event of truth—is a relationship between an individual student, equipment, and reality. Science teachers provide for their students' access to truth and they may show how their discipline holds a special relationship to reality. If the aim of science teaching is to enable students to disclose reality, the science curriculum will challenge some of the current practices of schooling. If teachers base science teaching upon the hermeneutic philosophy of science, science will assert itself as the intellectual discipline that derives from nature, and not from the inclinations of human beings. Science teachers teach nature's own science.

Keywords: science, hermeneutics, science education, Heelan, truth, Newton

Introduction

When teachers teach science—knowingly or otherwise—they project a philosophy of science. Ideas about science itself are imposed on students along with the content taught. This article sets out a modern philosophy of science and indicates why it is superior to those more familiar to teachers. It brings back into education the notion of truth and shows how the individual student is the bearer of truth. If teachers adopt this philosophy of science they will improve their students' experience of science.

The article is in two Parts, (Part 1) the hermeneutic philosophy of science and (Part 2) the implications of this philosophy for science education. Thus, Part 1 first relates the hermeneutic philosophy of science to alternative accounts of science and then provides an historical sketch of its development by way of its leading protagonists, Kant, Heidegger, and Heelan. Part 2, entitled 'Teaching Science as Truth' draws particularly upon

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Heidegger and indicates the implications of the hermeneutic philosophy of science for science curriculum and pedagogy.

Science teachers dread one question more than any other question. What is science? As science cannot answer this question about itself the education of scientists does not equip them to respond. Nevertheless, the question appears reasonable, to require an answer, and it presses upon those responsible for curriculum and the allocation of resources to schools. There is an international trend towards the inclusion of the history and philosophy of science in school courses (Matthews, 1992, 2009; McComas, 1998, p. xii). This is well established in North America and Europe, and now in the South Pacific. For example, New Zealand's official curriculum statement requires that students will make sense of the 'nature of science' and 'critically evaluate ideas and processes related to science ... and become aware that scientific understanding is developed by people' (New Zealand Ministry of Education, 1993, p. 24).

Many government officials—those elected and those appointed—sidestep the question: they deem science and its associate technology sufficiently useful to claim resources—the drivers of a modern economy—and it should not concern us if we cannot say exactly what science is in and of itself, or so they imply. This sidestep leaves teachers to teach each day something that is a part of science without their being able to say fully what it is that they teach. Many scientists, not to mention laypersons, find the nature of science problematic. For example, when science declares its discoveries as mathematical statements that are incomprehensible to all but an initiated few, people wonder about the reality that science investigates. The incongruence between quantum mechanics and relativity theory popularised the uncertainty of scientific theories and thus made science itself appear negotiable and untrustworthy. The biographer of an esteemed physic teacher records when researchers first felt disquiet about the relationship between science and reality, in the 1940s subsequent to the Manhattan project which produced the first atomic bomb:

> Even when quantum physics worked, in the sense of predicting nature's behaviour, it left scientists with an uncomfortable blank space where their picture of reality was supposed to be. (Gleick, 1994, p. 5)

It is apposite to enquire into the nature of science at a time when physics routinely announces new discoveries whilst its theory still remains enmeshed in the crisis about objectivity and realism that was precipitated by quantum mechanics at the beginning of the 20th century (Heelan, 1965, pp. ix-xiv; Mehra & Rechenberg, 1982, vol. 1).

Philosophers of science also find the nature of science problematic. Theories in the philosophy of science can be characterised as (1) those that cast science as an abstract body of knowledge that in itself is independent of human beings, and (2) those that maintain a necessary place for the involvement of human beings in science. The former accounts of science—sometimes collectively called the 'the Received View'—stress the structure, coherence, and logic of scientific knowledge. Science is an axiomatic system that depends on correspondence rules to define theoretical terms, to guarantee the cognitive significance of theoretical terms, and to specify the admissible experimental procedures for applying a theory to phenomena. Most of the debate about the Received View has been about modifications to the admissible forms of rules (Suppe, 1974, p. 17).

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In schools this view of science is most probably in evidence when science is conceived as timeless, certain, and independent of culture or human inclination. Science forms a rigid structure of theory in a manner that is similar to mathematics. As recently as twenty years ago this was a common view of science in schools and universities and its fortunes are effectively tracked in the rise and fall of positivism (Matthews, 2004).

The latter group of theories of science (those outside the Received View), involve human beings in the disciplines of science—people are relevant in every aspect of science including the demarcation of its purpose and scope, scientific observations, and the advance of theory. The philosophy of science blends with the history of science when the context of discovery becomes a necessary part of any account of the nature of science. These more recent alternatives to the Received View ferment around the issue of what it means to say that someone has a theory. Western school curricula today often adopt a constructivist conception of science and constructivist theory is an example of this latter group of theories of science (Matthews, 1997, provides a bibliography; for a philosophical critique see Nola, 1997; 2004). In one rendition, each student constructs their own scientific view and that holds value because it is their personal achievement, others stress the communal nature of constructions (Slezak, 1998, p. 163). As recently as 1964, a symposium of leading philosophers of science drew the conclusion that whist there is agreement about the inadequacies of the Received View, there is no adequate contender for its replacement. Whilst constructivism has some support in schools, it has little support amongst philosophers of science. The hermeneutic philosophy of science is a recent alternative to the Received View. It has some features akin to constructivism (particularly that it makes human beings indispensable to science), but it contrasts with the constructivist theories in its engagement of truth and reality.

Hermeneutics is the theory of interpretation—broadly, what it means to understand texts, utterances, or nature. Whenever someone makes an interpretation of something, there is the potential to say that hermeneutics is involved. Ancient hermeneutics has many conflicting histories which extend to the origins of writing itself. Scholars find a beginning for hermeneutics in ancient Greek works, which reflect the etymology of the term as *hermeneuō* (translate or interpret), and which include Aristotle's work of about 360 BCE with its Latin title *De Interpretatione*. From its origins until today, 'hermeneutics' may refer to translation, proclamation, or explanation. In the West, hermeneutics came in the middle ages to describe what was involved in the interpretation of important texts in the Bible. The dawn of the modern era, the Enlightenment, heralds the advent of modern hermeneutics. Pivotal was Kant's 1784 essay to answer the question 'what is Enlightenment', which brought reason to the foreground—as a means to access truth.

In the last three decades hermeneutic theorists have made significant progress in response to the question, what is science? Insight into the nature of human beings and a more adequate account of the history of science facilitate a credible theory of science. This theory describes and unifies the practices of scientists in diverse disciplines of science. It accords with many of the beliefs of scientists about their discipline, such as that science is international, breaks cultural barriers, and that scientific theories are more than a matter of opinion. It also overcomes many of the inadequacies of constructivism because it indicates why scientific knowledge is not a mere artefact of human culture, but

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instead achieves a special status because it is non-negotiable. In the idiom of theorists, it is the hermeneutic philosophy of science.

The hermeneutic philosophy of science maintains a close interest in the work of practicing scientists and the wider circumstances of scientific discovery. It also acknowledges the human transmission of science is an important aspect of the discipline itself. Whatever the discipline of science is, the discipline depends on students entering into a common understanding with their senior colleagues. Each generation initiates the next into the truths of science and accordingly schooling is a necessary, integral part of the discipline of science. This observation—that science needs recruits—indicates further the importance of the question about the nature of science itself. What is at issue in the present article is what scientists hold as their common understanding.

Part 1: The Hermeneutic Philosophy of Science

Modern Science and Truth

The philosophy of science takes physics as its paradigm. Physics as a distinct subject began in antiquity when the first scientists brought together descriptive studies of optics, astronomy, and mechanics, because the methodology of these subjects involved geometry. The word 'physics' derives from the Greek word *φύσις* meaning 'nature', and consistent with this the discipline considers phenomena that comprise nature or it investigates nature itself.

As physics today attends to energy and matter it still heeds Aristotle's premise that we may reduce the physical world to one or more basic starting points. Physics is 'reductive', meaning that it searches interminably for smaller objects and more precise explanations. A dramatic example of this direction of enquiry at present is the Large Hadron Collider which intrigues us with the prospect of discovering new, *smaller* particles as the result colliding beams of sub-atomic particles (European Organization for Nuclear Research, 2008).

Physicists usually use the term 'modern physics' to refer to the theory that developed from the early 20th century, particularly relativity theory and quantum mechanics. Modern physics is concerned with the forces that exist between objects and the relationship between matter and energy—as described by Einstein's paradigm. Philosophers and historians of science find that the remarkable advance in physics—insights that most significantly overturned the tradition of thought—occurred earlier, particularly with the work of Galileo and Newton. Heidegger uses the expression 'modern science' in this precise manner and the present article adopts his terminology. He also uses the word 'research' to refer to modern science, this being the leading characteristic of modern science. Accordingly, modern physics/science begins with Galileo and Newton and proceeds with Maxwell, Planck, Heisenberg, Schrödinger, and Einstein. Modern physics did not evolve from medieval physics, and nor did medieval physics evolve from ancient physics. Each of these forms of physics stands independently of the other forms because incompatible world-views constitute their foundation. The bid to understand science by the hermeneutic philosophers of science addresses only modern science in Heidegger's sense (Glazebrook, 2000, 2001; Shaw, 2009, 2010).

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Those engaged in modern science—researchers and teachers alike—forget that modern science began in a struggle to discern truth. Galileo and Newton (nonetheless Heisenberg and Einstein) were consumed in the struggle about truth. Einstein in his 1935 essay, 'The World As I See It', nominates 'Truth' as an ideal that 'lit' his way (Einstein, 1954, p. 9). As mentioned, the explicit involvement of truth distinguishes the hermeneutic philosophy of science from other accounts of science that involve human beings. An analysis of truth provides access to the entities that are involved in physics. What is truth? Heidegger's cardinal concepts of truth are *adaequatio* (truth as correspondence) and *alētheia* (truth as disclosure). It is these concepts that enable us to specify the inner nature of science.

'*Adaequatio*' is truth located in an agreement, or correspondence, between reality and mental or linguistic representations. This includes, for example, the correspondence apparent in 'the sky is blue' (a relationship between 'the sky' and 'blue'), 'blue is a colour' (a relationship between 'blue' and a concept, namely 'colour'), and '2 + 2 = 4' (relationships between abstract concepts). Heidegger dubs correspondence theories of truth the 'traditional' and 'usual' concepts of truth and he considers their exposition in ancient and scholastic philosophy (Heidegger, 1962, p. 257; 2002, p. 6; 2007, p. 280). He finds such accounts of truth undoubtedly meaningful and observes that there are many renditions of the correspondence theory of truth. The generic word Heidegger prefers to refer to this form of truth is the Latin *adaequatio*, because it indicates 'similarity' which implies a human judgement that involves an equation whilst remaining silent on the content of the equations or judgement.

Adaequatio is the notion of truth that we engage when we say something is right or wrong. It is ubiquitous in Western schooling. This formation of truth is the foundation of all school assessment. When teachers 'mark' students work they depend on the correspondence theory of truth. If the student's answer conforms sufficiently to the required answer they receive a tick or praise. Likewise, the notion of correspondence is involved when students conform to school rules. 'The truth is you broke the rule ...', says the teacher with a firm grasp of *adaequatio*. In science, an enduring example of *adaequatio* is 'empirical verifiability', the conformity of a stated prediction to a fact—for example, any statement about a new discovery in astronomy. 'We have discovered that ...' is a declaration that some alleged reality can now be described in words. When gravitational microlensing provides evidence of extra-solar planets, *adaequatio* contends they really do exist independently of ourselves.

Alētheia (truth as disclosure to a human being) is distinctly Heidegger's notion of truth. He allegedly finds it in the writings of ancient and scholastic scholars and calls it the 'traditional' concept of truth. It is the truth inherent in the 'disclosure', 'uncoveredness' or 'unconcealment' of beings. It is the human way of being to abide with this truth and all abidance (human living) with beings (that which we find meaningful) necessarily involves this form of truth. *Alētheia* rests upon the primordial phenomenon of human disclosedness and is inherent in all disclosures of beings including those beings that are the occurrent, physical entities of modern science. Truth as disclosure is an ontological truth and indelible in the complex that is Dasein (the human being involved) and the beings disclosed:

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> *The most primordial phenomenon of truth is first shown by the existential-ontological foundations of uncovering* ... With and through it [Dasein, the human being] is uncoveredness; hence only with Dasein's disclosedness is the most primordial phenomenon of truth attained. What we have pointed out earlier with regard to the existential Constitution of the 'there' and in relation to the everyday Being of the 'there', pertains to the most primordial phenomenon of truth, nothing less. (Heidegger, 1962, p. 263, his emphasis)

Accordingly, *Adaequatio*, the truth of judgement, ultimately presupposes *alētheia*. What is primarily true is the uncovering of beings including Dasein, and this perspective enables Heidegger to say that Dasein is 'in the truth' (Heidegger, 1962, p. 263). Accordingly, there is a difference between seeing the new astronomical object and reading about it. In the former we experience truth as disclosure whilst in the latter it is only words and their correspondence which engages us.

Science involves both the formations of truth, although it has not been obvious how truth is involved in science. In 1664, 22-year-old Isaac Newton, at Trinity College, heads his notebook '*Questiones quædam Philosophiæ*' (Certain philosophical questions). Above the title he writes '*Amicus Plato amicus Aristoteles magis amica veritas*' (Plato and Aristotle are my friends, but truth is a better friend). With this, he borrows an expression from the English physician and natural philosopher Walter Charleton, who in turn drew his inspiration from Plato and Aristotle (Cambridge University Library, 2002; Newton, 1664–65, folio 1; Tarán, 2001, pp. 4, 12). In whatever form the statement appears, it means that truth stands superior to the teachings of any human teacher. Thus, truth is independent of human beings. And yet, truth is also an event of human beings.

The role of truth in Newton's philosophy of science becomes apparent in his *Opticks*, of which Cohen (who translated Newton's *Philosophiæ Naturalis Principia Mathematica* and wrote extensively on Newton), says it is the 'most comprehensive public statement he ever made of his philosophy of science or his conception of the experimental scientific method' (Cohen & Westfall, 1995, p. 127; Newton, 1999). The period of relevant work is that subsequent to his 1672 paper on colours (sent to Oldenburg), and it is a time that 'tells us less about optics than about Newton' who for 'eight years ... had locked himself in a remorseless struggle with Truth', eight years of 'uneaten meals and sleepless nights ... of continued ecstasy as he faced Truth directly on grounds hitherto unknown to the human spirit (Westfall, 1980, pp. 238, 239). Newton's practical engagement with truth did not achieve for him a hermeneutic philosophy of science—nevertheless, it set others on that pathway.

The Hermeneutic Philosophy of Science

The hermeneutic philosophy of science is an intellectual tradition that runs from Kant, to Heidegger, to Heelan. Of course there are other theorists involved, but these three are pivotal. The debates between Ricoeur, Gadamer and Habermas are peripheral to the tradition that maintains a essential role for truth (Murray, 1988, p. 108). All the requisite elements of the tradition are problematics for Kant, Heidegger provides the structure necessary to advance the investigation and begins essential work with his investigations

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into the human being, and Heelan, particularly with his insights into the phenomenology of both vision and mathematics, begins to detail our human involvement in modern science. As this tradition enquires into modern science, it could hardly have begun before there was sufficient development of modern science by Kepler, Galileo, and Newton.

Kant

Immanuel Kant (1724–1804) is a generalist philosopher who spends much of his intellectual energy on the philosophy of natural science. He develops his ideas over a long period of time and it is impossible to discern all of his conclusions in his works (Kockelmans, 1968, p. 13). Kant begins his deliberations in the philosophy of science having been involved in practical and theoretical physics. This begins with his lecturer's (Teske) 'impressive', dramatic, courses on experimental physics (Kuehn, 2001, p. 78). Kant's 1755 treatise, *General History of Nature and Theory of the Heavens*, begins with a 'short outline' of the Newtonian philosophy that Kant says is the foundation of his own deliberations about the formation of galaxies, including the Milky Way. Whilst it is a commonplace for us that the universe has a discernable structure, in Kant's time most people thought the 'random' distribution of the stars in the sky was evidence that there was no underlying structure for much that we see. Kant credits 'an Englishman, Mr [Thomas] Wright of Durham ... [with the] happy step' that shows the stars are not a mere swarm, but are a part of a 'Systematic Constitution of the Universe' (Kant, 1969, pp. 51, 54). This title declares there is order in the stars and planets. Although Kant's 1755 work contains intriguing ideas (for example, that because nothing in nature is balanced the planets do not have circular orbits, and that the movements of the outer most planets in the solar system 'gradually cease'), its importance is that it provides a cosmological model that does not invoke direct divine intervention. Instead, its conclusions derive from purely mechanical natural laws (Kant, 1969; Friedman in Kant, 2004, pp. viii–iv). This rejection of divine intervention in hypotheses about phenomena sets those who follow on the road towards the hermeneutic philosophy of science because it raises the question, why is there order?

In 1756 Kant publishes *Physical Monadology*, which addresses a central issue that continues in the hermeneutic philosophy of science. What is the relationship between mathematics and physical objects? If matter ultimately constitutes of simple elementary substances (physical monads), and these substances exist in space, how can we reconcile their existence with the infinite geometrical divisibility of space? Kant's answer builds on Leibniz's notion that monads have 'point-like' centres. True substances are metaphysical points which, Leibniz asserted, are both real and exact, mathematical points are exact but not real, and physical ones are real but not exact.

In contrast to empiricist philosophers, for whom the philosophy of science consists of an analysis of fundamental concepts and methods of enquiry extant in science, Kant from 1770, with growing confidence, asserts that the philosophy of science is to be concerned with the prior conditions that make science possible at all. The period of this advance which is the birth of the hermeneutic philosophy of science, is that between Kant's inaugural address upon obtaining his professorship the University of Königsberg in 1770 and the publication of his *Critique of Pure Reason* in 1781 (Kockelmans, 1968,

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pp. 9–10). Kant observes that human experience is the foundation of the laws of physics, and he argues that the experience and the laws must be founded upon a regular, discernable structure or framework that enables them to be brought together.

Each of Kant's three accounts of physics (and as we shall see Heidegger's account) differ in what they say about the nature of this foundational structure. In the first book ever committed to a philosophical reflection on modern physics, *Metaphysical Foundations of the Natural Sciences* (1786), Kant argues for a schematism that systematically relates *a priori* conditions (particularly those that involve space and time) to empirical representations. *A priori* knowledge, that which we know independent and prior to all experience, has a structure which we attempt to discern. As Kant says, 'science proper, especially [the science] of nature, requires a pure portion, lying at the foundation of the empirical, and based upon an *á priori* knowledge of natural things' (Kockelmans' translation, Kockelmans, 1968, pp. 19–29). This conclusion is possible for Kant only because earlier he shook off classical metaphysics, the view that the task of metaphysics is to investigate a supra-natural reality that is the site or foundation of God, human freedom, immortality, and all existence. Modern science is now distinctive in philosophy.

A specific topic that engages Kant is the relationship between mathematics and physics. This relationship was an issue at the birth of modern physics, as Galileo wrote vehemently of his adversary:

> ... I can almost hear him shouting in my ears that it is one thing to deal with matters physically, and quite another to do so mathematically, and that geometers should stick to their fantasies and not get entangled in philosophical [scientific] matters—as if truth could ever be more than one; as if geometry up to our time had prejudiced the acquisition of true philosophy [science]; (Drake, 1978, p. 172)

Having decided that physics is concerned only with the laws of the moving forces of matter as given in experience and as mediated for us by an *a priori* framework or schema, Kant is not inclined to allow mathematics to intrude. Consistent with his insights into the nature of metaphysics, Kant argues that mathematics cannot provide insight into the essence of the many kinds of physical force. Moving forces cause motions, and motions (because they relate to space and time) are amenable to mathematical description, yet these descriptions are not the essence of physics.

Heidegger

The second significant person in the hermeneutic philosophy of science is the German philosopher Martin Heidegger (1889–1976). Heelan (1995, p. 579) says Heidegger is not 'well versed' in physics. He did study physics and mathematics at Albert Ludwig University in Freiburg after he abandoned the idea of becoming a priest and Kockelmans' judgement is that 'for a philosopher' Heidegger is 'remarkably well informed about several sciences' (Kockelmans, 1985, pp. 22, 117). His knowledge of physicists apparently does not fetter Heidegger when he says:

> ... contemporary natural scientists, in contrast to scientists working on the level of Galileo and Newton, have abandoned vigorous philosophical reflection and no longer know what the great thinkers thought. (Heidegger, 2001, p. 57)

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The current physicists' lack of self-critique is not a consequence of their 'negligence or laziness' but is 'due to the blindness determined by the destiny of the present age' (Heidegger, 2001, p. 60). Such categorical statements indicate the tenor of Heidegger's views about modern science and, as we shall see, have relevance in science education.

Theorists concerned about the nature of science did not seize upon Heidegger's work. One of the reasons that Heidegger did not initially appear relevant is the way in which the philosophy of science defined itself at the start of its modern tradition, in accordance with the Received View:

> If any problem in the philosophy of science can justifiably be claimed the most central or important, it is that of the nature or structure of scientific theory. For theories are the vehicle of scientific knowledge and one way or another become involved in most aspects of the scientific enterprise. (Suppe, 1974, p. 3)

Those who define the philosophy of science in the exiguous way that this quotation implies will agree with Richardson's memorable statement 'On the longest day that he ever lived, Heidegger could never be called a philosopher of science' (Richardson, 1968, p. 511). Actually, Richardson immediately qualifies his assertion 'But he is a philosopher—an important one—and no genuine philosopher can afford to ignore the problems of science'. The hermeneutic philosophy of science rejects the notion that the nature of theory is the most central, or most important, issue. Heidegger achieves standing as a philosopher of science in the more recent tradition that emphasises the entanglement of human beings and institutions in the scientific enterprise. Heelan nominates Heidegger as the 'key figure' in the emerging tradition (Heelan, 1982; 1997, p. 272; 1998, 2005).

Although a characteristic of Heidegger's work is the extent to which it integrates into a single theoretical structure (his metaphysics) there is an aspect of his work that is of particular relevance in the philosophy of science: there is a schematism, which enables human beings to interpret perceived phenomena. What is the hidden schematism by which human understanding deals with phenomena? As indicated above, Kant earlier sought a schematism that would serve as the foundation of modern science.

Heidegger's philosophy of science first appears cogently in his lecture course of 1927–28, *Phenomenological Interpretation of Kant's Critique of Pure Reason*. It particularly develops in *Kant and the Problem of Metaphysics* (published in 1929). At the end of his lectures, Heidegger refers to the manner in which the 'Kantian architectonic of presentation' makes it difficult to see the essential core of Kant's work, which he says is found in Kant's section entitled 'The schematism of the Pure Concepts of Understanding' (Heidegger, 1997, p. 291). What appears crucial for Heidegger is that the categories (roughly, the concepts that we use to think, which includes thinking in science) cannot be taken as isolated concepts of understanding, because they are all essentially related to time (for example though notions such as permanence, succession, movement, and coexistence). He indicates the way forward to a philosophy of science:

> ... categories belong essentially to the original whole of the pure time-related imaginative synthesis. This it would not do at all to set up an isolated analytic of concepts and then to inquire into their employment in a subsequent part.

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> The question is the following: What belongs to the pure synthesis as such and how do its concrete variations look as regional principles of nature? (Heidegger, 1997, pp. 291–292)

The concrete variations (regional ontologies, ontic disciplines, sciences), which include the discipline of physics, or equally the theory of teaching, are grounded in fundamental ontology, and it is fundamental ontology which unifies Heidegger's metaphysics. Those concerned with the hermeneutic philosophy of science must proceed from his insight into being and categories but away from fundamental ontology, whilst always taking appropriate account of fundamental ontology. As Heidegger says of this:

> The question of Being aims therefore at ascertaining the *a priori* conditions not only for the possibility of the sciences which examine entities as entities of such and such a type, and, in so doing, already operate with an understanding of Being, but also for the possibility of those ontologies themselves which are prior to the ontical sciences and which provide their foundations. *Basically, all ontology, no matter how rich and firmly compacted a system of categories it has at its disposal, remains blind and perverted from its ownmost aim, if it has not first adequately clarified the meaning of Being, and conceived this clarification as its fundamental task*. (Heidegger, 1962, p. 31, his emphasis)

What is the *a priori* foundational structure that enables intellectual disciplines that became our school subjects? That is, what links the pre-theoretical foundation of understanding to the form of understanding that is characteristic of modern science? Heidegger's schema from the *Kriegsnotsemester*, the 1919 War Emergency Semester (KNS), is a sketch that relates the pre-theoretical and the theoretical. He drew this diagram at the end of a lecture to assist his students (student Brecht records the sketch that Heidegger did not include in his own notes, Heidegger, 2000b, p. 186). The sketch indicates what is involved in the hermeneutics *of* facticity and it is an attempt to complete Kant's project (for descriptions of the schema, Kisiel, 1993, pp. 21–24; 1995, 2002). This schema shows the relationship between physics and the foundational ontology of the human being which Heidegger described in *Being and Time*. It helps to explicate the 'central phenomena of factic life experience which is always at once active experiencing and the passively experienced' (Kisiel, 1994, p. 177). It is this theory that relates the life world to the disciplines of science (Heidegger, 2000a, p. 92).

For example, the physicist's every involvement with physics involves a cultivation of the hermeneutical situation that is physics (Heidegger says physics is a particular 'thematization'; 1962, p. 449). Thus, the physicist must move beyond the standpoint of ordinary everydayness (abiding with things as equipment or as objects of contemplation) to take up the particular restrictive stance of physics. The stance of modern mathematical physics which he describes is, in the words of Babich (1995, p. 590). , that which realises a 'perpetual motion machine'. This perpetual motion machine is the construction of institutionalised, experimental projection. This, in turn, is the outcome of a particular hermeneutic schematisation achieved by the human being through, and to reflect, a series of engagements with truth as *alētheia*.

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Heelan

Patrick A. Heelan (1926–) is a member of the Society of Jesus and a leading figure in the hermeneutic philosophy of science. He is a physicist, who for his second doctoral degree undertakes a study of the 'crisis of objectivity' or the 'crisis of realism' in modern physics (Heelan, 1965, p. ix). In schools this crisis shows itself in the view that science is some form of cultural expression. To advance his project, Heelan investigates the 'physical philosophy' of Werner Heisenberg (1901–1976), one of the architects of quantum mechanics. In 1965, with reference to physics, Heelan asserts that there are two worlds with one identical referent. These he casts an observation language and an explanatory language:

> The difference between observation language and explanatory language, then, is not that they deal with different sets of referents, but that they consider the same set within different contexts. One considers them within the context of a World-for-us, while the other considers them within the context of a World-for-things. (Heelan, 1965, p. 177)

This 1965 work—which stays close to the practice of physicists—advances the hermeneutic philosophy of science that Heidegger inaugurates. Heelan says the task of the hermeneutic philosophy of science is to:

> ... explore at a philosophical level the sense in which interpretation is at work in all of physics and other experimental science, and to contribute to opening up a new philosophical—and metaphysical—perspective on physics that was possibly foreshadowed by Einstein and Heisenberg in their attempt to make sense of their discoveries. (Heelan, 1998, p. 273)

As mentioned earlier, Kant sets this very task himself in relation to Newton. At the start of his major work on the philosophy of science and space perception, Heelan says the method of enquiry is 'phenomenological and hermeneutical':

> ... what we know is not limited to the deliverances of a unique privileged perceptual framework constitution an absolute transcultural empirical basis for all knowledge, and we can have access to a multiplicity of possible perceptual horizons, both of the Euclidean and of non-Euclidean structure, ground both in unaided perception and in the use of special technologies ('readable' technologies) invented using scientific theories. (Heelan, 1983, p. 2)

Whilst Newton's mechanical physics confines itself to the perception of moving objects and involves Euclidean geometry, modern physics is now engages with a number of geometries and the mathematical determination of objects whose nature and very existence is highly problematic. The advent of fractal geometry provides exciting prospects: for example, biologists use recursive algorithms to model 'many objects in nature including trees, coral formations, cumulus clouds, and coastlines ... mammalian lungs and hearts, as well as many other anatomic structures' (West, Novaes & Kavcic, 1996, p. 269). The relationship between mathematics and nature in biology is precisely that which was established in modern physics:

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> … of course there cannot be true fractals in nature, only in mathematics, as a true fractal must scale to infinity. (Iannaccone & Khokha, 1996, p. 11)

Measurement is the contrived act designed to render publicly verifiable information about the state of a physical system as shown though instrumentation (elaborated in Heelan, 1977, pp. 31–32).

Heelan asserts 'scientific states of affairs are given in an originary way to the experiencing scientist during the course of scientific observation' (Heelan, 1977, p. 26). Heidegger uses Kant's word 'apprehension' to refer to this more foundational form of 'perception' which posits a public reality and involves foremost disclosing truth, *alētheia*. However, truth within apprehension is not all that modern science entails. Science also involves *adaequatio*, truth as correspondence, in order to structure the situation in which the event of disclosed truth will occur. Whilst we may say this event of disclosure is 'public' (to indicate that it is available to all and known universally), it is actually an event that occurs for an individual scientist. As we will find in Part II, the challenge of science education is to engage the student with *alētheia* and maintain an understanding of *adaequatio*.

Part II: Teaching Science as Truth

Introduction

Part I introduced the hermeneutic philosophy of science as the tradition of Kant, Heidegger and Heelan. It indicated how Newton grappled with relevant issues and argued that Kant begins the tradition when he rejects divine intervention and asks why there is order in the heavens. Heidegger's two formulations of truth enable us to obtain insight into how science constitutes and endures. Heelan elaborates this with his work on perception and alternative geometries. Science,in this philosophy, is not an artefact of culture or any kind of group phenomena. Nor is gender relevant. It is a formulation of truth available to every ordinary human being. The achievement of truth as an event of disclosure is, as Kant understood a distinctly human event, and, as Heidegger understood, an event which in modern science reveals to human beings unsuspected aspects of reality.

The present account of the *hermeneutic philosophy of science* contrasts with that of Eger which is influential in some schools (Eger, 1992, 1997, 1999; Shimony, 2006). The expression 'Heidegger's hermeneutic philosophy of science' (or just 'Heidegger's philosophy of science') implies an unequivocal stance in relation to hermeneutics, truth, perception, and reality. As Part I indicated, the integration of ideas about these topics, as a description of what science is in itself, emerges from the tradition of the thought which runs from Newton, to Kant, to Heidegger, and which subsequently becomes the foundation of Heelan's conclusions about science which he draws from his work on perception. This is the tradition which Kockelmans and Babich discuss particularly. If there is a near alternative to Heidegger's hermeneutic philosophy of science it is expressed in the work of Gadamer, Habermas, Ricoeur, and Eger. This is an alternative hermeneutic philosophy of science for those not attracted by truth. For the historical background to the two traditions see Murray, 1988.

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The Implications for Science Education

The hermeneutic philosophy of science offers much to science teachers and curriculum developers. It satisfies many of the requirements that scientists and teachers require for their discipline (Shaw, 2005). It conceives of reality in a manner that allows its limited, but progressive, investigation by human beings. Thus, it renders historical science non-historical, which is to say modern physics is not a cultural artefact, nor are the practices of bench scientists today *in their essence* derived from the work of predecessors. According to Heelan, the principal supporters of 'historical science' today come from the social and behavioural sciences, and he cites a behaviourist's book, *Beyond Freedom and Dignity*, as an exemplar (Heelan, 1977, p. 10; Skinner, 1971).

It is convenient to draw specific conclusions about the implications of the hermeneutic philosophy of science for science teaching by addressing the three *characteristics* of modern science which Heidegger discerns (Heidegger, 1977a, p. 118). Science: (1) restricts that into which it may enquire to very specific kinds of beings, (2) arranges things to force a hidden reality to reveal something of itself, and (3) generates specialisations (institutional and managerial structures) as more of reality is forced to reveal itself to us.

1. Restrict that into which you may Enquire—Decide Reality

The essence of research consists in the 'fact that knowing establishes itself ... within some realm of what is, in nature' (Heidegger, 1977a, p. 118). The 'realm' establishes the nature of the truth that scientists will admit to their discipline. For example, the scientists who operate the Large Hadron Collider know what counts as a particle before they operate their machine. They will recognise what they seek when they see it, because they already understand the realm of physics. Anything that falls outside of this realm will not enter into their scientific papers, although it may enter into their autobiographies. Einstein describes how scientists accept their predetermined reality:

> To him who is a discover in this field, the products of his imagination appear so necessary and natural that he regards them, and would like to have them regarded by others, not as creations of thought but as given realities. (Einstein, 1982, p. 270)

In *Being and Time*, Heidegger mentions Einstein's theory and refers to nature as it is 'in itself' (Heidegger, 1962, p. 30). He elaborates (rather more cogently) in his 1938 lecture, *The Age of the World Picture*, where he turns from the metaphor of the tree and nature to speak of a 'ground plan' and the 'sphere opened up'. Subtly, this makes his account less suggestive of an individual scientist and more suggestive of an intellectual discipline. The opening of the sphere is the fundamental event in research and those involved in physics are obliged to adhere precisely to this ontological understanding in their practice—they are obliged to abide with that which allows nature manifest. Physics is, in general, the knowledge of nature, and, in particular, the knowledge of material corporeality in its motion; for that corporeality manifests itself immediately and universally in everything natural, even if in a variety of ways (Heidegger, 1977a, p. 119).

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The aspects of the ground plan, suggest pedagogy. Students already bring expectations about corporeal reality to the classroom but there is scope to make the relevance of this more specific. The corporeal moves in waves and this pattern is available on the seashore. Feynman singles out this phenomenon to assist his students' entrée into physics. As a biographer says, he places his students:

> ... mentally at the beach . 'If we stand on the shore and look at the sea,' he said, 'we see the water, the waves breaking' ... Nature was elemental there, though for Feynman elemental did not mean simple or austere. The questions he considered within the physicist's purview—the fundamental questions—arose on the beach. (Gleick, 1994, p. 22)

Unerringly, the master physics teacher brings his students to the very phenomenon that displays the first characteristic of modern science: the 'mental' sphere (ontological space) that allows for physical objects that move.

Another aspect of the ground plan that suggests pedagogy relates to mathematics. How mathematics enters into the physicist's engagement with reality is important. The Greek expression '*ta mathēmata*' refers to a 'deep' sense of mathematics, which indicates that those involved know something in advance of their use of mathematics (Heidegger, 1977a, pp. 118–119). To see this we might reflect that we cannot discover through mathematical reckoning what mathematics itself is (Heidegger, 1977b, p. 177). Thus, when we measure something, we already abide with an understanding that what we are measuring is the kind of thing that we can measure (within the sphere). We cannot measure ghosts and gods, they are not within the sphere, and we exclude them from physics. Consider one further aspect of measurement. The ruler is technology designed to measure. We expect that every marked centimetre is the same as every other centimetre regardless of the technology involved. Yet it is not, as we all know. We know this because we bring to the physical centimetre our own 'mental conception' of a centimetre, which is the one that appears in all mathematics. Students need to appreciate the ontology of mathematics, before it becomes involved in science. Rightly, this reminds us of Heelan's work mentioned earlier.

Heidegger develops other aspects of the ground-plan of modern physics which hold implications for pedagogy. For example, that natural science itself deals only with 'present nature', and thus the natural sciences admit 'a historiographical consideration of their own past merely as an addendum' (Heidegger, 1994, pp. 46–47). Another aspect is the nature of 'logic' that science and everydayness involve, the 'logic of logic' and the logic of categories that is necessary for science to construe objects (Crowell, 2005, pp. 60–61).

In the terminology that Heidegger largely abandons after *Being and Time*, the 'aspects' of the ground-plan are *equiprimordial*. Which is to say each scientist's understanding of them is basic (primordial), equal (non-hierarchical), and mutually interdependent. In the tree analogy of truth and metaphysics, they constitute in a flow (sap/truth) from the roots of the tree to the branch that is physics. The consequence of this is that students must grasp the first characteristic of modern physics holistically, in a gestalt moment. (The moment is within the second characteristic of research described below.)

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Both Galileo and Newton were troubled that they came to abide with an equiprimordial complex that is difficult to explain to others without lamely saying it is a 'worldview'. This is one reason why it is difficult to initiate students into the disciplines of science: much has be in place before you proceed to the second characteristic of research, and students do not see the point of it all until they subsequently abide with *alētheia*. As Heidegger might say though his latter metaphor: there is a 'leap' required to achieve science and you must prepare for that moment (Heidegger, 1987, p. 43) .

2. Force Revelations

We now come to that characteristic of modern science which is most familiar to science teachers. Modern science involves the method of 'decisive superiority', whereby scientists entrap and secure that part of the Real that is within the available sphere:

> The methodology, characterized by entrapping, securing, that belongs to all theory of the real is a reckoning-up. ... To reckon, in the broad, essential sense, means: to reckon with something, i.e. to take it into account; to reckon on something, i.e. to set it up as an object of expectation. (Heidegger, 1977b, p. 170)

What Heidegger indicates in this quotation is that the procedures of science force an aspect of reality to reveal itself to us (each of us) individually. The event of revelation is the event of truth, a kind of 'reckoning-up'. In summary, when the circumstances are correct (*adaequatio*), the characteristic truths of modern science (examples of *alētheia)* constitute in a manner that involves the individual human being, the equipment and the Real.

There are two aspects of the event of modern science to consider: (1) that which involves *adaequatio* and which we associate with the methods of science, and (2) that which involves *alētheia* and which is the distinctive personal revelation of the Real in science. In a sense this is the 'goal' of the first aspect. Science in schools is much concerned with the first and little concerned with the second. The present article seeks to reverse this state of affairs.

2.A With regard to the first aspect: Heidegger refers to the familiar method of enquiry in science—the procedure of prediction by way of hypothesis, measurement, comparison, and the testing of laws. This characteristic of modern science encourages us to see the virtues of the scientist—she is orderly, honest, sincere, systematic, pedantic, open-minded, reliable, collegial, skilled, and diligent. As these virtues are also acclaimed in other disciplines and human purposes, their presence encourages some to conclude that modern science is essentially the same as those disciplines. With regard to *adaequatio* this may be the case, but not as we shall see with regards to *alētheia*.

Newton displays the virtues of science—and thus his belief in *adaequatio*—when he concludes his famous letter to the Royal Society (see Figure 1). He is confident that if others establish the right circumstances they will achieve the result that he achieved.

The achievement of correspondence or adequacy or similarity in modern science is an ongoing challenge. Newton struggles with *adaequatio* in his early work on optics. For example, in his manuscript 'Certain Philosophical Questions', Newton writes a word to

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> This,I conceive, is enough for an Introduction to Experiments of this kind ; which if any of the *R. Society* ſhall be ſo curious as to proſecute,I ſhould be very glad to be informed with what ſucceſs: That,if any thing ſeem to be defective,or to thwart this relation, I may have an opportunity of giving further direction about it, or of acknowledging my errors, if I have committed any.

Figure 1: Extract from Newton's Letter to the Royal Society. (Newton, 1671/2, p. 3086)

	white	& cdsr	blew	y^{n} e	~~yello~~ Red.
	black		blew		~~Greene~~ blewer.
	blew		black		Greene, or Red
	black		red		blew.
	red		black		redder.
If abdc be	red	& cdsr be	white	y^{n} eodc is	blew.
	white		red		redder.
	white		whiter		blew.
	whiter		white		redd.
	black		blacker		Greene or darke red
	blacker		black		blew.

Figure 2: How is truth involved when Newton indicates his uncertainty in his notebook? (Diplomatic text, Newton, 1664–65, folio 63)

describe a colour and then changes his mind (crossed out the text) and he records uncertainty about colours (green and dark blue). See Figure 2.

If Newton was fatigued, say, on the first occasion and thus mistaken about the correct word to associate with the colour when he wrote 'yellow' and 'green', we might reason that Newton's apprehension was consistent with regards to *alētheia*, but not with regards to *adaequatio*. We are not inclined to say that the colour he observes changes. We are inclined to repeat Newton's demonstration with a prism and a beam of light—to name of the colour for ourselves. All questions about the recording of observations are questions that depend on the correspondence theory of truth.

Consider a more recent example when *adaequatio* is at issue, a discussion about the errors inherent in the optical observation of binary stars. A physicist tells us that in all cases, long-term variations such as those visually observed as binary motions orbits are the result of measurements over a long interval of time and that these measurements 'have to be combined' (Heintz, 1971, p. 133). He sets out the sources of error (it is necessary to take the word of the observer because visual observations leave no re-measureable records, faint pairs of stars and close pairs of stars present a particular challenge), and the techniques of amelioration (corrections to micrometer observations,

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the use of sufficiently long and homogenous data that enables systematic errors to be determined, rejecting data that falls outside of a specific parameter, and the use of reversing prisms). Such discussions display truth as *adaequatio*. The observers must be truthful in the records they make (there must be correspondence between what they see and what they write), skill is involved particularly with close pairs and faint pairs (there is a judgement about the actual situation, and some are more adept at making such judgements than others), to remove systematic errors in long-run data it is necessary to adhere to the notion that there is a correct measurement to which the actual measurements must be brought by way of mathematical technique).

Science teachers know the difficulties inherent in making demonstrations 'work' and the importance of consistent method. Students know that if they do not adhere to the requirements of the method, they will not achieve adequate results. The hermeneutic philosophy of science suggests to them that they understand this through the correspondence theory of truth.

In summary, there are three arenas in which truth as correspondence, *adaequatio*, holds relevance in relation to science education. First, truth is involved in the practical work required to establish and maintain the institutions of modern physics, which includes research institutions, universities, and schools. Science administrators, managers, scientists, science teachers, science technicians, and science students are all subject to rules that facilitate their institutions.

Second, correspondence formulations of truth abound in all facilities that convey information from one person to another. Lecture theatres, textbooks, and academic journals all depend on the correspondence theory of truth. This arena particularly, although also the first arena, participate in the covering-over of the essence of modern physics. Teachers who adopt the hermeneutic philosophy of science as their philosophy of science will be able to do much to counter such concealment of modern physics.

The third arena for the involvement of truth as correspondence is that which relates to preparations for *alētheia* (2B below) Teachers must teach science students to plan, to organise, to construct, to use equipment correctly, to observe, and to calculate. Such activities involve standards that constitute much of the ontic disciplines of science. The requirements include such things as the need to keep the workspace clean, honesty, physical skills, and the mastery of specific techniques such as those of error management. The correct use of equipment entails standards that are universal for those who participate in science. The standards of science do not derive from moral theory or the conventions of civil society. They derive from the bestowed character of reality which presences in the event of *alētheia* (2B below). If the physics demonstration does not produce disclosed truth it fails not because of some inadequacy of nature, but because of a student's failure with respect to *adaequatio*. Reality is unforgiving, but always available to respond to further efforts.

2.B We now turn to the second aspect, the human abidance with the disclosed truths of science. These make science uniquely a human activity because only human beings can experience truth. We may say the human being is *in* the truth or *with* the truth. Perhaps this is similar to the sense of truth that Jesus called upon when he said, 'I am the way, the truth, and the life' (John 14).

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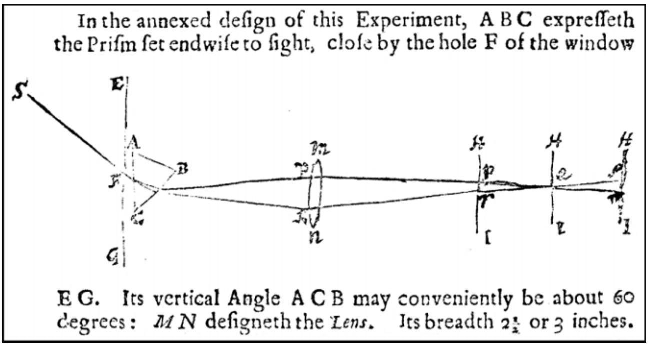

Figure 3: Extract from Newton's Letter to the Royal Society. (Newton, 1671/2, p. 3086). The same diagram is in his draft dated at Trinity College, February 6, 1671/2 (465v, Ms 3970.3). [The quality of this diagram is in accordance with the electronic version.]

Consider this example from Newton's optics, early in 1666. Where do we locate disclosed truth, *alētheia*, in Newton's demonstration with a light beam, a prism, and a screen? He begins his account of the demonstration: 'I procured me a Triangular glass-Prisme, to try therewith the celebrated Phænomena of Colours' (Newton, 1671/2, pp. 3075–3076).

Consider the situation as it is for Newton and our students (see Figure 3). Newton and the students must darken the chamber/laboratory and have a 'small hole' in the window/screen. The light from the Sun/lamp passes through the hole, and falls on a wall/screen. Newton and the students force reality/nature to reveal itself.

It is pertinent that Newton's account of what occurs is personal. He does not record dry 'findings' or 'results' until later in his letter, but initially he writes—remember this is five years later and he is writing to the Royal Society—of his excitement and perplexity. Of the refracted image on the wall he says in his first paragraph, 'I became surprised to see them in an oblong form; which, according to the received laws of Refraction, I expected should have been circular'. Then follows an account of various attempts, successful and unsuccessful, to enquire into the enrapturing image. Students may achieve exactly the same abidance that Newton achieved, and indeed they do in many school laboratories.

Elation is a good indicator of disclosed truth. So is certainty. When you observe something that is stunning, distinctly personal, emphatic and incontrovertible, you abide with truth. Not every example of disclosed truth is within science. Only when the ground-plan is that described in 1, and the methods are those described in 2A, is the disclosure within modern science. Disclosures that are within modern science are the *forced* disclosure of an aspect of nature.

In the example cited above, school students are sometimes confused about what is the significant event. They see the colours produced by the beam of light and the prism, and that is impressive. If the student says, 'that is pretty', they have not adhered to the ground-plan of physics. For Newton, the consequential truth is the relationship between the image and mathematics. He forces nature to show that it conforms to geometric shapes and ratios. Specifically, the image is a rectangle, and the ratio of the sides is 5:1. With this, optics enters the era of modern science. The history of optics is now irrelevant, for the truth of optics is available to every human being. In Newton's words:

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> It was at first a very pleasing divertisement, to view the vivid and intense colours produced thereby; but after a while applying my self to consider them more circumspectly, I became surprised to see them in an oblong form; which, according to the received laws of Refraction, I expected should have been circular. (Newton, 1671/2, p. 3076).

> Comparing the length of this coloured Spectrum with its breadth, I found it about five times greater; a disproportion so extravagant, that it excited me to a more then ordinary curiosity of examining, from whence it might proceed. I could scarce think ... . (Newton, 1671/2, p. 3076)

Unless students are prepared (which requires truth as correspondence, 2A above) they will not come to abide with the truth of disclosure that intoxicated Newton. Once Newton, or the student, develops work habits and skills with light, prisms, and observation, he achieves a situation where the instrument, the procedure (including prediction and measurement), *and the disclosure* constitute a single embodiment. In experimentation the context of disclosed truth is always apparent:

> ... experimentation in the fullest sense involves the possibility of a human subject embodying himself in instrumentation not only for the purposes of observation, but also to create that context, physical and noetic, which is the condition of possibility for the scientific object to manifest itself in observation. (Heelan, 1977, p. 34)

The scientific objects (disclosed truths) that Heelan refers to are achieved in science education though demonstrations.

Demonstrations perpetuate modern science. Students do not enter into scientific truths when they develop and test their own hypothesise. Because demonstrations—and not student-inspired experiments—are essential to the continuation of the disciplines of science, it is impossible to overestimate the importance of the science teacher in the perpetuation of scientific truth. It is through their own involvement with phenomena that students abide with the essence of science. For modern science to presence it must hold its foundation in truth, and it is the science teacher who provides students with access to *adaequatio* that enables the event of *alētheia*.

The event of modern physics occurs within a demonstration. The student deliberately manipulates equipment to abide, or to dwell, with the very beings that engage others. Modern physics, of and in itself, in its essence, is not experimental. The aim is not to produce and prove, or disprove, an hypothesis. An hypothesis is always an assertion that holds forth *adaequatio*. Experimentation may be a road to discovery, but it is not a mandatory or dependable path. The pragmatic, pluralist, and relativistic theories that minimise the importance of truth, or deny truth, emphasise procedures that physicists may adopt, in original discovery. These procedures of enquiry are not essential to physics. The existential analytic, Newton's ontological biography, suggests that he physically engaged with equipment until the phenomena eventually appeared in a dramatic moment, *alētheia*. Once reality reveals more of itself to someone, humanity partakes of the opportunity the method affords.

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The construction and testing of student hypotheses diverts attention away from the reservoir of experiences that involve the *alētheia* of modern science. Students can share in the truth of science, but they are highly unlikely to stumble upon it. At all times in the science lesson, the teacher must know precisely which disclosure is at issue, and teach towards that truth.

The previous section introduces Heelan's work on the equiprimordial complex student-equipment-mathematics-truth-reality (Heelan, 1983). It is possible to illustrate how teachers might move their students towards the event of truth with a simple example. Most science teachers have presided over the class visit to an astronomical observatory. Often on such visits the telescope is set on an object of significance, say Saturn or Jupiter, and students in turn peer though the eyepiece and see the object. This is an intense, memorable experience for students and it does motivate them towards the study of science. However, commonly the students are not given the opportunity to experience the truths of modern science. To achieve the unique truth of modern science, the teacher should place the telescope out of focus for each student. Thus, the student must engage with the equipment to bring about the event of truth (that is they must focus the telescope and look at the critical object). When the student has the opportunity to interact with the instrument they can force a previously hidden aspect of nature to reveal itself. Further, the student can then in a rudimentary way, but still usefully if the goal is to gain the insights of modern science, measure the rings of Saturn or the distance of the moons from Jupiter. Students sometimes invent the units Saturn-widths and Jupiter-widths to facilitate such measurements. Instrumentation and measurement (even if it is only a first approximation) are essential to the truth of modern science and without these elements in the experience the student experience is likely to be another formation of truth. For example, we hear some say 'it's pretty'.

3. Specialise

As scientists work, they reveal new aspects of the Real and develop methods that force these beings to reveal more about themselves:

> This having-to-adapt-itself to its own results as the ways and means of an advancing methodology is the essence of research's character as ongoing activity. (Heidegger, 1977a, p. 124)

The engagement with these unmasked beings may require new resources, specialist management, skills, experimental arrangements, and training. In response to this situation the disciplines of science establish sub-disciplines then sub-sub-disciplines and the emergence of specialities shows in the literature of the discipline (for example, Small & Crane, 1979). Science is an ongoing activity, and as the subject matter becomes refined institutions restructure to provide the human and physical resources necessary. We see examples in the science programmes of the National Aeronautics and Space Administration and the Large Hadron Collider. In biology the same demands are illustrated in the human genome project and the work of James Dewey Watson (McElheny, 2003).

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This characteristic of science—its escalating demand for resources—enables us to proffer career advice to students. Specialise as quickly as possible and develop practical skills within a research programme. Select for yourself an area of specialisation that will differentiate in your lifetime.

Research institutions require recruits for science-work and these people must be reliable, disciplined, and responsive to instructions (all the province of truth as correspondence). Reasoned advice is available on how physics educators in universities might advance students in this circumstance (Stith & Czujko, 2003). The planning aspects of institutions themselves and the planning of science-work within institutions, is vital. The science manager is necessarily a part of modern science. The implementation of plans requires a certain kind of individual, one who works well with others, can concentrate on exacting, repetitive work, and who above all is dependable. For the vast majority of people involved, the work is not glamorous or particularly intellectual. Science education produces individuals for the machinery of science—employees who are exceptionally fortunate if they ever experience *alētheia* in their work.

A further implication of the third characteristic of modern science is that for students it 'covers over'—hides or obscures—the essential truth that constitutes in the first two characteristics. Students find it difficult to see science itself when the needs of institutions and technology dominate science lessons. National education policy also contributes to this effect (de Alba *et al.*, 2000, p. 113, suggest examples). In educational institutions, timetables and other procedures of communal life are in the foreground. Most consequential in this regard, because of its pervasive negative effect, is the school and university examination. *Adaequatio* smothers students who learn science just for the purposes of examinations. Science remains a mystery for those students—as diligent as they may be—who never experience the event of truth, *alētheia*.

The third characteristic of modern science was not always so prominent. Galileo and Newton worked alone during their long periods of productive work. They engaged *alētheia* and *adaequatio* without the distractions apparent in modern classrooms and research institutions. By engaging students in the perplexity of Galileo or Newton, science teachers can establish circumstances favourable to the gestalt moment that enables students to abide in truth with modern science. Galileo's work with pendulums, or his attempt to show the inadequacy of Aristotle's account of falling bodies, and the failure of his experiments with falling objects, can lead students to consider Heidegger's first two characteristics of modern science. It is best if students abide with the disclosures of modern physics by way of their practical use of apparatus of their own construction. Sobel (1999, pp. 19–21) gives an account of Galileo's work that is sufficient to construct lesson plans.

The third characteristic of science may distract educators who must make decisions about curriculum. The introduction to the present article alludes to this. The influence, credibility, and esteem of institutions today associate with science itself in the minds of students, the public, and curriculum planners alike. Many students first encounter science as an aspect of an institution, usually a school. Institutional arrangements influence the way students' perceive the discipline. They see physics as a time-tabled event, and watch as physics attracts resources and associates with persuasive institutions such as the National Aeronautics and Space Administration. With this entrenchment in

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institutions, few curriculum planners are inclined to question the nature of science or its foundation in the human beings involvement with truth.

For all that, it is impossible to obliterate the truth of science. As long as there are human beings to force nature to reveal itself—to achieve the disclosed truth of modern science—modern science will endure as a human potentiality.

Conclusion

Science teaching always involves the projection of a philosophy of science. That projection will be confused if the teacher is confused about the nature of their subject. If teachers adopt a positivist or constructivist account of science their justification for science education will primarily be the utility of science. This stands in strong contrast to a justification that involves truth.

This article attends to a particular conception of modern science. It is Heidegger's concept and truth is essential to that concept. Modern science begins with Galileo and Newton and it is not a continuation of earlier traditions such as those of Greek or Medieval science. Newton deliberated on truth and the intellectual tradition which develops his problematic moves particularly from Kant, to Heidegger, and to Heelan. Similar notions of science, sometimes also called 'hermeneutic' or 'phenomenological' are available and have been brought into science education, but they tend to underplay the importance of truth.

As teachers in Western countries must now teach about the nature of science, as well as science itself, they face the challenge of philosophers. However, if this results in the restoration of truth in science education the future looks bright. When science teachers can establish their claim to truth they will transcend the levelling effects of modernity, and stand against the constructivists and theorists of culture who have for the moment captured science. What is more important, the essential role of science education in the perpetuation of science will become obvious and teachers will inspire their students in the same quest for truth that engaged Newton. For science teachers the immediate challenge is to engage with a new discipline as they seek to answer for themselves and their students the enduring question, what is science?

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