JUST HOW DOES SCIENCE WORK?
THE SCIENTIFIC METHOD AND KS4 SCIENCE

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Abstract

The new programme of study for KS4 science has, as an underpinning approach, ‘how science works’ (HSW). This paper reports on some small scale research into trainee teachers’ understanding of the scientific method and definitions of key terms in science that relate to HSW. After a brief examination of aspects of the history and philosophy of science and approaches to the scientific method, the paper documents the results of a questionnaire put to 25 trainee secondary science teachers. Respondents were asked to provide an account of their understanding of the scientific method and definitions of terms such as facts, theory, law and hypothesis. Results from this research shows that there is no commonality of understanding of the scientific method and varying definitions of key terms that reveal misconceptions about the actual status of theories and Laws in science. The implication of this research is that a better approach to the teaching of HSW must be developed that includes agreed aspects of the scientific method and revised terminology that removes ambiguity from the definitions of key terms in science.

Introduction

In September 2006 new orders for the national curriculum Key Stage 4 science orders came into force. At the heart of this revised programme of study is the notion of 'how science works' (HSW). This idea, as defined by the Qualifications and Curriculum Authority (QCA, 2006) *"includes (the) scientific method and the way scientific knowledge develops."* Central to this, according to the QCA, is the development of ideas and theories and 'how science works' will focus on how evidence gathered by experiment or investigation can be creatively used to either support or refute ideas and theories. In considering this grass roots change to how science is taught at GCSE we must necessarily consider aspects of the philosophy of science, what we mean by science and how any accepted notion of 'The Scientific Method' may fit into a school based science curriculum. In implementing the changes to KS4 science, it would be reasonable to assume that the notion of 'how science works' has an agreed definition and that those terms subsumed into HSW, such as facts, theories, laws and hypotheses are also subject to commonly agreed definitions. To test this idea of a commonality of approach to HSW, some small scale research was undertaken using a cohort of PGCE science trainees reaching the end of their training year. The research was designed to ascertain whether graduates in science from a range of disciplines have common ideas and definitions of key terms such as theory, law, fact and hypothesis and a common understanding of 'the scientific method'.

Science as a branch of learning

Definitions of science characterise it as the process of acquiring knowledge and understanding of the natural world, or as a way of arranging ascertained knowledge (Thompson 1995 p.1236, Walker 1999 p.1020). For a branch of learning which seeks to explain the billions of possible observations that nature provides and that people make day in and day out it is not surprising that this holistic, inclusive term 'science' is subdivided into many distinct and not so distinct disciplines. The main 'sciences' of biology, chemistry and physics are the three traditional school-based curriculum areas; these also include aspects of geology and astronomy. For the purposes of this paper, biology, chemistry, physics, geology and astronomy will be referred to as the 'natural sciences'. As a student progresses into undergraduate and postgraduate degree level study, the range of sciences explodes, with numerous modular routes leading to the award of Bachelor of Science (BSc) and yet further specialisation at Master's level (MSc) leading to highly specialised doctoral studies. The study of psychology is also now included under the umbrella of 'science' by the QCA. For the purposes of this article, psychology, alongside technology based subjects such as electronics are not included within the suite of subjects called 'natural sciences'

The notion of a Scientist

While science may be defined - albeit simplistically - as the acquisition of knowledge of natural phenomena; the notion of what a scientist is has also briefly to be explored. Studies of pupils' perceptions of science and scientists using a DAST (Draw-a-Scientist Test) activity, have typically shown that they are often driven by stereotypical images consisting of white, male, middle class characters, often grey-haired, balding and with glasses (Buldu 2006, Quita 2003). Yet it seems that while these images may contain references to the tools of science, such as the inclusion of scientific instruments to help reinforce the image of a scientist e.g. a microscope or test tubes, the notion of how scientists work or operate and how they develop understanding of the phenomena they observe is absent. For most children, HSW is dominated by the notion of the scientist working in a laboratory. This is reinforced by a pupil's own experience of science at secondary school level where the activity of science or science lessons almost always takes place in a laboratory setting. Furthermore, the lack of practical opportunities for pupils and the declining quality of laboratory provision has been identified as contributing to the lack of uptake of science at post 16. In Its evidence to the House of Lords Select Committee on Science and Technology, the Association for Science Education (ASE) stated that *"practical work has become routine and uninspiring so that, rather than engaging students with the excitement of science, such experiences contribute to students considering science as 'boring'."* (ASE 2006, p10). Furthermore, it paints a damming picture of the current state of school science laboratories as unfit for the purpose of teaching science in many cases. Even where some refurbishment and investment in upgrading facilities has taken place, the results do not always meet the demands of teaching science that will fulfil the programme of study requirements (ASE 2006, p. 11). The assumption from reading the ASE evidence is that the most effective science is taught in a laboratory setting and through a practical based curriculum. This view is also endorsed by the National Science Teachers Association (NSTA) of North America *"Laboratory experience is so integral to the nature of science that it must be included in every science program for every student."* (NSTA, 2006). This is not necessarily how science, or indeed how scientists, work on a day to day basis. Although the practical, laboratory based, experimental basis of science cannot be denied, the degree to which all scientists undertake day to day practical and experimental work to further their knowledge and understanding is something which cannot be easily measured. The theoretical physicist spends much of his or her time developing mathematical models to explain known phenomena. The astronomer is a largely observational scientist where the chance to set up and 'run' an experiment is limited by the nature of the phenomena under study, phenomena that happen vast distances away from Earth and on a huge scale, too big for conventional laboratory study. The ASE and NSTA acknowledge that the term 'laboratory' can be limiting. They include reference to working in the environment and working in the community as equally valid 'practical experiences'. There is, however, in both organisations a seeming lack of consideration of the notion of science as a non-practical endeavour, for example the philosophy of science; the process of deduction, induction and inference as logical processes and the benefits instruction in the process of logical argument may have in improving pupils' understanding of HSW and, more specifically, how scientists work. The notion of the scientific method, though implied in the curriculum, for example in 'Investigative Science' the first attainment target of the national curriculum, is neither fully explored nor expanded upon explicitly as a theoretical underpinning to HSW, yet 'scientific method' is specifically mentioned in the QCA definition of HSW (QCA, 2006).

A Brief History of the Scientific Method

A full work on the various influences and origins of the scientific method, by looking at a comprehensive view of the history and philosophy of science, is beyond this paper. Three periods may be considered as defining in the history of science; the ancient Greek philosophers and their attempts to explain science from a naturalistic standpoint; the Baconian revolution in science and the development of inductive reasoning and the major developments of the twentieth century with the work of Thomas Kuhn, Karl Popper and Paul Feyerabend.

The Greek Naturalistic Movement: Thales and Aristotle

The Greek philosopher Thales of Miletus (circa 624 BCE - 546 BCE) is often credited as an originator of the scientific method (Williams 1994, p.475, Ronan 1984 p.67-68) and a founder of the school of natural philosophy. Rather than rely on a supernatural explanation of observed phenomena, i.e. the causal explanation for everything being 'The Gods', Thales and the Greek natural philosophers, searched for naturalistic explanations. For Thales there must have been a primary substance or primary principle from which all things originate. His conclusion was that this primary principle was water. His problem was explaining how everything originated from water and how, eventually, everything returns to water. His answer was that the Earth, as either a disc or cylinder 'floated' on a universal sea of water (Ronan 1984 p.68). To explain how the Earth floats on this cosmic ocean, he hypothesised that it had properties similar to that of wood. Miletus, a Mediterranean coastal town, would have had a harbour and, most likely, wooden ships sailing in and out all the time. It is possible that seeing how 'heavier than water' wooden ships could float on the sea prompted Thales' ideas that the earth, to which he gave properties similar to wood, could then float on a cosmic ocean. Indeed the region is also well known for its volcanic activity and the observation of lighter than water rocks, such as pumice stone, common in Mediterranean areas, may also have prompted Thales' notion of a lighter than water Earth.

Some 200 years after Thales, Aristotle (384 BCE – 322 BCE) - one of history's most prolific natural philosophers - made countless observations of nature, especially the habits and attributes of plants and animals and focused on categorizing things. He also made many observations on the large-scale workings of the universe, which led to the development of a comprehensive theory of physics. His method of working included the implementation of questions and answers in order to arrive at 'truths' or axioms. He applied this logical method at deriving 'truths' to the many and varied observations he made and developed 'laws of reasoning' to arrive at conclusions about the nature of his observations and, more importantly, explanations for those observations. The aim of Aristotle's written works, known collectively as the *Organon* was to develop this universal method of reasoning by means of which it would be possible to learn everything there is to know about reality. Aristotle's book "*Categories"* produced the description of particular things in terms of their properties, states, and activities. His works, "*On Interpretation, Prior Analytics, and Posterior Analytics"* examine the nature of deductive inference, outlining the system of syllogistic reasoning from true propositions that later came to be known as categorical logic. His philosophical approach had a long lasting influence on much of Western scientific thought and processes.

The Scientific Revolution

Sir Francis Bacon (1561 – 1626) is often credited as one of the prime figures of the so-called 'scientific revolution' (Ronan 1984, Williams 1994, Marks 1990, Gribbin 2002). Alongside Newton, and Galileo he holds a position in the history of science that has been seen as an influential one on many generations of scientists (Gribbin 2002, p.134). His position is not, it seems, due to his work as an experimental scientist, since this was one aspect of his work that was lacking, but in the arena of the development of a philosophical approach to science. Bacon performed few actual 'experiments', his influence being to promote the study of science from a position of gathering data and then, by inference or inductive reasoning to come to conclusions. Bacon's method, while influential, did not secure his place as one of the great thinkers or philosophers of his time (Marks 1990, p.81). His influence though, lasted the test of time until the early twentieth century.

Popper, Kuhn and the nature of science

Bacon's inductive method was prevalent for over 300 years, but its application in certain areas was seen as limited by Sir Karl Popper (1902 – 1994). In thinking about the nature of science and the status of theories, he said;

> *" 'When should a theory be ranked as scientific?' or 'Is there a criterion for the scientific character or status of a theory?' The problem which troubled me at the time was neither, 'When is a theory true?' nor 'When is a theory acceptable?' my problem was different. I wished to distinguish between science and pseudo-science; knowing very well that science often errs, and that pseudoscience may happen to stumble on the truth.*
>
> *I knew, of course, the most widely accepted answer to my problem: that science is distinguished from pseudoscience—or from 'metaphysics'—by its empirical method, which is essentially inductive, proceeding from observation or experiment. But this did not satisfy me."* (Popper 1963, p.33)

Popper believed in a creative force in scientific thinking and that everyone, including experimental and theoretical scientists would have a bias. He stated that science advances by 'deductive falsification' through a process of 'conjectures and refutations', the title of his 1963 book. He asserted that if a theory can be shown to be falsifiable then it is scientific, if it cannot then it is pseudoscience. He went on to claim that experiment and observations test theories they do not necessarily produce them.

In contrast, Thomas Kuhn in his book *"The Structure of Scientific Revolutions"* (1996) promulgated a view of how science proceeds or operates through 'revolutions'. He postulated that competing scientific workers initially generate a number of theoretical standpoints or frameworks, which are in direct competition. Over time, one of these becomes the dominant framework. The dominant framework is the one that explains the largest number of phenomena observed. Kuhn called this a durable 'paradigm'. Once this paradigm is accepted and used, during a period that Kuhn calls 'normal science', contradictory observations and accounts test the paradigm, undermining its dominant position. New frameworks are then developed to account for the anomalous observations and eventually a new 'paradigm' is adopted. This is the nature of what Kuhn terms his 'scientific revolution'. What is important here is that the new model or paradigm does not always completely replace the old paradigm and the two may co-exist, e.g. Newtonian Physics and Einsteinian physics.

Feyerabend's anarchistic theory of science

Paul Feyerabend (1924 – 1994), a one time visiting lecturer at the University of Sussex in 1974-75, countered the notion of any form of scientific method. In his most famous book, *"Against Method"* (1975), derived from a 1970 essay of the same title, he set out his argument against the notion of any scientific method. Feyerabend later conceded that he had merely introduced another rigid concept, perhaps even another form of scientific method.

> *"One of my motives for writing Against Method was to free people from the tyranny of philosophical obfuscators and abstract concepts such as "truth", "reality", or "objectivity", which narrow people's vision and ways of being in the world. Formulating what I thought were my own attitude and convictions, I unfortunately ended up by introducing concepts of similar rigidity, such as "democracy", "tradition", or "relative truth". Now that I am aware of it, I wonder how it happed. The urge to explain one's own ideas, not simply, not in a story, but by means of a "systematic account", is powerful indeed."* (Feyerabend 1995 p.179-80).

Science, for Feyerabend, is an anarchistic enterprise, his idea being that theoretical anarchism is more humanitarian and more likely to encourage progress than any 'law-and-order' alternative. This, he believed, was shown both by an examination of historical episodes and by an abstract analysis of the relation between ideas and actions. The only principle that did not inhibit progress for Feyerabend was 'anything goes'.

The Scientific Method and School Science

Neither Bacon, Popper, Kuhn nor Feyerabend provides us with an uncontroversial picture of what science is or, indeed, how it works. By reading their views on science we can however gain a much deeper understanding.

Scientists are not all Baconian observers; they may indeed 'become Baconian' when they describe their observations in their published work. Scientists are rigorous in how they present and finally publish their work. Data are the currency of science and they are always treated with great regard and respect. Should data have been found to have been improperly generated or reported it rightly shocks the community and brings harsh penalties on those who perpetrate scientific fraud.

Scientists do not have to falsify of their own theories; there are many others who will oblige and attempt to falsify a rival's theory. Although Kuhn's notion of scientific revolutions may suggest wholesale step changes in how we view the workings of the world around us, scientific progress is, perhaps, more incremental than revolutionary. The science of the twentieth century has undoubtedly provided more explanation and more detailed understanding of natural phenomena than the explanations for those same phenomena put forward in the 18^{th} and 17^{th} century. It is almost a foregone conclusion that as the 21^{st} century progresses so to will our knowledge and understanding progress. The move from Newtonian physics to Einstienian physics was a revolution, but science and, indeed, the physics textbooks have not thrown out all of Netwon's 'laws' and neither should they.

The fundamental question of whether or not there is one agreed 'scientific method' and that this is indeed 'how science works' appears to have no simple answer. Indeed Chalmers (1990), in describing the difficulties that science has in either proving or disproving theories states that, *"…the reconstructions of philosophers bear little resemblance to what actually goes on in science"* his reaction to this being that we should *"give up altogether the idea that science is a rational activity operating according to some special method or methods."* (Chalmers 1990, pxvii) Neither Chalmers nor Feyerabend were the first to postulate that the 'scientific method' does not exist. The philosopher Cornelius Benjamin (1897 – 1968), stated that:

> *"The strongest grounds for contending that there is no scientific method is the fact that science consists, in the final analysis, of scientific discovery, and that there are no rules by which this act takes place."* (Benjamin 1956 p.234)

So where does an examination of the history and philosophy of science leave us in relation to school science and meeting the needs of the new Key Stage 4 programme of study based on the notion of HSW? In generating the new specifications for GCSE sciences, all examination bodies moved from a content based approach to a process based approach that was determined by HSW. It would be reasonable to assume that this followed some agreed definition of how science works or that scientists, due to the nature of their studies in scientific disciplines, would have a common approach. In addition, definitions of common terms used in science should also have a degree of commonality and consistency. The intention of this small scale research was to discover whether there is indeed a common understanding and consistency that will allow the teaching of the new KS4 science programme to be successful and produce the desired aim of a scientifically literate population. To this end, the views and understanding of trainee science teachers about how science did actually work was sought.

Research Methodology

Questionnaires were completed by a sample of trainee science teachers in the 2005-2006 PGCE science 11-18 cohort from Sussex University. Prior to the administration of the questionnaire, the trainees received input on the new programme of study and its change of focus from content to process based science and information on the pilot programme of 21st Century Science, from a partnership school and advisor involved in the pilot. At the start of the training year (September 2005) some work was done on 'the nature of science' and why we teach science, though this did not explicitly focus on definitions as requested in the questionnaire and the relationship between key terms, e.g. as a 'scientific method'.

The objective of the questionnaire was to ascertain two things; what understanding did trainees have of 'the scientific method' and do trainees have a common understanding of definitions of key terminology associated with the scientific method?

The questionnaire comprised 5 sections; section 1 sought personal data, the respondent's highest formal qualification and the title of any 'A' level examinations taken (or equivalent). Section 2 asked for the respondents' understanding of 'the scientific method' either in a narrative form or as a concept or mind map. Section 3 asked for definitions of key terms, including theory, fact, law and hypothesis. Section 4 explored the respondent's understanding of the relationship between theory, fact, law, hypothesis, observation, experiment and prediction and section 5 contained nine true/false statements on how scientists act and behave, adapted from Goodstein (2000). This paper reports on aspects of the trainees' understanding of the scientific method and some definitions of terminology.

The trainees were given instructions to complete the questionnaire with their understanding and definition of the scientific method and of the key terms. It was emphasised that this was not a test of knowledge and understanding.

Personal Data Analysis

In all, 25 trainees responded to the questionnaire, 16 female, 9 male. The distribution of ages revealed that 18 were under 30, 4 under the age of 40 and 3 over the age of 40. 16 had biology or biology related degrees, 1 had a chemistry related degree, 2 had physics related degrees and 6 had general science degrees. 19 were qualified to first degree standard, 4 had Master's level qualifications in science and 2 had doctoral level science qualifications. Analysis of section 3 of the questionnaire used a categorisation of definitions and respondents definitions were allocated to the closest match. The categorisations of the definitions were taken from standard published dictionaries of science (Walker, 1999) and the concise Oxford dictionary (Thompson, 1995).

Results

Table 1 shows a summary of the results obtained in the definitions section of the survey. 72% of respondents equated a fact with 'truth' and the notion of 'proven', category F4. Within this category the definitions were further broken down to extract those who specifically mention 'truth' or 'axiom' (52%) and those who simply relate facts with proof (20%). 44% defined a theory as 'unproven ideas' (T2) and 48% defined a law as a rule not to be broken (L2) with only 32% defining it as an idea that science fully supports (L1) Definitions of the term 'hypothesis' were the most consistent, with 52% recognising the predictive nature of hypotheses .

The results indicate a worrying lack of understanding of the true nature of a scientific theory and how a scientific law should be regarded. The notion of the hypothesis as a predictive mechanism is best understood, but the nature of facts in science, with nearly three quarters of the respondents equating facts with proof and truth indicates that the notion of the scientific facts as observations or a data points, is not commonly understood. Although the questionnaire clearly positions the items for definition within the realms of natural science and implicitly asks for 'scientific' definitions, many respondents could not articulate an acceptable definition of many of the terms, acceptable in that it conformed to a recognised scientific definition. In particular the notion of a 'law' relating to a legal definition was very common.

That 44% equated a theory with unproven ideas is a concern which undermines the status of the scientific theory. When teaching science and trying to equip pupils with a workable level of scientific literacy this misunderstanding of what a theory is undermines efforts to improve scientific literacy. True scientific literacy should enable people to apply their understanding of scientific terms to everyday reporting in the media on issues such as GM crops, alternative energy sources, creationism and intelligent design, to name but a few instances, and allow pupils to distinguish science from pseudoscience.

Scientific Theories and Pseudoscience

A common tactic for groups with an interest in casting into doubt sound scientific theory, such as the creationist movement, is to present a definition of a scientific theory as being only a 'guess' or a 'hunch'. For this type of pressure group, promoting this definition is crucial to discrediting the work of science and scientists.

> *"First, they play upon a vernacular misunderstanding of the word "theory" to convey the false impression that we evolutionists are covering up the rotten core of our edifice… In the American vernacular, "theory"*

often means "imperfect fact"—part of a hierarchy of confidence running downhill from fact to theory to hypothesis to guess. Thus creationists can (and do) argue: evolution is "only" a theory, and intense debate now rages about many aspects of the theory. If evolution is less than a fact, and scientists can't even make up their minds about the theory, then what confidence can we have in it?" (Gould, 1994)

That 44% of the respondents were inclined to define a theory more closely allied to a speculative idea, rather than a principle of science, shows a lack of understanding of the nature of theories. For example, one respondent defined a theory as *"An idea based on a little evidence, not fact"* another defined it as *"an idea about something, not necessarily true"* yet another as *"unproven ideas"* two others simply as *"an idea"*. No respondent defined a theory as an exposition of the principles of science, as robust and generally accepted by the scientific community.

Facts and Science

The notion of a 'fact' in science is also subject to misinterpretation. 56% of respondents equated a 'fact' with something that is either 'true', 'real' or 'proven' indicating a lack of understanding of facts in relation to science and scientific evidence. In the fields of philosophy, mathematics and law, it would indeed be correct to equate facts with proof and truth. In science, facts have a different characteristic. A scientific fact can be thought of as a repeated and verifiable observation, so much so that to not call that observation a fact would be illogical. The evolutionist Stephen Jay Gould's definition of a scientific fact is much the same, *"In science, 'fact' can only mean 'confirmed to such a degree that it would be perverse to withhold provisional assent.' "*(Gould, 1994). In science, it is recognised that as our understanding increases, so our theories will develop and change. Facts do not normally change, but science does not preclude facts that are counter to what we have known; for example, the force of gravity means that we can predict with almost unerring certainty that any object dropped would fall towards the Earth's surface. Yet we cannot state that in all known and unknown parts of the universe gravity will always behave in that fashion. The likelihood of gravity behaving counter-intuitively, i.e. forcing an object to move away from the surface of a large planetary mass, is so small that we dismiss this and call gravity a scientific fact. At no point do we assert that the laws of gravity as defined by us are 'true' and must hold 'true' in all situations.

Were we to chart the development of certain scientific theories over time we would see how new evidence obtained from the gathering of data (facts) changes our interpretations. For example, the apparent 'fit' of the continents (e.g. the fit that could be obtained by juxtaposing South America and Africa) has been explained in the past using an 'expanding Earth' theory with expansion accounting for the drift apart of two continents. When geophysical data gathered from the sea floor provided evidence that this 'continental drift' was not due to an expanding Earth, but due to the movement of crustal plates over the surface of the earth with new rock forming along mid oceanic ridges, the theory of plate tectonics was born and the expanding Earth theory effectively killed off. The facts or data that showed that at one time South America and Africa were indeed joined in geological history – the similarity in fossil fauna and flora, the chemical and stratigraphical similarity between the rocks – fitted both theories, but plate tectonics provided a better explanation than an 'expanding Earth' theory which had a number of deficiencies. An expanding Earth may explain how land, once covered by the sea, is now remote from the shore, but it does not explain how seas can invade lands, a phenomenon clearly shown in our geological history. If our Earth is expanding, why don't electricity cables, telephone lines and transatlantic undersea cables break more often as they become stretched between continents that are moving apart? If the Earth is expanding why do we have subduction zones which mean that continents move towards one another in some areas and constructive margins where new rock forces the Earth's surface apart in others, such as the mid Atlantic ridge? Finally how could we account for the necessary increase in the mass of the Earth need to fill the internal 'void' created by expansion? If the void is filled by a collapse of the oceanic crust the surely the ocean basins would accommodate more water and the seas would retreat further from the coasts.

The Scientific Method

As has been discussed previously, whether a scientific method actually exists and whether or not it is a fixed set of rules that govern how science is conducted is a matter of debate. That we now have a form of scientific method in our KS4 national curriculum programme of study for science leads us to an inevitable conclusion that we must strive to define what our vision of the scientific method is and how we relate this to the day to day teaching of science.

A majority of respondents, 36%, gave a narrative account of their understanding of the scientific method which corresponds to an account of how scientists carry out experiments or investigations to answer questions, e.g.

> *"the scientific method relates to the procedures that must or should be adhered to when carrying out experiments/investigations"*
>
> *"the scientific method concerns our approach to arriving at scientific principles through fair testing, reproducibility, accuracy, ethical testing."*
>
> *"It means the use of scientific ideas to investigate a problem and carry out practicals…"*
>
> *"a formal procedure to investigate a phenomenon, removing as many extraneous variables as possible."*
>
> *"A general way of investigating science used by most scientists. Aim, method, results, conclusion, analysis."*

20% of respondents simply listed terms, such as" hypothesis, method, fair test, data collection, conclusions", with no explanation or apparent relationship between them. The listings, as written were interpreted as hierarchical though not consistent across respondents. Only 1 respondent referred to falsifiability as a critical component of a scientific method, *"Predictions or hypotheses should be testable and can be falsified"* indicating an understanding of Popper's approach. Nearly a quarter of respondents (24%) produced a concept or mind map to explain their idea of the scientific method though few related the terms listed with meaningful links. No respondents alluded or referred to aspects of the inductive or deductive approach to science and its relationship to the scientific method.

Discussion and Conclusion

The general conclusion from this questionnaire is that there is no common understanding of the scientific method as understood within the realms of the history and philosophy of science by science graduates entering initial teacher training. The absence of references to the notion of falsifiability or scientific paradigms indicates that many respondents either were not aware of the work of Popper and Kuhn, or were not inclined to relate this work to the scientific method. No respondents agreed with or referred to Feyerabend's anarchistic notion of science.

The variation in defining commonly used words in science; theory, law, etc. is also of concern as these are part of the day to day language of science and should be used consistently and accurately if we are to produce a scientifically literate society. That there is confusion in the minds of science graduates about the status of laws and theories and that a theory is defined by a significant proportion of trainees as 'unproven' or 'speculative' is also a major concern. The new KS4 science programme of study, with its focus on HSW should have a common and agreed definition of HSW and of key terminology. This should be incorporated as part of the teaching scheme and not as an addendum in a glossary. It should be explicitly stated how HSW is related to the scientific method and how it should be presented to pupils studying GCSE sciences. Should this underpinning approach to science teaching be cascaded downwards to KS3, it becomes even more critical that science teachers are aware of the purpose of this approach and how this relates to accepted accounts of the scientific method. The relationship to the scientific method must be made explicit and the difference between the process of science as a whole, i.e. not just the experimental part of science, but the application of inductive and deductive logic, of inference from data and how and when these approaches are appropriate, must also be incorporated into an agreed framework for teaching science and HSW. For those involved in the writing of specifications and any supporting materials such as textbooks, teacher guides and resources there should be a commonality in the definition of key terms, such as theory and law. Indeed, it would be a positive benefit to refer to these terms with the prefix 'scientific'; i.e. scientific fact, scientific law, scientific theory, scientific hypothesis, in order to reinforce the special nature of these terms within the realm of science and to help distinguish them from common or vernacular definitions which may serve to obscure the true scientific meaning and hence impede understanding of these critical terms when applied to science. Unless and until this approach is adopted there is a danger that misunderstandings, misinterpretations and inconsistent teaching of HSW or, for that matter, how scientists work, will impede our move towards a more scientifically literate population.

Table 1 Survey Results

Fact	Number	(%)
a thing that is known to have occurred to exist	1	4
a datum of experience	1	4
an item of verified information; a piece of evidence	4	16
truth, reality, proven	18*	72*
a thing assumed as the basis for an argument or inference	0	0
definitions outside the above	1	4
Law	**Number**	**(%)**
a rule or generalization which describes specified natural phenomena within the limits of experimental observation	8	32
A rule or body of rules that govern behaviour in society	12	48
Definitions outside the above	5	20
Hypothesis	**Number**	**(%)**
a prediction based on theory	13	52
an educated guess derived from various assumptions, which can be using a range of methods, but is most often associated with experimental procedure	4	16
a proposition put forward for proof or discussion	3	12
definitions outside the above	5	20
Theory	**Number**	**(%)**
a supposition or system of ideas explaining something especially one based on general principles independent of the particular things to be explained	11	44
a speculative (especially fanciful) view	11	44
the sphere of abstract knowledge or speculative thought	0	0
the exposition of the principles of a science	0	0
definitions outside the above	3	12

* this category was further divided into definitions that contained the term ‘truth’ or axiom and those that equated a fact only with something that is ‘proven’. 13 respondents (52%) used the term ‘truth’ or ‘axiom’ in the definition and 5 (20%) included proof or proven only in their definition.

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