Developing Scientific Temper

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1. **Overview**: In this unit we shall understand the essence of scientific method, the characteristics of scientific temper and the methods by which you can develop scientific temper among the students and teachers in schools. We shall also understand how scientific method can be extended to all aspects of everyday life including spiritual pursuits.

2. **Objectives**: After studying this module you should be able to:
   
   (i) Explain the essential features of the scientific method.
   
   (ii) Define the characteristics of scientific temper.
   
   (iii) Identify the strategies for developing scientific temper among students at various levels of school education.
   
   (iv) Apply the scientific method to all aspects of everyday life including spiritual pursuits.

3. **Introduction**: Inquisitiveness is a fundamental trait of human beings. From times immemorial man has tried to comprehend the world in which he finds himself. The knowledge gained through observation of natural occurrences like apparent movement of sun, moon and other ‘heavenly’ bodies, storms and lightning, eclipses and meteoroites, growth and properties of plants, etc. was gradually systematized and classified, and the process of identifying causal relationships was initiated. The roots of modern science and scientific method can be traced to the early attempts to relate cause and effect: On full moon nights the waves in the sea were always higher than on moonless nights, eating certain plants always induced intoxication, stones thrown at a certain angle of inclination traversed the largest horizontal distance, etc. Another crucial step was: identification of patterns in observation: Full moon nights and moonless nights occurred at regular periods, there was noticeable periodicity and a pattern in occurrence of weathers: rains always followed summer, winter followed rains and spring followed winter; many plants flowered in spring and withered away in summer; certain diseases proliferated only in summer and others during monsoon, etc. Repeated observation of such patterns and causal relationships led to induction of generalizations or theories, many of which were often raised to the status of “laws of science” once the deductions from these theories were experimentally verified repeatedly. This in essence is the process by which even modern scientists progressively understand the nature better, thus enabling us to harness its potentials for the welfare of humanity.

4. **The Scientific Method**
   
   Thus the scientific method\(^{1,2}\) can be seen as comprising of five steps, viz.
   
   (i) Intensive **observation** of the phenomena under study with a view to identify the various parameters influencing it and any causal relationship between these.
(ii) Formulation of a general hypothesis to explain the phenomena. This hypothesis could be some kind of causal mechanism or even a mathematical relationship between the variables influencing the phenomena.

(iii) Using the hypothesis to make predictions about the existence of some other phenomena or about relationships between variables derived through mathematics and logic.

(iv) Verifying these predictions by performing carefully controlled experiments.

(v) If the experiments validate the predictions, the hypothesis is accepted as a theory or even a law of nature (when its predictions are confirmed through repeated experimental tests). But if the experimental results are at variance with the predictions, the hypothesis is either rejected or modified. (Fig 1)

Figure 1  Scientific Method
We shall discuss each of these steps in some detail to appreciate the nuances of scientific method.

4.1 **Observation**

Scientific method demands that the observations be carried out in a systematic manner taking due care to ensure that it is free from any bias and experimental errors. Often the observations involve measurements (like mass or temperature of an object, agricultural yield, blood chemistry etc.) and there are always some uncertainties associated with these arising from the ‘instruments’ used for measurement (like weighing balance, thermometer, titration equipment etc.). These can be quantified and need to be clearly stated to avoid spurious conclusions. Uncertainties may also arise from the presence of uncontrollable factors influencing the phenomena under investigation, and due care has to be taken to eliminate these. This is especially true in studies involving living organisms - be it plants, animals or human being. The nature of these ‘instruments’ are, of course, different in social sciences, and could take the form of interview, notes, case studies, questionnaires etc., and so the degree of precision is comparatively lesser.

4.2 **Hypothesis**

The formulation of an hypothesis to relate the various variables observed to influence the phenomena is mostly a creative act - an act of intuitive insight - and thus not easily amenable to description. The most important characteristic of a scientific hypothesis is that it should be verifiable, rather falsifiable. Thus the hypothesis that “magnetic substances contain young angels who get attracted towards the fairies contained in magnets, but these angels and fairies can not be seen by humans” is not testable since the ‘angels’ and ‘fairies’ are so designed that we can never see them. It is therefore not a scientific hypothesis. On the other hand the hypothesis “There are no young angels in magnetic substances” is testable. One can falsify it by catching one such angel!

Similarly the hypothesis that “light bends in a strong gravitational field” is verifiable and even suggests measurements that can be made to test/falsify the claim.

4.3 **Prediction**

The power and utility of a hypothesis lies in its ability to make predictions about phenomena other than the one which forms its basis. For example Newton’s hypothesis regarding existence of gravitational force of attraction between objects could be used to make such diverse predictions as the phases of the Moon, the phases of Venus and the hour of maximal tide in the sea! All these predictions were verifiable. Similarly Einstein’s formulation of the “hypothesis” of relativity predicted that a clock inside a fast moving spaceship would slow down as compared to an identical clock on earth. It took almost fifty years before this could be experimentally verified and give credence to this hypothesis.
The other startling outcome of the theory, viz. equivalence of mass and energy, was also verified much later in particle physics.

The predictions from a hypothesis may be made using logic or, where the hypothesis is mathematically formulated, by using mathematical tools, as was the case with gravitation and relativity.

4.4 Verification

The most crucial aspect of the scientific method is verification of the predictions of the hypothesis, by performing suitably controlled experiments. The need for control over the experiments is of paramount importance since otherwise random chance factors can force us to draw wrong conclusions. Many of the so called superstitions in various societies are associated with some spurious cause-effect associations noticed in some random observations. Thus a cat crossing the road or someone sneezing before you leave the home being bad omens, the number 13 being inauspicious etc. are said to be superstitions since these ‘hypotheses’ have not been established repeatedly in controlled experiments. The difference between a superstition and a scientific theory essentially lies in the repeated verifiability of the later in pre-planned controlled experiments. Thus while testing the efficacy of a drug, the doctors need to ensure that the effects observed are indeed due to the drug and not due to some random chance factors. This is usually done by taking two groups of patients; one group is given the drug under test and the other is given a placebo (i.e. a look alike pill of some common substance like milk of sugar), without the patients knowing about it. Statistical techniques are often employed to ensure that the observed difference between the two groups is “significant” to a high degree of a probability so that the conclusions are not distorted by experimenter’s wishes.

You must also be cognisant of the fact that the process of verification is always tentative, and within a certain domain of experimentation. There is no way that we can “prove” any hypothesis, for formal “proofs” are possible only in mathematics. In fact we can not even truly “verify” a hypothesis; we only fail to refute it. The history of science is replete with examples where some hypotheses elevated to the status of “laws of nature” after repeated verification were seem to be of limited applicability in the light of new findings over wider domains of data. The most notable example is that of Newton’s laws of mechanics which we now know are valid only when the velocities involved are less than the speed of light. Since the domain of human experience involves velocities very much lesser than the speed of light, the “laws” of mechanics got repeatedly ‘verified’ before Einstein brought in his relativistic formulation. Yet that verification did not lend finality to these laws, much less ‘prove’ them; and we now know that these laws do not give an accurate description of the principles governing the universe. Thus we need to bear in mind the “tentativeness” of all scientific theories. It is in fact, not proper to call these as “laws” of nature, since as pointed out by Dampier(3) the word ‘law’, “imparted a kind of moral obligation, which bade the phenomenon “obey the law” and led to
the notion that, when we have traced a law, we have discovered an ultimate cause”. Scientific theories are essentially creative generalizations of great practical significance which put together a conceptual model of nature but these can not unravel the intrinsic nature of reality.

4.5 **Modification/Rejection of hypothesis**

When the predictions of a hypothesis are not in agreement with experimental findings, the hypothesis may either be rejected as a description of the phenomena or modified till its predictions tally with experimental observations (See Fig. 1). There are numerous instances in history of science where prevalent theories were rejected in the face of experimental evidence. Thus the geocentric model of planetary system was supplanted by Copernican helio-centric model through experimental observations of Kepler and Galileo. Later this model was modified with its circular planetary orbits replaced by elliptical orbits which could eventually be derived from Newton’s laws of mechanics. Similarly the concept of “phlogiston”, the substance with negative weight which escaped from a body when it was burnt, was given up in the light of precise experiments of Lavoiser who showed that during combustion too the mass was conserved – although matter may undergo reconstitution, there is no change in its mass. The classic example of how hypothesis is modified in the light of predictions disagreeing with experiments is the method followed by Galileo, one of the harbingers of modern scientific method, in his study of falling objects. On the basis of his primary observation that falling objects moved with constantly increasing speeds, he formulated a hypothesis that the speed was proportional to the distance traversed. He was not able to test this hypothesis directly, but from it he deduced the conclusion that objects could fall through unequal distances in the same time. This was not borne out by experiments and so Galileo modified his hypothesis to: the speed attained is directly proportional to the time elapsed. This hypothesis led to the prediction that the distance traversed by an object is proportional to the square of time elapsed, which he verified experimentally by studying balls rolling down an inclined plane.

5. **The Practice of Scientific Method**

You would have realized from the above description of the scientific method that its main objective is to eliminate, as far as possible, the influence of scientist’s predisposition or bias, on deriving conclusions from the study of a phenomenon. Scientists also, like all human beings, have certain likes and dislikes which could influence judgement in many ways, e.g. preference, or even attachment, to a particular scientific theory, an aesthetic sense which prefers “simple” or “beautiful” formulations over complicated ones, or even personal or cultural beliefs like “God does not play dice”, which was a cryptic comment of a great scientist like Albert Einstein, on the probabilistic explanations emanating from quantum theory. This is also ensured to a great extent by the practice of “peer review” of the scientific findings before their publication in a scientific journal. Here a panel of fellow scientists without revealing their identity
examines the claims made, and the process followed in arriving at these claims, and gives its comments, to the author. This open communication among members of a scientific community, together with the possibility of experimental studies being repeated at different places, assures that individual biases get eliminated and a consensus develops in the community about the validity of scientific theories.

You must however appreciate that there is an element of subjectivity involved in the process of induction of hypothesis from the observations. There are numerous stories of scientists struggling intellectually to make sense of the observations of certain phenomenon, only to be “revealed” the hypothesis in a flash of inspiration in the most unusual manner. Archimedes is said to have discovered the law of floatation while bathing in a tub, and exclaimed, “Eureka”. James Watson discovered the shape of DNA molecule after he saw a dream where a snake was catching its own tail!

However the final acceptance of a theory is not based on these accounts, howsoever interesting these be, nor on the authority of the scientists, howsoever renowned they may be. Any scientific theory is accepted only when its predictions can be experimentally verified by one and all. This of course demands that the experimental data be collected properly, the methodology of data collection be revealed and the degree of uncertainty in measurements be quantified. It is also presumes ethical uprightness in that no experimental data should not be ‘rejected’, just because it does not fit the theory. There exist numerous examples in the history of science where due to absence of these checks and balances, scientific community had to face great embarrassment. The most recent example is the Cold Fusion experiment of Pons and Fleishmann, reportedly performed at the university of Utahm 1989. All subsequent attempts at replication failed calling into question the original work and eventually Pons and Fleishmann retracted their findings and resigned their university posts.

On the other hand, there are also some interesting examples where the apparent “anomalies” in data have led to path breaking predictions – for example the path of the orbit of Uranus, being not in tune with the predictions of Newton’s theory of gravitation, eventually led to the discovery of another planet, Neptune.

It is also important to appreciate that the five steps of scientific method are applicable to all the sciences, whether these be the so-called ‘exact’ sciences like physics and chemistry or the more descriptive sciences like zoology, anthropology and psychology. The only difference is in the nature of experimentation and the data collected. In the exact sciences – physics, chemistry – the data are in the form of numbers, for example the weight in kilograms, the charge in coulombs, the electric potential in volts, the temperature in Kelvin, etc., all of which are directly read from certain measuring instruments. In social sciences, the “instruments” are often questionnaires, case studies or interview notes from which inferences have to be derived, often by using statistical
techniques. The basic steps of the scientific method, making a hypothesis to explain certain observations and verifying the prediction of the hypothesis against carefully obtained experimental data, however remain unaltered. Although the ‘instruments’ that social scientists use do not yield the same degree of precision as in physics or chemistry, it is not the precision that makes a discipline “scientific” but the methodology by which theories are generated and tested.

6. Check your Progress:
1. What are the main ingredients of scientific method?
2. What is the difference between induction and deduction?
3. What care is necessary while observing a phenomenon?
4. Give examples to illustrate how scientific theories have been superseded/modified with advancement in knowledge.
5. Check whether the following are scientific hypotheses:
   (i) The Mars is inhabited by spherical red creatures who can read our mind and will hide whenever anyone on Earth looks at them or any spacecraft comes near.
   (ii) The ‘amulet’ given by that saint can cure Cancer.
   (iii) All matter turns into waves when no one is looking, and then turns back if anyone looks.
6. Find out from internet surfing some case studies of fraudulent practices in science. What lessons do you draw from these?

7. Scientific Temper
You must be already beginning to feel that the scientific method is in fact willy-nilly being applied by most rational and logically minded people even to solve everyday problems. What do you do, for example, when your television screen suddenly goes blank? You collect all the “information” pertinent to the phenomena – the state of cable connection at the TV and outdoors, whether this ‘blank’ screen appears in all the channels, is there audio-failure too or only video failure, any abnormal heating inside the television etc. Based on these observations, you “hypothesize”: There is electricity failure at the cable transmission office. To “verify” your hypothesis, you telephone the cable operator and he confirms the cause of the problem and assures you that it will be sorted out within a few minutes. Thus all the steps of the scientific method are involved in the process of solving this commonly encountered problem. We consider such a person, who imbibes the essence of scientific method in his outlook, and uses it in his everyday life, as possessing “Scientific Temper”. She may not necessarily be a scientist, not even a science student, and yet have scientific temper.

This scientific temper, or scientific attitude is characterized by following traits:

a. Healthy scepticism
b. Universalism
c. Freedom from prejudice or bias
d. Objectivity
e. Open mindedness and humility
f. Willingness to suspend judgement without sufficient evidence
g. Rationality
h. Perseverance - positive approach to failure

The attitude of healthy scepticism implies that you do not accept others’ assertions unless these are logical, rational and supported by proper evidence. It is an antidote to the credulous taken-for-granted attitude which accept things merely on the basis of authority or tradition. In ancient Greece, many believed on Aristotle’s authority that males and females have different number of teeth, without ever verifying this for themselves. This was clearly against this basic tenet of scientific temper. Scepticism, taken in its widest sense means that you do not even have to necessarily ‘believe’ in the evidence provided. You can redo the experiments yourself and determine whether the evidence is trustworthy. Scientific temper precludes acceptance of evidence which is not reproducible by others, and is claimed to be the exclusive prerogative of a select few. Universalism is thus an important characteristic of scientific temper. Naturally, there is no place for prejudice or bias, for otherwise the conclusions can not be universal. The observations have to be objective. You observe things as they are, without trying to manipulate these to fit in some pre-conceived worldview. This also demands an open mindedness, willingness to change conclusions in the light of reliable evidence and humility, freedom from pride and arrogance, which comes from realization of limitations of our intellect and ever broadening horizons of knowledge. In this regard it is always helpful to recall the words of Sir Issac Newton, one of the founders of modern science, “I do not know what I may appear to the world, but to myself I seem to have been only like a boy, playing on the sea-shore, and diverting myself, in now and then finding a smoother pebble, or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me”.

The hallmark of all decision-making by a person with “scientific temper” is logic and rationality. Perseverance, is another important characteristic of scientific attitude, for even the “flash of insight”, which characterizes many great scientific achievements, usually follows hard toil and reflection on the problem for long periods of time. To put it in the words of Thomas Elva Edison science is, “99% perspiration and 1% inspiration”.

There are numerous instances of scientists’ years effort at solving a problem resulting in failure. But such failure is often seen in a positive light. Dr. Paul Ehrlich, 1908 Nobel prize winner in medicine developed the treatment of syphilis after 605 unsuccessful attempts. In fact he called his discovery, Salvarson as “606”. Clearly, his 605 “failures” had contributed to the medical research by providing the necessary clues that led to the discovery of the correct formula.
Viewed in this perspective, scientific temper becomes an attitude, a way of life.

8. Developing Scientific Temper

In our country, where a large section of the society is still caught in the quagmire of superstitions and obscurantist practices, inculcating scientific temper among the citizens is of paramount importance for development of the nation. This is best done during the childhood while the child is learning how to respond to the vagaries of everyday life. It is therefore essential that the school curriculum should respond adequately to this important need. This demands inculcation of values like spirit of inquiry, courage (to question), objectivity, honesty and truthfulness, which are precursors to the development of various traits characterizing scientific temper. The spirit of inquiry, so natural in most children actually gets stifled by the drab teaching-learning environment created by the didactic teaching methodology. Even learning of science, which should be a joy of discovery, becomes a burden—memorizing so many ‘facts’, formulae, chemical reactions, etc. It is therefore of paramount importance that education process be made joyful, with the teachers acting as facilitators of learning, as friends and guides. The child must be free to learn, what he chooses to, at the pace that he relishes, and must be free to make mistakes without the fear of being reprimanded by the teacher. There exist numerous success stories of schools (5,6,7) where education is imparted by a variety of means like stories, painting, recitation, games, group projects, self-reading etc. so that the child’s enthusiasm for learning does not diminish. In such schools the children are not afraid of asking questions from their teacher friends, and thus their inquisitiveness is strengthened.

An effective method of fostering scientific temper is imparting knowledge of science through experimentation and demonstration, by involving students directly in activities similar to how scientists operate in discovering new knowledge. This is usually referred to as the discovery approach to teaching (8) and is eminently suited to teaching science. Carin and Sund (8) give numerous examples of discovery lesson plans for a variety of sciences – physical science, earth science, biological sciences – wherein through simple experiments the students discover for themselves various scientific concepts. Appendix-1 gives a sample of such a ‘pupil discovery activity’ taken from their book which indicates how the various steps which are a part of the scientific method get integrated in such a simple experiment. Clearly teaching of science in this manner would greatly develop scientific temper among the students for, as goes the Chinese proverb:

I hear, and I forget;
I see, and I remember;
I do, and I understand.

To inculcate scientific temper among the students they need to be placed in situations – through role play, quizzes, model making etc. - where critical and rational thinking are needed. We also need to make them aware of the impact of
science on society by arranging visits to factories, hospitals, research laboratories, showing suitable video films, organizing talks by eminent scientists and technologists, and encouraging them to participate in science exhibitions.

The attributes of scientific temper like, honesty, truthfulness, humility, perseverance, positive approach to failure, are essentially some of universal human values which are so important for happiness of an individual as also the society. Inculcation of these and other universal human values should become an integral part of the education process. There exist many well-established methodologies of value inculcation, which are themselves scientific in nature, and which can be easily integrated with the education system.

9. Scientific Temper and ‘Dharma’

As we have discussed above, scientific temper is an attitude, a way of living, which should be applicable to all aspects of our life. While most people find it easy to accept the applicability of this approach involving objective observation, rational analysis, and healthy skepticism - an attitude of questioning every belief – in personal, social, economic and even political aspects of our everyday life, you may not be able to ‘see’ how it can be extended to our religious life. This is because of widespread misconception about “religion” or “Dharma”. Unfortunately, the English word “religion” is not an appropriate translation of the Sanskrit word “Dharma” used in Indian tradition. The term “Dharma” literally means “natural law”. Dharma is thus an exposition of the laws pertaining to our inner world, just as science deals with the laws pertaining to the outer world. The difference between ‘science’ and ‘Dharma’ is thus only a difference in the realm of enquiry – as there are differences between the various “departments” of science such as physics, chemistry, zoology, psychology etc. Just as the understanding of laws of science enables us to bring an order in our ‘outer’ world, proper understanding of Dharma enables us to bring an order in our inner world. There is thus, no reason that the scientific method can not be extended to the pursuit of “Dharma”.

The word “religion” as used in the west however has a different connotation. Collins Cobuild Dictionary defines religion as: “a particular system of belief in god or gods and the activities that are connected with this belief, such as prayer or worship in a church or a temple”.

This, unfortunately, is a very limited vision of religion. We need to appreciate that every ‘religion’ has two dimensions, viz. its socio-political cultural expression, the outer sheath (smriti) and its core, the truly spiritual part (sruti). The smriti, comprising of various rites, rituals, dress codes, beliefs, methods of worship etc., is naturally conditioned by historical, social, cultural and political climate of the age when that “particular religion” was founded. It is parochial and not applicable universally. The sruti or the core teaching consists of the spiritual truths, which are universal. These are, as mentioned above, the “Laws of Nature” as applicable to the subjective world of man – his feelings, emotions, joys,
suffering, aspirations and aims – quite akin to the “Laws of Nature” applicable to the objective world and enshrined as “Science”. Like the laws of science, these too are universally valid, and can be subject to the same process of rational analysis and experimental verification. Swami Vivekananda pleaded vigorously for this:\(^{10}\) :

“Is religion to justify itself by the discoveries of reason through which every other science justifies itself? Are the same methods of investigation, which we apply to science and knowledge outside, to be applied to the science of religion? In my opinion, this must be so; and I am also of opinion that the sooner it is done the better. If a religion is destroyed by such investigations, it was then all the time useless, unworthy, superstition, and the sooner it goes the better. I am thoroughly convinced that its destruction would be the best thing that could happen. All that is dross will be taken off, no doubt, but the essential parts of religion will emerge triumphant out of this investigation. Not only will it be made scientific – as scientific, at least, as any of the conclusions of physics or chemistry – but it will have greater strength because physics or chemistry has no internal mandate to vouch for its truth, which religion has.”

Experimental verification is as much a part of “Dharma” as of science. The laws of the “inner world” – the Dharma – should in fact be taken as hypothesis to be accepted only on verification by experience, albeit personal and subjective, and not on authority. Of course given the nature of enquiry, it is not possible to do the kind of objective experiments – available for everyone to see – which can be done to validate scientific hypothesis. While studying the outer world – say an object falling freely, the observer is separate from the observed and it is relatively easy to be objective in observations and measurements. The laws of “Dharma” need verification within one’s own consciousness, and the ‘observer’ and the ‘observed’ are not so distinctly separate. This does not make the observation invalid, but more difficult since by proper practice it is possible to observe the inner world of feelings and emotions, sensations and reactions, objectivity, as it really is. These observations are surely personal, but everyone can do so, for these are not the exclusive privilege of a select few. The laws of the “inner world” are predictable and verifiable in the ‘personal experience’ of all investigators, just like the laws of science. All great ‘Dharma’ teachers in the east advise their disciples to “come and experience” (ehi passiko, as the Buddha would put it) these laws of nature, themselves.

There is also a need to be cautious in not equating scientific temper with a belief in materialism—the philosophy that matter is the sole reality, and everything else is essentially an epiphenomenon. Thus to deride the hypothesis, “Meditation can improve the rate of recovery of Cancer Patients” as unscientific merely because it posits the influence of a non-material practice on a physical disease, would actually not be in tune with scientific temper. Rejecting any hypothesis outright, without performing any experiments, without any rational basis, is as much “unscientific” as credulous
acceptance of a belief. In fact, the above hypothesis is now well established, after carefully controlled experimentation performed at numerous hospitals throughout the world! And the “traditional belief” that science supports “materialism” has been repudiated by the recent development in physics like quantum mechanics, theory of relativity, and developments in biology, neurosurgery, psychology etc. as has been brought out in a number of popular books by Fritzof Capra, Gary Zukav, Paul Davies and many others.

Thus ‘Dharma’ and ‘science’ are not antagonistic to each other, and the scientific method is equally applicable in the pursuit of the core of “Dharma”. In fact abdication of such a rational and analytical attitude in these pursuits is responsible for so much confusion, mutual distrust and acrimony among the followers of various “religions”. Development of scientific temper among the people, could enable shifting the emphasis to the universal essence of all religions and thus promote communal harmony in the society.

10. **Limitations of Scientific Method – Scientism**

Many thinkers have pointed out that the scientific method can not be directly applied in many situations, especially those involving abstract, attributes like interpersonal relationships, values, ethical and moral norms etc. which can not be measured objectively. They have even coined a word “scientism” to run down this excessive belief in scientific method.

Of course, difficulties are encountered when we extend this method to other fields of enquiry like social interactions, liberal arts, and even spiritual pursuits. In such cases, the most common difficulty arises from the impossibility of isolating the cause-effect relationships governing phenomenon under study. If multiple causes operate simultaneously, it is often not possible to discern the cause-effect relationships unambiguously. This, of course, happens even in many “scientific” problems like weather prediction, where the presence of a number of variables makes predictions very difficult; but no one questions meteorologists claim to be scientists. The issue it seems is more of a restrictive versus a flexible and broader interpretation of the scientific method. As mentioned earlier too, there exist scientifically validated ‘instruments’ by which changes in attitudes, values and other psychological attributes can be quantified. Of course the degree of precision is not the same as in “exact sciences”. Thus one can confidentially infer, with the help of statistical tests of significance, whether the hypothesis: “meditation reduces the anxiety of the practitioners”, is right or wrong and also specify the degree of confidence about the inference (e.g. 95%, 99%, 99.9% etc., as the case may be). However it may not be possible to quantify the magnitude of change in anxiety. If we take a restrictive view of scientific method, one could say that the hypothesis, “Meditations reduces anxiety” is not testable, and therefore not scientific. However, a broader view, which respects the spirit of scientific method would consider this as a scientific hypothesis, even though the exact magnitude of reduction can not be determined, since by controlled
experiments over a sample of population, one can verify that the change is statistically significant\(^{(11)}\).

The situation however becomes much more difficult when it comes to applying this method in social interactions, or art appreciation etc., mainly because it is not possible to repeat the “experiment” exactly since the very process of conducting such an ‘experiment’ would change the parameters. Thus the extent of appreciation of a piece of art would progressively change with every new ‘experiment’ at understanding it, and it may not be possible to scientifically test the relative efficacy of two methods of art appreciation. Similarly it would not be possible for a lawyer to “scientifically” assess the relative efficacy of two different styles of arguments in convincing the judges about his case – not only because he may never be able to do so practically, but also because the earlier set of arguments would influence the manner of response of the judges to the later set of arguments. Such situations – where the response of a system is influenced by its history – are also encountered in hard scientific disciplines, e.g. the phenomenon of hysteresis observed in magnetic and electric systems. In fact extensive studies of such phenomena have become new scientific disciplines and lead to many technological innovations like shape-memory alloys. It therefore seems prudent that rather than abandoning the application of logic, rationality and verifiability – which is the essence of scientific method – we investigate how even such complex situations can be logically and rationally analysed.

Finally, let us consider the challenging hypothesis, which is an anathema to many scientists of, viz.: “There exists a transcendent reality beyond the domain of our senses”. Again, if you take a myopic view of the scientific method, this hypothesis is obviously not testable. However, if we take a broader perspective, in tune with the spirit, rather than the letter of the scientific method, you will find that this is also a testable hypothesis. All you need to do is to restate the hypothesis in an obverse manner, “There does not exist a transcendent reality beyond our domain of senses”, and falsify it by actually experiencing such a state. In fact this assertion of the sages has been checked and rechecked by numerous sages throughout the world, and even the methodology of experiencing this has been laid down in some cases, as for example in the *Maha Satipathana Sutta*\(^{(12)}\) by the Buddha. Anyone can, given sufficient resolve and determination, follow the path and verify for himself the hypothesis, as also all other predictions (eradication of suffering) which emanate from this hypothesis. The difference from scientific pursuits, if any, is only in the “degree” of effort required. But if a scientist could spend years and sail through 605 unsuccessful attempts to arrive at the treatment of a disease, how many more years and perseverance would be worthwhile to experience “something” that transcends the sensory domain and thus overcome all suffering!

11. **Check Your Progress**
   1. Your telephone is out of order. Illustrate how would you apply “scientific method” in setting it right.
2. Formulate a discovery lesson plan to introduce laws of electricity to senior-secondary students.

3. What is the difference between the western concept of ‘religion’ and the Indian concept of ‘Dharma’?

4. Find out literal meaning of the Sanskrit words ‘sruti’ and ‘smriti’ and explore the possible reasons for the choice of these words to describe the “core” and the “superficial” aspects of religions.

5. What difficulties are likely to be experienced by anyone applying scientific attitude in analysing religion?

6. On what basis can you say that the hypothesis, “There exists a Four-dimensional, Space-time Continuum, of which our three-dimensional world is a projection” is scientific?

7. What is the difference between a scientific hypothesis and a superstition?

12. **Let us sum up**

   From ancient times Man has tried to make sense of the world in which he finds himself by systematization of the knowledge gained through careful observations. The roots of modern science can be traced to these early attempts at searching for fundamental principles governing causes and effects in the universe. The essence of its method can be said to be sincere rational thinking, which admits conclusions only when based on repeatable evidence.

   Scientific method can be divided, for the sake of clarity, into five steps, viz. (fig.1)
   
   (i) Observation of phenomenon, identifying patterns
   (ii) Hypothesizing
   (iii) Predicting new results from the hypothesis
   (iv) Experimental verification of predictions
   (v) Modifying/Rejecting hypothesis in the light of results of verification.

   The most crucial aspect of scientific method is accepting any hypothesis only after repeated experimental verification. The difference between a superstition and a scientific theory essentially lies in the repeated verifiability of the later in preplanned controlled experiments.

   The scientific method is in fact being willy-nilly applied by most rational and logically minded people even to solve everyday problems. We consider such a person as possessing “Scientific Temper”. Scientific Temper is characterized by following traits.
   
   a) Healthy scepticism
   b) Universalism
   c) Freedom from prejudice or bias
d) Objectivity  

e) Open mindedness and humility  

f) Willingness to suspend judgement without sufficient evidence  

g) Rationality  

h) Perseverance – positive approach to failure

These traits can thus shape our attitude to life, and in effect become a part of our character.

Scientific temper is best developed during the childhood while the child is still learning how to respond to the vagaries of everyday life. It is therefore essential that the school curriculum should respond adequately to this important need. This demands inculcation of values like spirit of inquiry, courage (to question), objectivity, honesty and truthfulness which are precursors to the development of various traits characterizing scientific temper.

A very effective method of developing scientific temper is the use of discovery approach to teaching, especially for science, for we usually understand best by actually doing experiments. Many of the attributes of scientific temper are also the universal human values which are important for happiness of an individual as also the society. Inculcation of these values can itself be done through education by using scientific methodologies which are extant.

Scientific attitude can be carried forward in all aspects of our life-personal, social, economic, political and even religious. We need to interpret the word “religion” in its holistic sense, as has been the practice in Indian tradition. The word “Dharma” (unfortunately considered as a synonym of English word religion) in our tradition actually means, “the natural law”. Thus “Dharmic” pursuit is self-discovery of the “Laws of Nature” as applicable to the subjective world of Man-his feelings, emotions, joys and sufferings, aspirations and aims. This could also be done in a manner akin to the pursuit of science. Development of scientific temper among the people could, in fact, bring into focus the essence of all religions-the universal laws governing the inner world of human beings-and thus promote communal harmony in the society.

Many thinkers have pointed out that the scientific method cannot be directly applied to situations involving abstract attributes like interpersonal relationships, values, ethical and moral norms etc. which cannot be objectively measured. Often, this view arises from a restrictive interpretation of scientific method. However, if we consider a broader view in tune with its spirit and interpret it as sincere application of logic, rationality and verifiability, such difficulties could be overcome by devising proper strategies, for example, discerning the change in such attributes, rather than measuring their actual magnitudes.
13. References

1. Scientific Method @ www.wikipedia.org/wiki/scientific_method
2. Introduction to the Scientific Method @ http://teacher.nsrl.rochester.edu/phy_labs/Appendix E/Appendix E.html
5. Overview of Steiner Education, @ www.ozemail.com.au/~cormhale
7. Krishnamurti Foundation of India-Schools @ www.kfionline.org/schools-index.htm
14. Further Reading


2. F. Capra, The Tao of Physics, Fontana Collins, 1976


4. G.Zukav, Dancing Wu-Li Masters, 1979, Rider, UK
Appendix
(Reproduced from ref. 6, p382 - 383)
A Typical Discovery Lesson Plan

How Is Light Changed When It Passes from Air to Water?

Concepts

A substance that is curved and transparent can be used as a lens.
Light may be refracted (bent) when it passed through water or glass.

Materials

Water
Ruler
Coin
Shallow Pan

Discussion

What is a lens?
How are lenses used?
How do light rays affect the appearance of an object in water?
How can the direction of light rays be changed?
How can light rays be bent?

Processes          Pupil Discovery Activity
PART I

Hypothesizing

Hypothesizing

Teacher’s Note: This activity should be done in groups of two.

How may water serve as a lens?
How do you think a ruler would look if you placed it in a jar of water?

1. Obtain a jar of water and a ruler.
Observing

2. Place the ruler in the jar.
3. Observe the ruler.
   How has the ruler changed in appearance?

PART II

1. Obtain a pan, a small coin, and a jar of water.
   Put the coin in the bottom of a pan. Have a student back away from the pan until the coin just disappears out of his line of sight.

Hypothesizing

How could it be possible for the student to see the coin again without moving?

Designing an experiment

2. Another pupil should gradually fill the pan with water until the pupil observing the pan sees the coin.

Hypothesizing

Why was it easier to see the coin after water added than it was before?

Applying

What must the water have done to the light rays coming from the coin to your eyes?

Inferring

How was the light bent?

Inferring

What conclusions may be drawn from the activity with the coin and ruler?

Teacher’s Note: After the activity you might insert the following diagram and discuss it.