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Diagnosing Learning in Primary Science

DLIPS Report - Part 3

Role of Experiments in School Science

Jayashree Ramadas, Chitra Natarajan,
Sugra Chunawala and Swapna Apte

HOMI BHABHA CENTRE FOR SCIENCE EDUCATION
TATA INSTITUTE OF FUNDAMENTAL RESEARCH

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Swapna Apte, Sugra Chunawala, Chitra Natarajan, Jayashree Ramadas

Contents

List of Tables

Chapter 1

About the DLIPS project

1.1 Students' spontaneous conceptions

A student entering the science classroom has a number of previous experiences, ideas, beliefs and expectations about the natural world. The content taught in the classroom is interpreted by the student in the light of this prior knowledge. As a result of new experiences, mental representation of knowledge undergoes gradual restructuring. Yet, even after formal instruction, students' spontaneous conceptions often remain at variance with accepted scientific ideas. Considering the wide prevalence and the persistence of such conceptions, they have been labelled *alternative conceptions* [14]. Research all over the world has gone into explicating alternative conceptions in different groups of students, and drawing their implications for learning [32].

It is fairly well recognised now that alternative conceptions cannot be easily replaced by correct scientific ideas. One way of looking at this resistance is to imagine that students' conceptions form an interconnected system of beliefs: about the nature of science, of school, of learning, and of the world around. Any one of these beliefs cannot simply be treated as a scientifically inaccurate idea that is easily corrected. That idea has to be understood in terms of a more general world view held by the student, and it has to be also tackled from that perspective.

Knowledge is constructed through interaction with the physical as well as the social environment. Alternative conceptions therefore need to be seen in terms of the context of learning, including the socio-cultural and linguistic background of students, and its relation to the classroom climate. This is what the DLIPS Project set about to do.

1.2 Diagnosing Learning in Primary Science

At the Homi Bhabha Centre for Science Education (HBCSE), research into students' learning has been going on in a consistent way over the last several years. The project 'Diagnosing Learning in Primary Science (DLIPS)' was taken up during 1993-96. The first two years were devoted to data collection, and the third to analysis and writing.

The aim of DLIPS was to diagnose the alternative conceptions of students in a few topics of the curriculum related with their natural environment, to examine these ideas in the light of some socio-cultural and linguistic factors, and to develop the pedagogical implications of these findings.

Prior research on alternative conceptions has been largely done in the developed countries. Consequently, little is known of cross-cultural variations in general, and about conceptions of Indian students in particular. Students in India grow up in a variety of economic and socio-cultural backgrounds. Although in school they follow a common curriculum, research and other observational evidence suggests that the experience of schooling may actually differ for students from differing home backgrounds. Similarly, girls and boys may experience school in different ways, as a consequence of the differing attitudes and expectations of the society, and of the teachers who are part of the society. It is possible that these factors shape their alternative conceptions.

Other influences on students' world views might arise from their life-styles and their environmental experiences. Finally, the curriculum and textbooks would have their own role to play in shaping students' ideas. Our documentation of alternative conceptions was motivated by these rather complex considerations. Thus we looked in our data for gender differences in alternative conceptions as well as for culturally and linguistically interpretable ways of thinking.

The study was done with middle school students from generally deprived socio-economic backgrounds. Our experience has been that these students, particularly in the school situation, are not used to expressing their own ideas freely. Therefore, instead of using paper-and-pencil tests and clinical interviews that are the usual stock-in-trade of such research, innovative methods were developed for eliciting students' conceptions. These involved regular interaction with students in their classroom over two years, rather than occasional visits for data collection. Through the medium of classroom discussions along with a variety of written tasks, games and activities, students were encouraged to express their ideas related to a given topic. The data analysis was largely qualitative, with testing for statistical significance where appropriate. The results are described in a series of three technical reports:

1. Students' ideas related to living and non-living (DLIPS Part 1)
2. Students' ideas about plants (DLIPS Part 2)
3. The role of experiments in school science (DLIPS Part 3)

1.2.1 Sample

The data was collected over two academic years during which the researchers interacted with students from three residential schools, one in Mumbai city (*Urban*) and two tribal schools in rural areas (*Tribal*) in the Konkan region of Maharashtra State. The urban school is run by a charitable organisation and has a mix of (a) day scholars from poor and lower middle-class families, (b) students belonging to an orphanage, and (c) students institutionalised for vagrancy or delinquency. The school allowed us three class periods per week for interaction with the students. Each class was visited about once per week.

The tribal residential schools or *Ashramshalas* are run by the Tribal Welfare Department of Maharashtra State, in response to the problem of educating children of migrant tribes living in remote hilly areas. Most of the students belong to the larger tribes in the region, such as *Katkari*, *Mahadev Koli* and *Thakur*. Their parents generally make a living by marginal farming, agricultural labour, hunting, food gathering, selling firewood, charcoal and catechu. The Tribal Department allowed us to spend one working day (about six hours) per month with each class.

Both urban and tribal students belonged to grades 5 and 6, and ranged in age from 10 to 15 years. About a hundred students each in the tribal and urban groups participated in the study. The ratio of girls to boys was about 1:2 in the urban school and 1:4 or less in the tribal schools, reflecting a severe gender bias in schooling opportunities. The gender ratio decreased further in the higher grades. The medium of instruction was Marathi, the language of Maharashtra State. The tribal students' mother-tongue was a dialect of Marathi.

1.3 Overview of results

The study was done in the context of a science curriculum which is sometimes excessively formal in its approach particularly when seen against students' spontaneous conceptions. The treatment of "living things", "plants" and "experiments" clearly illustrated the shortcomings of this approach. In all of the topics investigated, we found a mismatch between textbook science and students' conceptions. Nevertheless, the conceptions held by students did show some internal coherence and also consistency within groups of students. Analysis of these ideas led to insights into the nature of learning difficulties in school science.

1.3.1 Living and non-living

Students had their own spontaneous criteria for distinguishing between living and non-living, though these criteria varied with the task context. There was a tendency to mistake non-living for living ('animism') and vice versa ('inanimism'). Natural but non-living objects and phenomena (like the sun, earth and water) were likely to be judged living by students, while human artifacts were less likely to be thus mistaken.

Tribal students displayed better ability to make scientifically correct judgements of life, than did urban students: contrary to the common notion that tribal people are animistic. Gender differences were noticed in the types of non-living objects cited by students, and in their judgements of life and non-life. Girls were found to be more person-oriented, anthropomorphic and animistic.

Students often believed that seeds, eggs and bulbs were non-living, showing up two unexpected alternative conceptions: that a living thing can become temporarily non-living, and that the transition back to living might imply a vital force! What was even more striking was that all the six teachers involved in the project also believed that seeds are non-living. Ambiguous examples from the environment were found useful in clarifying the criteria for life for students and teachers.

Socio-cultural variations in students' ideas about living things might also be related with their attitudes. Tribal students were found to be more positive about plants than animals while urban students preferred animals. The preference for trees amongst the tribals is consistent with the fact that in tribal cultures, there is a direct dependence on plants for survival, shelter, food and medicine. Overall, the tribal students' attitudes reflected their environment and lifestyles, while the attitudes of the urban students seemed shaped by their knowledge through books or stories.

Confirming some common stereotypes, girls expressed dislike towards animals of the lower classificatory order — insects, worms and lizards — more than boys did. "Relation to humans" was the most important factor in determining preference, followed by *appearance* and then *image*. Taking cognizance of students' preferences in designing learning activities would, we believe, improve the quality of instruction in biology.

1.3.2 Plants and forests

Students' ideas about plants were seen to be influenced by physical and social settings and by textbooks. Mere presence of plants in the environment did not result in students being aware of them. Everyday use of, and interactions with, plants and plant products had a greater influence on students' ideas about plants.

For example, despite having a large variety of vegetable plants around the *Ashramshalas*, tribal students chose to describe fruit trees, flowering trees, garden plants, and other trees and plants of local social, medicinal and religious significance. On the other hand, urban students who had many of the above trees around their school, preferred to describe only a few typical fruit trees and common garden plants. Overall, the variety of plants described by tribal students was much larger.

There was a wide gap between students' spontaneous ideas about plants — which were varied and rich in ecological content — and the knowledge in the textbooks. Tribal students incorporated in their drawings of plants and forests, many features that reflected their understanding of ecology, like leaves floating to the ground, a sapling near the tree, or humus, twigs and logs on the ground, food webs, and other interdependences in the forest ecosystem. Tribal students' keen observations were further evidenced in the many instances they gave of seasonal features, like references to time of flowering, shedding and sprouting of leaves, etc.

In contrast to textbooks, students gave few detailed structural descriptions, focusing rather on gross shapes. Tribal students drew realistic pictures of a large variety of fruit, flowering and other forest trees, often correct in placement of leaves, fruits and flowers. They frequently expressed their feelings towards plants, unlike textbooks, which tend to underplay feelings. Tribal students tended to relate their feelings about forests and individual trees to their uses. The uses which they gave compared well with those cited in advanced botany textbooks.

Textbooks however depict very few whole plants or trees, nor do they incorporate affective or ecological features in the pictures they do give. Classroom intervention is necessary here. The study of botany can become meaningful to students only if ecological features, seasonal variations and affective factors are woven into classroom teaching through appropriate activities and interactions that highlight the relevance of this knowledge in everyday living.

1.3.3 Experiments

This study was concerned with some conceptual problems arising while teaching science through experiments. In it, an analysis of the role of experiments in science and in pedagogy was combined with empirical data on textbooks and on students' perceptions of experiments.

The empirical study showed that students used the idea of experiments in a variety of contexts, thus over-generalising it. On the other hand, in the case of specific experiments related to science, students sometimes felt that only scientists or teachers could do experiments. They did not connect an experiment to a question or hypothesis.

Given an experiment and a set of questions, students had difficulty relating one to the other. Students freely drew unwarranted conclusions from experiments. Sometimes, they had difficulty in distinguishing their own beliefs about the phenomenon, from the evidence presented by the experiment.

The hypothetico-deductive view that is presented by science textbooks has many difficulties associated with it, some endemic to experimentation in science, others arising from cognitive limitations and pedagogical needs. Textbooks themselves were found to be guilty of obscuring the connection between experiments and questions by calling for very high levels of inference, often leading to untenable conclusions.

In the context of Indian schools, the idea of experiments as activities performed by people in authority, perhaps only reflects the actual state of affairs. Similarly, the over-generalisation of the word "experiment" is to some extent also present in textbooks. The models of experimentation held by students and those presented in textbooks were found to differ from scientists' and philosophers' models of experimentation. Each of these however, has aspects that can help us to formulate desirable models of experimentation for science learning.

Four papers based on this work were presented at the Second International Symposium on Cognition and Education at Varanasi in December 1995. The DLIPS project will form an input into the writing of textbooks for primary science, which is being undertaken in 1996.

Chapter 2

Introduction: The study of experiments

Experiments are central to the enterprise of science; and for learning, they are invaluable. Ideally therefore experiments should be indispensible to science teaching. Regrettably, this is not so in most Indian schools. Science curriculum developers and textbook writers do try to introduce at least a minimum number of experiments in the curriculum, and to some extent, these experiments are demonstrated by teachers in at least some schools. But their incidence remains low. The reasons given are mostly practical, involving lack of time, shortage of equipment etc.. But it is also likely that the importance, and significance, of experiments is simply not realised by teachers, teacher-educators and administrators. In all of the projects carried out by the Homi Bhabha Centre for Science Education, the component of experimental work has been found to be the most difficult to implement.

The DLIPS Project tried to probe some conceptual problems involved in the use of experiments in science teaching, which arise from a confusion about the role of experiments, in the minds of students as much as in textbooks. We explored the significance of experiments for science education, collected data on the way students relate to experiments in the curriculum, and through an analysis of textbooks, looked at the present status of experiments in schools of Maharashtra State.

The empirical part of the study is based on data from three sources:

1. experiments in the current primary science textbooks of the State Government of Maharashtra (India)

2. group interviews with students of grades 5 and 6 regarding their views about experiments

3. classroom interaction with the same students to explore and develop their notions of experiments.

The report is organised as follows. A brief review of the role that experiments have historically played in science (Chapter 3), is followed (in Chapter 4) by a comparison with their role in the classroom. The possible roles that experiments can play in science classrooms are in some ways similar to, and in other ways quite different from, the role of experiments in science. This theme is further expanded, based on the results of the DLIPS project.

In Chapter 5, research on students' epistemologies is reviewed, which has a bearing on how students perceive experiments. Group interviews to probe students' views of experiments are reported in Chapter 6. These views were found to differ significantly from the hypothetico-deductive (h-d) view of science that is explicitly outlined in their textbooks. Some of the classroom interactions that were taken up to develop students' ideas of experiments are listed at the end of this chapter. Chapter 7 presents some data on their relating of beliefs with experimental evidence. This discussion points up to some of the reasons that the h-d view might not work in the classroom.

Analysis of the textbooks (Chapter 8) shows some more problems. These arise from a conflict between the overt formal view of experiments presented by the textbook, and their hidden pedagogigal objectives.

Historically, the h-d view entered the curriculum because of the perceived need to present science not as a mere collection of facts, but as a process of discovery and theory-building. How one should go about this is still an open question. The exploratory work done in classrooms makes a beginning. Based on this analysis, alternative pedagogical objectives are suggested for experiments.

Chapter 3

Experiments in science

Experiment is one of the hallmarks of science. We take it for granted that experiments are done, yet we rarely reflect on what exactly is the role that experiments play in shaping our understanding of the world. In the last century, some scientists, and many others, who are philosophers, historians and sociologists of science, have analysed the role of experiments in science. They have looked at the rationale for doing experiments, the processes involved in experimentation, and the relationship between experiments and the growth of scientific knowledge. What follows is an elementary introduction to these ideas. This background will help us to analyse the role of experiments in school science, and further, to understand the kind of ideas students hold about experiments.

3.1 Magical origins

From the time that humans first appeared on this earth, they have been fascinated by natural phenomena, trying always to gain control over them. The magical traditions of ancient times arose from this sense of wonder about nature, and from the urge to manipulate it.

Early experimental science had its origins partly in traditions like alchemy. Even today, the romantic appeal of experiments comes from the feelings of power and wonder that they evoke. This is especially true for experiments done by and for children.

3.2 The engineering role

Human beings from ancient times have shown an urge to continually improve their ways of living. They have tinkered with materials, developing important technologies like metal-working, architecture and ship-building. For this, they needed to "experiment", to try different ways of doing things, selecting the ones that were the most appropriate to the task. Often, their aim was not to test a theory or to find an explanation, but simply to produce a desired phenomenon in the most efficient way. This phenomenon could be say, a particularly attractive colour, a malleable metal, or high stability in a structure. Further sophistication in technology followed from the needs of navigation, surveying, cartography and fortification.

The efforts of these people from ancient times resulted in great feats of engineering and invention, ultimately paving the way for what we now call "science" [6] [20]. In the history of science, there are numerous examples of science developing out of experiments that were done with purely technological motivations [19].

In the debate on science, this "engineering" role of experiments has unfortunately remained neglected and under-valued. Nevertheless, as we shall see in Chapter 4, the engineering role of experiments happens to be crucial in education.

3.3 Classical Greece

Greek mathematicians and philosophers, starting from the 5th Century BC, developed the method of "deductive proof". To "deduce" means to derive a conclusion by reasoning logically from some premises. If the premises are true, then a series of simple steps leads to a conclusion, which may not have been obvious before, but which is now seen to be necessarily true. This method flowered fully in the works of Euclid, around 300 BC.

The intellectuals of classical Greece preferred the deductive method to the exclusion of all other ways of gaining knowledge (for example, by experience). They believed that deduction was the only way of getting at absolute, certain truths. Although early Greek philosophers, like Thales, used mathematics in practical applications, soon there came about a tendency to look down on practical work, on trade and technical skills [26].

Even a great scientist and inventor like Archimedes thought that mechanics was a lower form of activity than mathematics [11]. Astronomy was seen as merely observation, and the most important task was to create mathematically perfect models of the cosmos. In this era therefore, experimental science did not develop much, except in specific applications like military-arts and navigation.

3.4 Indian and Arabic science

Experimentation of the engineering kind did exist in Ancient India, as can be inferred from the remarkable developments in the practical sciences, most notably in *Ayurveda* [33] [25]. *Ayurveda*, developed during the post-vedic period (600 BC –400 AD), was concerned with the preservation of human, animal and plant life. It attempted to combine internal medicine and surgical techniques with theoretical analyses of the functioning of the body. However, by and large in India too, the practical and the speculative sciences remained separate, to the detriment of both.

The most systematic use of experimentation in early times occured during the Golden Age of Arabic Science (700 AD –1200 AD), when science was turned from metaphysical speculation into experimental and operational paths. The Arabs made extensive contributions in various fields. Of these, experiments were most important in the fields of optics, chemistry, biology and medicine. The scientist Al-Haytham' (also known as Alhazen) took a rigorously experimental approach to physics: his *Optics* cites no authority but that of empirical evidence [34].

3.5 Scientific method (Induction)

Early thinking on scientific enquiry came from Aristotle (384 – 322 BC). Aristotle said that scientists start with observations, from which they "induce" general explanatory principles (the process is called "Induction"). From these principles, they "deduce" statements about phenomena. Aristotle, however, did not specify in great detail the inductive part of this process, and his followers corrupted his method to lay undue stress on deduction: not from observational evidence, but from Aristotle's own sayings! [29]

Thus, in those days, a widely accepted way of gaining knowledge was to speculate about the world, and in times of disagreement, to consult the sayings of older authorities like Aristotle and the Bible. Galileo (1564 – 1642), known today as the first great experimenter, changed all that. He brought about a revolution, not only in science, but in the way that people thought about scientific knowledge. Galileo showed that reliable knowledge must come from first-hand experience, not from appeal to some authority. Francis Bacon (1561 – 1626) analysed this new view of the process of science, and outlined a "Scientific Method".

Bacon's "Method of Induction" involves several steps. First, data is collected through observation and systematic experimentation. Then it is written down in a proper and well-arranged fashion. Next, certain rules are applied to the data to derive axioms. Finally, predictions are made from the derived axioms so that their validity and generality can be confirmed [4].

The importance of Bacon's method was that it helped to clearly separate science from non-science. The use of observation and experiment is what distinguishes the scientific approach to nature from the ways of magic, theology and speculation. Bacon was instrumental in helping to gain recognition for experimental research as a legitimate activity of scientists.

3.6 Scientific method (Deduction)

Aristotle's was the first attempt to apply the deductive system to science. Ever since Euclid (300 BC) laid out the deductive system for mathematics, scientists and philosophers have tried to fit science into the same logical mould. Leonardo da Vinci in the 15th century advocated that "practice should always be based on a sound knowledge of theory".

The method of induction, in its simplest form, assumes that unbiased observations (from experiment or otherwise) lead to the discovery of new facts, and that theory is obtained from a generalisation of facts. In contrast, adherents of the deductive view (for example, Descartes, 1596 – 1650), tried to begin with generalisations to arrive at facts.

As the natural sciences, in particular Physics and Chemistry, developed, theory came to play in them an increasingly important role and with it, deduction gained prominence. Many scientists contributed to the development of deduction as a method of science. Prominent among them were Galileo, Newton and Herschel.

More recent philosophical contributions to this work have come from Karl Popper and Imre Lakatos. The idea that in science we start with hypotheses, design experiments to test the hypotheses, and deduce conclusions from the results, is known as the hypothetico-deductive (h-d) view. Extreme forms of this view claim that experiments are merely a test of theory, and that all observations and experiments are performed on the basis of expectations deriving from theory.

Either the deductive or the inductive aspects of science have from time to time held prominence, but generally, an integrated view remains, in which it is understood that both theory and experiment build on each other in the creation of a body of scientific knowledge. In fact, at every stage in the development of any science, there is a certain dynamical relationship between experiment, technology/ inventions, and theory. It is important that at every stage of learning too, such a relationship is established.

3.7 Positivism and the popular conception of science

In the early part of the 20th century, a strong intellectual movement came about in Europe, called "Positivism". Positivism came down heavily against speculation in science; its adherents stressed that statements about the world had meaning only if they could be verified empirically, that is, by observation and experiment. This way of thinking was really an extreme form of Inductivism, for it said that a theory was not even worth considering, unless it was supported by observation.

Very few scientists hold such an extreme view today, though more moderate versions of positivism do exist. Interestingly, positivism has a strong appeal to the popular conception of science: that it is based on facts of experience, on things that we can see, hear and touch. Any controversy in science is supposed to be resolved by observation or experiment. This popular view is sometimes termed "naive inductivism" [10]. It is a position that is easy to grasp intuitively. Research done with students (see Chapter 5) shows that this conception of science is fairly widespread. Often it does not even allow for the fact that experiments are guided by theory.

3.8 Theory-dependence of observations

The extreme inductivist view lost support mainly due to the work of the philosopher Karl Popper. One of the arguments against induction is that pure, unbiased observations simply do not exist. Observations are always combined with interpretation [21]. What we perceive of the world depends in part on our expectations, which are derived from past experiences and prior knowledge. This idea, which arose with Descartes, is supported by a large body of research in Cognitive Psychology [1], and also by evidence from the history of science [22], [12].

Further, the way in which observations are stated, requires the use of terminology and concepts, which pre-suppose some kind of a theory. Since theories can, at a later date, be discarded in favour of better theories, it follows that the observations which had assumed these theories, are also fallible. To give a simple example, early experimenters in static electricity reported that electrified rods became "sticky" [10]. When these observations were first made, there was no theoretical basis for using the terms "attraction" and "repulsion". Later, when the theory became available, this description could be replaced by one assuming forces of attraction and repulsion acting at a distance.

Only if an experimenter has some idea of what to expect from an experiment, would he or she be able to recognise or interpret the results. Even what are popularly known as accidental discoveries, could only be grasped by a mind that was already prepared to see their significance [12].

3.9 Studying the practice of science

Induction and deduction are both concerned with the logical process of science. In the later part of the 20th century, attention shifted to the social context of scientific discovery. It was recognised that a new result in science becomes an established 'fact', only when it is so accepted by the scientific community. The process of acceptance is often not strictly logical [5]; its important aspects are psychological and sociological.

Early historical and sociological studies of science (eg. Kuhn) continued to emphasise the theory-building process, seeing experiments as little more than a means of getting at empirical data. This is not surprising, since any good scientist, when presenting the results of an experiment, does so in the context of a theoretically well-formulated problem. The experimenter tries to show that decision between alternative theories rests on the verdict of the experiment. Thus the "public account" of an experiment focusses only on the results, and on the arguments for them [17]. The process of experimentation is not examined. This is entirely consistent with the aim of science, which is to go from particular results to general conclusions. In education however, going from the particular to the general happens to be only one of many aims. It makes sense here, to give importance not merely to the results of experiments, but to the processes involved in the practical work, and to the act of making meaning out of it.

Recently, experiments have begun to be studied in detail [17] [13] [27]. These studies document the motives behind selecting a problem, the interaction between experimenter and instruments, the interpretation of observations, and the process of argument and persuasion that is necessary before the results are accepted by the scientific community.

The unique contribution of these studies of experimental science has been in their analysis of what is called the "material culture of science" [27]. This includes the practical imperatives of choosing certain modes of investigation, including instruments, procedures and strategies, and manipulating various parameters till the experiment is found to "work". It is too early to say, but this research may eventually better our understanding of the role of experiments in teaching.

Chapter 4

Experiments in science teaching

4.1 Looking for parallels between science and its teaching

For many years after science acquired a place in the school curriculum, it was seen as a body of often unrelated facts, to be transmitted to students. Neither experimental methods nor theoretical coherence played much of a role in teaching. But the evolving views about the nature of science did eventually influence curriculum development. The inductive view has been the most influential, followed by the hypothetico-deductive view.

4.2 Influence of the inductive view

In the 1960s and '70s a powerful new idea was introduced into the science curriculum: the idea of learning science by doing science. Science was seen not merely as a collection of facts; but as a way of thinking, a method of finding out about the world around us. If the teaching of science is to reflect the nature of science, went the argument, then students should not be asked to memorise facts, but to explore, investigate, discover, and engage in authentic problem-solving. This idea, which arose in the USA and UK, eventually led to a worldwide movement for curriculum reform in school science. With the benefit of hindsight, it has been remarked that the new approach to teaching was perhaps a combination of the then-new child-centered theories of education, and the positivist influence in the philosophy of science.

The emphasis on practical activity in many of the new curricula was also accompanied by an impressive attempt to present science as a coherent system of ideas. These curricula aimed to integrate concepts under larger theoretical ideas, like, atomic theory and evolution. Their weakness probably lay in the lack of connections between the experimental observations and theoretical ideas.

The new approach to science teaching was enthusiastically taken up by many innovative curriculum development agencies in India, including the NCERT. At the national level at least, it did not meet with much success. The discovery approach was found to be too ambitious for the majority of classrooms. Similar disappointing results were obtained in other countries which had had the benefit of better facilities, generous funding, and better training opportunities for teachers.

A number of arguments were advanced for the failure of the discovery approaches to deliver results. One of these was that the approach was itself not an accurate reflection of the process of science. There was too much emphasis on inductive methods, little appreciation of the complex relationship between observation and theory, and a neglect of the activities of the scientific community in validating and disseminating scientific knowledge [23]. The practice of enquiry learning was thought to reinforce a "scientistic ideology": a belief that the scope of scientific authority is unlimited and beyond reproach [15].

Other criticisms of the discovery approach were that it encouraged naive realism, a *tabula rasa* view of the mind, a credulous faith in the existence of the 'critical experiment', and a belief that science brings us gradually nearer to the truth by a process of accumulation of facts (Nadeau and Desautels, cited in [8]). The tabula rasa view was directly opposed to the idea that observations are dependent on theory.

4.3 Developing enquiry skills

The discovery approach did have one very happy consequence: from that time onwards, practical work came to form a necessary component of all science curricula, in most countries of the world. Most educators now acknowledge that practical work has two main roles to play. One is in helping in the understanding of science concepts, the other is in developing skills of scientific enquiry. These process skills like, "observing", "classifying", "identifying patterns", "conducting controlled experiments", "measuring", "tabulating" and "graphing", are now part of the vocabulary of science curriculum development.

Emphasis on enquiry skills is however questioned by some educationists. Millar [31] argues that the processes of science are actually features of general cognition which are used by everyone. They need not be taught explicitly, nor is it possible to teach them as skills isolated from the content of science. Many of the criticisms also derive from the practical difficulties in assessing enquiry skills.

4.4 Influence of the hypothetico-deductive view

Many of the well-designed discovery curricula did attempt a rather naive hypothetico-deductive model of science. Unfortunately, they did not take account of the significant intellectual effort required to make the connections between observations and theory. Practical work in these curricula was therefore easily interpreted in a naive inductivist way.

After this experience, some educators pointed out that it is not enough to develop enquiry skills; students should be able to subject their scientific enquiry itself to a process of enquiry. That is, they should reflect on how they come to understand something, and where their present ideas originate. Again, this approach shifts some of the emphasis of experiments on to theory-building and metacognitive analysis of the theory-building activity. A curriculum unit based on this idea has actually been attempted [8].

4.5 Implications of theory-dependent observation

A lot of attention has been given in recent years to the idea that observations are dependent on theory, that what we see depends in part on what we know already, and what we expect to see. In science education, this idea received further support through the study of "alternative conceptions" [14]. As outlined in Chapter 1, students have a number of experiences, ideas, beliefs and expectations about the natural world. The content taught in the classroom is not simply transmitted — with or without errors — to the students. Rather, it is interpreted by them in the light of their prior knowledge.

Students, not unlike scientists, can be rather slow in giving up their preconceived notions, even in the face of empirical evidence [16]. Their prior conceptions also affect their interpretion of the results of experiments [18].

We noted earlier that the correct interpretation of an experiment depends on the availability of certain concepts and terminology. This point is probably even more relevant for students than it is for scientists. The terminology and concepts assumed by the textbook would not be those held by the students. Thus, their observations and descriptions of phenomena are likely to differ from those expected by the teacher.

One need not look to research studies to show that this in fact happens: a common experience of teachers is that a single experiment can be described by several students in widely different ways. It is precisely for this reason that teachers often cue students before the experiment, towards what they should expect to observe. For example, the experience of observing a biological specimen under a microscope: unless the standard textbook drawing is given to students beforehand, they are likely to miss the essential features and record irrelevant ones.

4.6 Cautionary remarks on theory

The role of theory in school science is circumscribed by the pedagogical objectives of experiments. In the classroom, often the very purpose of an experiment is to introduce the relevant concepts and the terminology. To this end, one does experiments that serve to simply categorise phenomena (see Chapter 8). One should not confuse this pedagogic mode with the manner that a scientist might, at another time, have done the same experiment.

An experiment in science serves to either confirm or refute an accepted theory. It is therefore planned so that alternative interpretations are, to the extent possible, ruled out. By the very nature of classroom experiments, this is not possible to do. One cannot always control all the variables that one can think of.

Even though an experiment may be done by students, the teacher is constantly called on to guide its course. The teacher decides what variables to explore, and how to explain (or explain away) discrepant results. Classroom experiments cannot, therefore, be considered to be real tests of theory. If they do not yield the results that they are supposed to, then those results will be simply discarded. The textbook or the teacher will then stand as the final authority.

Finally, the assertion that "observations depend on theory" should not be taken to mean that the correct theories should be introduced before tackling experiments, or that all experiments should be motivated by prior expectations. Rather, for students, one can make a case for simply "messing around", for gaining experiences about the world that need not be immediately crystallised into well-developed theories.

4.7 First-hand and second-hand enquiry

There are other important differences between science in schools, and the work of practising scientists. A scientist's knowledge is obtained through first-hand inquiry, while a student's inquiry is aimed at verifying some piece of knowledge that may be common among scientists. Blurring the distinction between the two may afford some temporary pleasure to students, but ultimately, this approach would be misleading and dishonest.

Kyle [28] says that scientific inquiry is performed "after a person has aquired a broad and critical knowledge of the subject matter through formal learning processes". Students should not be led to believe that they are performing 'scientific enquiry' when in fact they are learning.

Woolnough and Allsop (cited in [30]) suggest a way to clarify this distinction, and yet to retain meaning in student investigations. They recommend that the problems dealt with in school science should explicitly concern specific local issues, and not aim at generalisations. In this way, the results would only be expected to hold locally.

This however, is not a very satisfactory solution to the problem. Ultimately, the link between theory and experiments needs to be established. How to do it without resorting to rote learning on the one hand, and avoiding intellectual dishonesty on the other, is a thorny question. To some extent, the question has been addressed by recent "constructivist" teaching strategies [36]. In general these strategies, like those of Carey et. al. [8], depend on getting students to make their own ideas explicit, and to subject these ideas to critical scrutiny, in the light of both experimental results, and the conceptual models deriving from science.

One should be aware there are always logical problems in connecting experiments with conclusions. But more importantly, experiments have important pedagogical value, which we hope to bring out.

4.8 Engineering vs. science models

A common distinction one tries to make in school science is between an activity and an experiment. The educational philosopher John Dewey (quoted in [35]) suggested that there are two ways of interpreting scientific activity: as practical exploration for purposes of achieving a desired effect, and as investigation for achieving scientific understanding. He suggested that students' spontaneous interest in generating effects may help engage them in the reasoning process, if accompanied by "thoughtful effort".

Schauble et. al.'s [35] study is briefly described in Section 5.3. These researchers support Dewey's recommendation of starting with practical activities aimed at producing a recognizable outcome. Dewey suggested growing healthy plants or baking a delicious cake! The next part is to let the students' interest shift naturally, away from results, towards understanding the means for achieving them. Schauble et. al. say that tasks with a recognizable goal may provide an easier entry point for students, and they may also be more motivating.

However, experiments producing spectacular effects have their down side too, for the students' tendency is to remember a magic effect and to forget the principle, or to concentrate on getting expected results rather than considering alternative interpretations. Sustained effort is thus required for the transition from the engineering to the science models. One possibility is to repeatedly ask students to make predictions and to justify their conclusions with "what did you learn?" and "how do you know?".

4.9 Presenting science as a human activity

In the current view of science, importance is given to the process of consensus amongst a community of scientists. Applying this view to education, a crucial aspect of any school science experiment ought to be a classroom discussion. The discussion should enable communication both among students, and between students and the teacher. This would let students examine their own alternative conceptions in the light of other competing ideas. It would also convey to them the importance of discussion and debate as a part of scientific activity.

Chapter 5

Research on students' epistemologies

5.1 Stages of development

By "students' epistemologies" we mean, how students understand the process of acquiring knowledge about external reality. Jean Piaget carried out path-breaking research in this area. Inhelder and Piaget [24] studied the responses of students in the age groups from 5-15 years on a variety of experimental tasks, largely deriving from physics. They found a series of stages.

The youngest students were "precausal", that is, they gave explanations involving animism, final and moral causes etc., and generally ignored mechanical causation. They were unable to record experimental observations, because they relied on global ways of thinking, and often could not distinguish their own actions from the motions in the apparatus. A child at this age, therefore, had difficulty in understanding the point of even simple experimentation. Piaget and Inhelder found that with increasing age, students gradually became better at reporting empirical data. They could use operations like classification and seriation to organise their data, and could handle single variables at a time.

However, the full logic of confirmation became available to them only at the final stage, which occured around 13-15 yrs. At this stage, students were able to entertain and evaluate hypotheses in a systematic way. They could distinguish clearly between possibility and reality; they could isolate and control variables in multiparameter situations, understand the role of random variation, and use correlational reasoning.

Inhelder and Piaget's results have been often replicated, except for the last stage; but their interpretations have been criticised [7].

5.2 Common-sense epistemology

Carey et. al. [8] reviewed research in this area. They concluded that there is some indirect evidence to show that young adolescents hold an "inductivist, scientistic view of the nature of scientific knowledge and its aquisition". The research which they cite, on common-sense epistemology, found that young adolescents do not differentiate between beliefs and the world, between accounts of the world and the world itself, and between knowledge and reality. Carey et. al. concluded from their study that students' failures in designing experiments and interpreting data are due to a to lack of metaconceptual understanding of the distinction between theory and evidence, and between understanding and producing a phenomenon.

Later research on scientific reasoning continued to find that preadolescents were not able to distinguish theory from evidence. However, research with younger children [37] found that first and second graders were capable of doing so in simple task contexts. The literature on children's theory-of-mind [3] finds that even at age 4, children are able to answer questions about the source of their beliefs, while at age 7, they recognise that knowledge depends exclusively on the availability of critical evidence [2]. The problem thus seems to occur only with complex tasks involving several potential factors, as for example in school science.

Solomon et. al. [38] remark that in common English usage, "experiment" is used as a last resort in situations where people have no idea what to do or expect, as in the expression, "We'll just have to experiment". Here, experiment implies trial-and-error. This study also found students believing that when scientists do experiments, they have no expectations about the results. Other stereotypes of scientists found in this study included, scientists as all-knowing (most experiments had already been done), as technologists, and as teachers. Very few students thought of scientists as seeking explanations for phenomena. In fact, students often did not differentiate between "explanation" and "description". This study also, like that of Carey et. al., found that students' epistemologies could become more sophisticated through appropriate instruction (in this case, the use of a historical approach).

5.3 Models of experimentation

The influence of students' a-priori ideas on their planning of experiments was studied by Cauzinille-Marmeche et. al. [9]. They found that 11-13 year-old students used experiments to resolve differences of opinion, and thought of them as a method of proof. They did not find it important to test out factors on which there was already agreement amongst them. They also expected that replication of an experiment would always yield identical measurements. Consequently, they attempted replication only when the results contradicted their expectations.

Schauble et. al.[35] did an interesting study of students' understanding of experimentation. They hypothesised that the observed inadequate inquiry strategies of students may result from their alternative model of experimentation. They did in fact find students holding on to an "engineering model" of experimentation, as compared with the "science model" assumed by the curriculum.

Students holding the engineering model assume that the goal of the experiment is to make a desired or interesting outcome occur, rather than to understand relations among causes and effects. Consequently, the strategy they use is to compare highly contrastive instances, instead of focusing in turn on the effect of each potentially important variable. Their inferences turn out to be inclusion or causal ones, rather than exclusion or non-causal ones, and inferences of indeterminacy. In other words, from a limited experiment, they jump to the conclusion that a certain factor is effective, and they ignore other factors, or negative results. They focus on variables believed to cause the outcome and stop when the desired outcome is achieved. They do not seek to systematically test all combinations of variables.

Schauble et. al. make the important point that students' strategies and their "errors" are in fact highly consistent with the model of experimentation that they hold. From an engineering perspective, the goal is to obtain a given outcome. Thus the most efficient strategy may well be to simply cluster all features believed relevant to the desired effect. In trying to attain a practical result, it is often better to focus only on variables believed to be effective, rather than to spend time establishing that other variables do not play a role !

Chapter 6

Students' views of experiments

The curriculum for Grades 5 and 6 in Maharashtra State introduces the idea of experiments in a formal way. The term 'experiment' is displayed prominently and frequently in the textbook for the first time in Grade 5, while in Grade 6, the hypothetico-deductive view of science is presented explicitly. An indication that the concept of 'experiment' may be problematic at this juncture, came from a spontaneous question asked to the researchers by several students in Grade 5 of the urban school. The question was "What is an Experiment?". Apparently, students were conscious of being exposed to a new idea; and they were trying to work out its meaning for themselves.

Before the students' question was taken up for response, it was put back to them in the form of a short exploratory questionnaire. Earlier interactions with these students had shown that they tended to be reticent in individual interactions; a better way of encouraging them to express their ideas was by talking in small groups. The questionnaire was therefore administered via interviews conducted with groups of 5-8 students. There were 24 groups in all, 13 Tribal and 11 Urban. The questions were as follows:

- Q1. What is an experiment?
- Q2. When and where did you first hear the term "experiment?"
- Q3. Who does experiments, and where?
- Q4. Have you seen experiments being done? Give examples.
- Q5. Will you be able to do experiments? Have you done any experiments?

- Q6. For what reason/purpose are experiments done?
- Q7. What things are needed for doing experiments?
- Q8. Can you think of any other examples of experiments?

6.1 Results of the group interviews

Q1./Q6. What is an experiment?/ For what reason or purpose are experiments done?

Table 6.1 shows that the most frequent justifications for doing experiments were, "to understand something", "to observe" and "to get information". However, the common theme which ran through all the responses was: "doing. An experiment was largely equated with "activity": 5 of the 24 groups talked exclusively about "doing something", without any reference to the purpose of the activity. Experiments were also seen as "doing something that is given in the textbook", and they were often associated with "drawing diagrams".

Table 6.1: What does an experiment involve ? Students' responses (%)

Response	Q.1 What is an expt.?	Q.6 Why is an expt. done?
Observing	42	29
Comparing	13	4
Getting information/ knowledge	13	42
Understanding	21	63
Proving	13	8
Just doing something	21	—
Making things/ working with hands	21	13
Drawing diagrams	17	—
Reading	4	—
Entertainment	4	8
Achievement in school	—	17
Just tautology	4	21
Discovery	—	17
Science	—	17
No response	4	—

The statement that experiments are done to “prove something” was made by three of the groups, but, when probed, it turned out that two Marathi verbs “*siddha karne*” and “*siddhis nene*” were being confused. While the former means “to prove, the latter refers to carrying out a process or a ritual (sometimes, a religious ritual) to some conclusion!

Q2. When and where did you first hear the term “experiment?”

For all except one of the groups, the word “experiment” was first introduced in school, and for two (both Tribal groups), it remained the only context in which they used it. One student mentioned that he had first heard this word in the context of magic shows.

Table 6.2: Where and when did you hear the word experiment for the first time? Students' responses (%).

	Tribal	Urban
Only in School (Book/Teacher)	8	
in Std V	4	8
in Std IV	29	13
in Std III	8	17
in Std II	4	4
in Std I	—	4
Total in School	54	46
Outside School		
Magic shows	4	—

Q3. Who does experiments, and where?

Tables 6.3 and 6.4 show the responses to this question. The persons most frequently to be seen doing experiments were, teachers, students and scientists, in that order. Other responses like, “doctors”, “educated people”, “important people”, “sahibs”, “parents” and “magicians”, were also interesting. Remarkably, 6 of the groups (5 Tribal and 1 Urban) omitted “students” from their response (although in response to later questions they did give examples of experiments that they had done, or seen done, in class).

Thirteen of the groups mentioned only school/ laboratory contexts, and some of these were severely restricted: for example, “only teachers, and they do them on the black-board" or even, "only Mr. X (teacher) does experiments". For a large number of students therefore, experiments were something to be done by teachers, elders and important people, not by themselves.

Table 6.3: Who does experiments ? Students' responses (%)

Who	Tribal	Urban
Teachers	38	42
Scientists	13	25
Students	25	42
Doctors	13	—
Educated People	8	4
Magicians	4	—
Elder People	4	4
Parents	4	4
Everyone	4	—
Not Students	21	4

Table 6.4: Where are experiments done ? Students' responses (%)

Where	Tribal	Urban
School	25	29
Out of School	29	17

Q4./Q5./Q8. Kinds of examples of experiments given by the 24 groups.

Questions 4, 5 and 8 were meant to identify the specific experiments that were known to the students. In the group interview situation, it was not possible to probe exactly to what extent students themselves had participated in doing these experiments. Still, the researchers had some first-hand knowledge of the schools, and also, knowing the generally low incidence of experimentation in Indian classrooms, this participation was likely to have been limited. Students did, however, give a number of examples of experiments, largely from the school curriculum. These were roughly classified into three categories: (1) activities/ observation (2) comparison of two events and (3) magic/ demonstration.

The numbers in brackets eg. (m/n) refer to (number of examples/ number of instances of these examples)

Activities/ observation (22/23 non-science, 33/75 curricular science)

Earlier results (from Q.1 and Q.6) indicated that students related experiments with "doing something". It was not surprising therefore that most of students' examples fell into the "activities" category. These activities seemed to be purely (in Dewey's sense) practical explorations for the purpose of achieving some desired effect. There was no apparent intention to observe cause-effect relationships. The kinds of non-science examples in this category were, carpentry ("making chairs and tables out of wood"); moulding shapes out of wax, clay and paper mache; making sling-shots to drop tamarind from trees; pasting pictures; watching TV; doing gymnastics; playing cricket; constructing a school building.

Several science-related experiments (eg. evaporating salt-water, observing skin of onion, parts of germinating seed) were also described by students in a similar way, i.e., as activities, with rare reference to any understanding that followed from them.

Comparison of two events (12/32 curricular science)

A special class of experiments that that were often described with reference to cause-effect relationships, were those involving comparison of two events. Early in the science curriculum, a simple idea of controls is introduced through such experiments: for example, comparing a plant in a dark room with one kept in sunlight, or seepage of water through clay versus sand.

Magic/ Demonstration (producing an effect) (11/13 non-curricular science)

These were examples of striking demonstrations which students had seen, sometimes at science exhibitions, or read about. Two books, "Experiments are Fun", and "Novel Experiments", published by the Homi Bhabha Centre for Science Education, were known to students; sometimes the experiments in them had been tried out in the class. The magic-like effects of such experiments (eg. "lighting a bulb with a matchstick", "dancing candle", "atom bomb") were recalled by students, though with no mention of the cause-effect relationships involved.

6.2 Summary of students' views

To summarise, students often equated "experiment" with "activity" i.e., with doing something with one's hands. The word "experiment" was over-generalised to a wide variety of contexts, from carpentry to gymnastics. On the other hand, students tended to under-generalise, i.e., restrict the context, when it came to the specific experiments related to science. These were thought to be done largely, sometimes exclusively, in school, by a few teachers or older people. Experiments were related with textbooks and with drawing diagrams.

These results should be seen in context of the situation in Indian schools, and particularly the state of the science textbooks, described later in this paper. The idea of experiments as activities performed by people in authority, perhaps only reflects the actual state of affairs in the schools. Similarly, the over- generalisation of the word "experiment" is also something that is noticed in textbooks.

Students' views: An observation on language

Another way that the simultaneous over- and under-generalisations noticed here can be reconciled, is via an observation on the Marathi language. The word *"prayog"* in Marathi refers to an experiment, as well as to a performance of a play, or a magic show. Thus an experiment might be perceived as a "performance" or a "show". It is a performance by an expert, using equipment, and its aim is to show something. In this sense, experiment is not spontaneously related to a question that is being posed.

6.3 Classroom Interactions

The group interviews showed that students had little idea of the motivations behind doing experiments. In particular, they did not realise that experiments were done to satisfy some curiosity, to answer some questions. In the sessions following the group interviews therefore, the students were explicitly told that there is a close relationship between questioning and experimenting, and that experiments are done to answer questions.

Several classroom activities were taken up to reinforce this idea. These were of the following types:

I Relating a given experiment to the question(s) it answers.

II Doing an activity and asking students to raise questions based on their observations.

III Raising questions through an activity and doing a sequence of experiments to answer these.

IV Skill development: activities on measurement.

V Practice in doing a variety of experiments.

The first of the activities listed above is discussed in some detail in the next Chapter and in Apendix A. The other activities are given in Appendix B.

Chapter 7

Linking experiments with questions

The observation that students did not spontaneously link an experiment with a question that was being posed, may be related with their epistemological beliefs. As discussed in Chapter 5, one of the reasons could have been a difficulty in evaluating a given phenomenon in the light of their beliefs about the causal factors operating to produce it. The students then would have difficulty in distinguishing their own beliefs about the phenomenon, from the evidence presented by the experiment.

Before the evidence is evaluated for what it says about the causal factors operating, one has to judge whether the evidence is at all relevant to a particular question being posed about the phenomenon. This sensitivity is surprisingly rare. To take an example from science teaching: a burning candle covered with a glass is shown to be extinguished, after which teachers routinely ask, "what does this experiment show ?" or "what do we understand from it ?". The result can be a range of answers from "the candle stops burning", to "oxygen is necessary for combustion". Our experience is that such responses are often accepted uncritically. Factually correct statements, particularly those using technical terminology, are appreciated by teachers, although they may draw totally unwarranted conclusions from the experiment. Textbooks too are often guilty of such over-extensions (Chapter 8).

Linking of an experiment to a question is essential to hypothetico-deductive thought. Following the interviews (Chapter 6) which showed that students failed to make this link spontaneously, classroom discussions were held around some familiar experiments. Students were told that experiments are often done to help answer a question. Then they were asked about particular experiments: Why were they done? Were there any questions that they helped to answer? In this situation too, students were unable to formulate questions of any kind. Often, they were very excited about knowing and articulating the right answers to questions, though they did not easily raise questions of their own.

Given the students' preoccupation with right answers, it is all the more plausible that prior knowledge or beliefs about a phenomenon (along with a conviction about the correctess of these beliefs) might interfere with the task of raising questions. Such knowledge might cloud students' judgement of the relevance of the given evidence to any question that is posed about the phenomenon.

7.1 The belief-evidence tasks

To probe this issue, some tasks were designed using simple examples of experiments, along with possible questions that could be linked to each experiment. Since the spontaneous tendency of students, as we had found, was to answer the given question, this is what they were asked to do first, before considering the link between the question and the experiment. Thus, students first answered the given question, and then stated whether that question was answered by the given experiment. One of the tasks is given below, and the whole set is given in Appendix A.

Sample task

Experiment: Plants need sunlight.

Take two similar potted plants. Keep one in sunlight and the other in the dark. Water the two regularly. Observe after a few days.

a. First answer the given question.

b. Then say if the question is answered by the experiment.

1. Do plants die if not given water?
2. Is sunlight necessary for growth?
3. Can plants grow in the dark?
4. Do plants prepare their food in sunlight?
5. With sunlight but no water, will a plant grow?

As it turned out, these tasks were fairly demanding. The difficulties found earlier in getting students to respond individually to the general questionnaire, were compounded in the case of these tasks. After some trials, we decided to administer the tasks to a group of students at one time. We found that participation was enhanced when the tasks were administered as a team game in the classroom. The correctness of the response given by any team was judged by students in the other team in consultation with the teacher/ researcher, and scores were awarded. Another approach was administer the tasks to groups of students within a class. Both these procedures had the disadvantage that a few students dominated the group while many others simply showed agreement with one or other of the responses. Quantitative data therefore could not be collected. Only qualitatively different responses from subgroups of students were recorded.

The experimental situations were all well known to the students. The questions were also such that the students were expected to know the answers to most of them. There were five exceptions: these were "why?" questions that are easy to phrase (eg. "why does salt dissolve in water?") but clearly not answerable by middle-school students. The first five tasks in the Appendix were administered as a game or in groups —these are the tasks analysed further; the next two tasks were simply used in classroom discussions. For the purpose of analysis, the questions were classified based on two factors:

The first factor was, whether the answer to the question happened to be positive (Y) or negative (N). Sometimes the questions were not phraseable in Y/N terms. In the Appendix, these questions are marked with a "_", if they could be answered at some level by those students who were familiar with the course work. In the group administering condition, these questions were invariably answered by some student in the group. The questions whose answers were indeterminate to the students in that grade, are marked with a "?". The questions in this "indeterminate" category all required some additional knowledge and higher levels of inference.

Table 7.1: Types of questions in the belief – evidence task.

Answer to question Yes/No/Indeterminate	Whether the question is answered by the experiment	Type of question
Yes	Yes	YY
Yes	No	YN
No	Yes	NY
No	No	NN
Not phrased as Y/N	Yes	_Y
Not phrased as Y/N	No	_N
Indeterminate	No	?N

The second classifying factor was, whether or not the question was answered by the given experiment. Consideration of this second factor did carry some problems. While answers to the first part could be based on both experience and prior knowledge, answers to the second part had to be based strictly on inferences from the experiment. The stand taken in classifying the questions was, that only the lowest levels of inference were acceptable. Thus, from an experiment showing that one type of seed sprouted under certain conditions, one could not conclude that another type of seed would do the same. The types of questions are summarised in Table 7.1. One can see that there were seven types of questions: YY, YN, NY, NN, _Y, _N and ?N.

7.2 Results of the belief-evidence tasks

Each task was administered in about eight classes. (The two most frequent responses to every question are listed in Appendix A. Responses given by less than three subgroups are not listed). After each experiment was explained to the students, the questions were presented one at a time and they were first asked, "What is the answer to this question?." Usually students answered this part correctly, since the questions themselves (except those in the "?" category) were quite simple. One exception turned out to be the question "Does vapour feel hotter than boiling water?" to which the expected answer was "Yes", but most students answered "No" (they had not learnt about latent heat). A few other wrong answers showed the presence of some misconception. Students also often attempted an answer to the "indeterminate" questions (for example, "Why does steam come out when water is heated?"). If questioned, they sometimes — though not always — accepted that they really did not know these answers.

The real problem, however, arose when students were asked, "Does the experiment answer this question?". Here, students made various kinds of errors, but the tendency in general was to say that most of the questions were answered by the experiment. There were cases, when the answer to a question about the phenomenon was known to be in the affirmative, then even though the evidence said nothing about it, students erroneously believed that it did, and that it even supported the assertion (Expt.1, Qns. 2,5; Expt.5, Qn.3). However, there were also a number of similar situations when students realised that the evidence was irrelevant to the question asked (Expt.2 Qns.1,6; Expt.3, Qn.3). It seemed as if students were more likely to make such errors when the words used in the description of the experiment were similar to the words used in phrasing the question.

The number of errors on this count was in contrast with the almost invariably correct answers to the questions themselves. The YY and _Y categories of questions turned out to be the ones answered correctly with the greatest frequency. However, our initial guess, that there might be a tendency to transfer the answer to the question itself, to the problem of whether the question was answered by the experiment, was not supported by the data. The fact of the answer being positive or negative was not found to affect their judgement of the relevance of the evidence to the question.

The data did however confirm that students have difficulty in evaluating evidence: they freely draw unwarrated conclusions from experiments. Some of these responses suggested that students were being influenced by their previous knowledge. For example, perhaps because it is known that the percolation experiment with clayey and sandy soils is connected with particle sizes, students easily agree to this conclusion. Similarly the connection between the candle extinguishing when covered, and oxygen being required for combustion, is probably too well learnt to be subjected again to critical inquiry.

Apart from students' prior beliefs, other factors too appeared to influence interpretation of evidence, for example, the commonality of words in phrasing the question and the experiment. Students sometimes made remarks like, "the question has 'water' and the experiment also has 'water' in it, so the question is answered!".

Generalisations, although counted here as errors, are one category of responses that need careful treatment. Discussing the implications of experimental results certainly ought to be encouraged in classroom situations. For example, it would be quite justified to conclude from the percolation experiment that plants would dry quickly in sandy soil. Similarly, doing an experiment with seeds of *matki* ought to lead us to expect the same results with *moong*. However, students need to be critically aware of the fact that these are generalisations.

Chapter 8

Experiments in the science curriculum

Experiments and activities play a relatively minor role in science teaching in most Indian schools. They also do not figure in assessment schemes. Classroom time spent on experiments might easily be an order of magnitude less than in British schools, where it is estimated that 11 to 13 year-olds spend over half of their science lesson time in practical activities, while 16 to 18 year-olds may spend about one-thirds [30]..

Part of the problem lies in the fact intensiveness of Indian textbooks, which are often the only resource available to both teachers and students. Current revisions of textbooks have resulted in some experimental orientation, though this is more obvious in the National-level textbooks than in the State-level ones. In all the books though, there remains a confusion in the status of experiments vis-a-vis the information content.

8.1 Science curriculum of Maharashtra State

In the State of Maharashtra, "General Science" is introduced as a subject from the third grade onwards. The textbooks for the third and fourth grades abound in observations of the environment. Experiments are not as common: in a book of 74 pages for Grade 3, there are only 10 activities/ experiments. Still, the simplicity and lucidity of the text is such that the few experiments are integrated into the narrative flow.

As far as possible, when facts are presented, students are encouraged to verify these by observation. The following are two examples of interesting observations that students are asked to make:

- Notice similarities and differences between different plants and between their leaves.
- Observe a beehive, notice that different cells are used for different purposes.

There are also a number of simple activities that students are implicitly encouraged to do, with suggestions like, "Have you done this?" and "Can you do this?". There are only 10 activities that students are explicitly asked to do. Using John Dewey's system of classification, these are not simply practical explorations for the purpose of achieving a desired effect. Rather, some level of scientific understanding is expected to follow from them. Therefore, we call these "experiments" rather than "activities".

A typical experiment at this level starts with producing some phenomenon. Observation is usually followed up by an inductive inference, with the level of inference kept appropriately low. The following is an example from a demonstration experiment:

- Melt pieces of wax and pour the liquid into an empty matchbox (shows that solid wax melts when heated and becomes solid when cooled — there is no inference about what happens to solids in general when heated).

Even within the limited number of experiments given in the grade 3 textbook, some of the specific roles of experiment in the classroom can be illustrated.

i Giving supporting evidence (often not by itself adequate) for a statement of fact (eg. "Soda water has carbon di-oxide gas dissolved in it." The experiment involves opening a bottle of soda-water and watching the bubbles.)

ii Illustrating how a certain property (of a substance) might be useful in daily life (eg. rub kerosene on cloth that has been stained with tar).

iii Suggesting a new way of classifying phenomena or materials, for the purpose of introducing some terminology (eg. some substances can be poured into a pile ("solids"), while others flow ("liquids")).

iv Noticing of a correlation is followed by an inference (eg. uproot some weeds, notice that some are easier to uproot than others, and observe the kind of roots on both types).

v Rudimentary measurements, followed by ordering of substances by some property (eg. which is more soluble in water?).

The experiments in the book are somewhat weak in terms of introducing the idea of controls, although this is attempted occasionally (eg. "take equal amounts of hot and cold water and add one teaspooon of sugar into each").

8.2 Formal approach

In the fourth grade, the idea of controls is introduced. But, the emphasis on keen observations rapidly decreases after this point. In later grades, ideas of "experiment" (grade 5) and "method of science" (grade 6) start to be introduced more formally and self- consciously. The hypothetico-deductive view is explicitly presented in grade 6.

At this point, there appears a conflict between an overt formal view and the hidden pedagogical objectives. The earlier fairly unproblematic role of experiments (illustrated in the list (i)-(v) above), is obscured by theory-laden statements. Higher levels of inference are called for from the data, often leading to untenable conclusions. Some examples from the grade 5 textbook:

1. On blowing into lime water, it is seen to turn milky. Students are asked why, then told that carbon dioxide turns lime water milky, therefore exhaled air must contain carbon dioxide. (Prior knowledge is confounded with evidence.)
2. A jar containing seeds soaked in water is compared with another containing seeds boiled and then left in water. Lime water in the first jar turns milky. The unexpected conclusion is that plants need oxygen to live and grow.
3. A glass filled with water is covered with a piece of cardboard and turned upside down. The cardboard does not fall, or the water spill, because upward pressure of air is higher than the downward pressure of water.

Such hurried and formal conclusions from experiments can at best be confusing, and at worst amount to sleight of hand or verbal trickery. Far from illustrating hypothetico-deduction, they completely obscure any connection between a question raised and an experiment done to answer it.

Having introduced the term "experiment", the textbooks also tend to over-generalise it, applying it to simple, almost trivial activities, for example, pressing parts of one's body to feel the bones, or erasing a pencil-mark to introduce the term "mutual interaction".

There is thus a certain view of the nature of science that is explicitly sought to be conveyed by textbooks. In addition, the particular choice of experiments in the textbook, the way that they are introduced, and the way that they are presented by teachers in the classroom, are likely to create certain impressions on students about the role of experiments in science. Such impressions, which are often conveyed in an unintended and unplanned way, are popularly referred to as the 'hidden curriculum' of science. Language and everyday experiences outside of school, would also contribute to such impressions. The analysis suggests that implicit pedagogical objectives are one source of the confusing messages conveyed by the textbook.

Chapter 9

Conclusions

This study of students' response to experiments and the analysis of textbooks, has given us some understanding of the conceptual problems in teaching science through experiments. The hypothetico-deductive view has many difficulties associated with it, some endemic to experimentation in science, others arising from cognitive limitations and pedagogical imperatives. However, the study also suggests that the elusive link between theory and experiment, that one seeks in hypothetico-deduction, may actually be rather low on one's pedagogical objectives.

The models of experimentation held by students are quite different from the models presented in textbooks, which in turn differ from historians' and philosophers' models of experimentation in science. Each of these however, have some aspects that can help us to formulate a desirable model of experimentation for science learning.

The experiments that students remember well, often have magical and therefore motivational aspects. The romantic appeal of experiments should not be lost in school science. The fact that students relate "experiment" with "activity" is also significant for pedagogy. An important purpose of "experiments" in the primary and middle schools might be simply to work with different materials, gaining experience of the world. The experience of doing something, with an opportunity to reflect on one's own actions, is important at this age.

A simple use of experiments in primary science is to produce a phenomenon and provoke discussion on it. "Experiments" serve to introduce new terminology, suggesting new categories for understanding nature. They also frequently illustrate applications of a principle in daily life.

One of the important aims of experimentation is to develop skills of scientific enquiry. Due to the lack of emphasis on practical work in our schools, one finds even basic skills like measurement of length, lacking in middle school students (see Appendix B).

The classical hypothesis-testing model of the experiment is of course most important for science learning. But when there is a hypothesis to be tested, experiments usually do not provide incontrovertible evidence for accepting or rejecting it. They do provide supporting evidence, suggest a model or analogy for understanding a phenomenon, or give plausibility to some explanation.

There is therefore no single ideal approach to experimentation. Carey advocates a "constructivist" (theory-prominent) model, while Schauble et. al. suggest starting with an "engineering model" and transitioning to a "science model". But it is more reasonable to expect a multiplicity of models, selected for their suitability to the subject matter and to the students.

An essential aspect of any pedagogical model must be classroom discussions on the design, process and results of experiments. Only in this way would students be able to critically examine their own preconceptions and those of other students, and in the light of these, assess the significance of the experimental observations. The view of science as a social activity is particularly relevant in the classroom situation.

Experiments have their own limitations and strengths, which textbooks and teachers need to recognise. If curricula and textbooks are not clear about the aims of experiments, it leads to a conflict between precept and practice, and confusion in the minds of students. Clarifying such basic issues is a necessary step towards science literacy in the adult population.

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Appendix A

Questions in the belief-evidence task

Of the following experiments, 1 through 5 were already known to students and presented to the class written in large type on sheets of cardboard (as a team game or in subgroups in the class). Experiments 6 and 7 were done in the classroom and the questions were discussed with students.

The first column following the question refers to the type of question classified as in Table 7.1. The next column gives the responses of students. The two most frequent responses to every question are listed here, with the number of student subgroups giving those responses. Responses are listed only if given by three or more subgroups.

Experiment 1: Plants need sunlight.
Take two similar potted plants. Keep one in sunlight and the other in the dark. Water the two regularly. Observe after a few days.

Question	Type	Students' responses	
1) Is sunlight necessary for growth?	YY	YY	
		19	
2) Do plants die if not given water?	YN	YY	YN
		14	9
3) Can plants grow in the dark?	NY	NY	NN
		19	5
4) With sunlight but no water, will a plant grow?	NN	NY	NN
		9	5
5) Do plants prepare their food in sunlight?	YN	YY	YN
		13	10

Experiment 2: Germination of Matki seeds.
Soak seeds of Matki in water in two glasses. After a few hours, remove seeds from one of the glasses and wrap in a damp cloth. Let seeds in the other glass remain under water. Observe after a day.

Question	Type	Students' responses	
1) Would matki sown in soil sprout?	YN	YN	YY
		12	4
2) Would matki remaining under water spoil?	YY	YY	NY
		14	3
3) Could matki sprout without water?	NN	NY	NN
		8	3
4) Is only water sufficient for germination?	NY	NY	NN
		9	7
5) Is air necessary for germination?	YY	YY	YN
		9	8
6) If instead of matki, moong was used, would you see the same thing?	YN	YN	NN
		8	5

(Note: Sprouted seeds of moong and matki are a common part of the diet in Mumbai as well as in the residential tribal schools)

Experiment 3: Clay and Sandy Soils.
Fill one funnel with clay and another with sandy soil to the same level. Pour a glass of water into each of the two funnels and collect the drainage in two measuring flasks.

	Question	Type	Students' responses	
1)	Through which funnel will more water drain?	_Y	_Y	
			18	
2)	Why do plants dry quickly in sandy soil?	_N	_Y	_N
			8	6
3)	Will rice grow better in clayey soil?	YN	YN	YY
			11	6
4)	Which kind of soil holds more water?	_Y	_Y	
			18	
5)	Why is more water retained in clay? or, Why does water pass quickly through sand?	_N	_Y	_N
			12	7
6)	Does more water pass through the sand because its colour is different?	NN	NN	NY
			6	4
7)	What is the difference between the particle size in the two soils?	_N	_Y	
			10	

Experiment 4: Condensation
Boil water in a pot and observe the steam. Hold a cold plate over the steam.

	Question	Type	Students' responses	
1)	If water is cooled, will it evaporate faster?	NN	NN	NY
			7	7
2)	Does vapour feel hotter than boiling water?	YN	NY	YY
			11	3
3)	How to convert vapour into water?	_Y	_Y	
			14	
4)	Is water converted into vapour?	YY	YY	
			15	
5)	Why does steam come out when water is heated?	?N	?N	_Y
			11	7
6)	Is vapour lighter than water?	YY	YY	YN
			12	4

Experiment 5: Candle needs air.
Light a candle on a flat surface, cover with an upturned glass.

Question	Type	Students' responses	
1) Why does the candle extinguish when covered?	_N	_Y	
		11	
2) Does the candle need nitrogen to burn?	NN	NN	NY
		7	3
3) Does the candle need oxygen to burn?	YN	YY	YN
		9	4
4) What happens if burning candle does not get air?	_Y	_Y	
		12	
5) Is air necessary for the candle's burning?	YY	YY	
		10	
6) Is there oxygen in air?	YN	YN	YY
		8	7

Experiment 6: Dissolving
Take equal quantities of water in three containers. Put a spoonful of salt, sugar and chalk-dust respectively in each of the containers and stir.

Question	Type
1) Does salt dissolve in water?	YY
2) Does chalk dissolve in water?	NY
3) Which dissolves faster?	_Y
4) Will chalk dissolve in salt water?	?N
5) Why does salt dissolve?	?N
6) Why does chalk not dissolve?	?N
7) How could one separate salt and chalk?	_N

Experiment 7: Lime water milky
Blow into colourless lime water. It turns milky.

Question	Type
1) Why does it turn milky?	?N
2) Does our exhalation contain CO_2?	YY
3) Which gas do we give out in exhalation?	_N
4) Does CO_2 turn lime water milky?	YN
5) Why does CO_2 turn lime water milky?	?N

Appendix B

Contact sessions on experiments

A large number of experiments were done, some in demonstration mode, others done by students. Some examples are given here, in the following categories:

I. Relating a given experiment to the question(s) it answers.

II. Doing an activity and asking students to raise questions based on their observations.

III. Raising questions through an activity and doing a sequence of experiments to answer these.

IV. Skill development: activities on measurement.

V. Practice in doing a variety of experiments.

I. Relating a given experiment to the question(s) it answers

In the first few activities of this series, the students were shown a written description of a familiar experiment and asked to suggest questions that were answered by the experiment. These experiments were selected from the ones given as examples by students in the group interviews. It turned out that the students had difficulty in framing questions. Where the observation was not given, they tended to state what would be observed in the experiment (eg. "The water will turn into vapour and go into the air"). In later trials, therefore, the questions were suggested and students had to say whether they were answered by the experiment. Some of the experiments were given in written form while others were done in class.

(See Appendix A for tasks and results)

II. Doing an activity and asking students to raise questions based on their observations.

3 candles: Three candles were lighted, Three bottles of different sizes were kept inverted on them, students were told to observe the effect.

Spring balance: Students were given materials such as a spring balance, weights, springs and rubber bands, strings. They were asked to suggest questions that could be answered using the given materials. Their difficulty in reading scales here suggested that practice in measurement was needed.

Absorption of water: Stems of *Terda*, *sadaphuli* and some other plants were kept in coloured water. After a few hours the students cut the stems at various points and examined the cross-section.

Dissolving: A number of different things were dissolved in water and students were told to ask questions arising in their minds.

Soil and water: Experiment as described in Appendix A.

III. Raising questions through an activity and doing a sequence of experiments to answer these.

The starting activities of this series were:

A flat wooden ruler was kept on a table with a portion of it projecting outside the table. The part on the table was covered with a large sheet of paper. The projecting portion of the ruler was struck sharply. The sheet of paper was not lifted up, but when the experiment was repeated with a sheet of folded paper, it was lift higher. Why did this happen? When the paper was replaced by a wooden chalk-board duster, it was thrown up higher. Why did this happen? The hypotheses arising were tested in subsequent experiments.

An empty glass was inverted into a jar filled with water. Students were told to observe what happened. Various hypotheses arising were then tested.

IV. Skill development: activities on measurement

Discussions were held with students on daily life examples of measurement of length, weight/ mass, volume and time, various large and small units, and in what situations these were used.

Length of a line: Students were asked to draw a straight line and measure it's length. This led to many problems. Some students did not know where the scale of the ruler began, or the difference between the centimetre and the inch markings. Often fractional lengths were ignored, and when this was pointed out to them, students had the expression of, "what's all the fuss about little bits here or there?"

There was thus a need for some motivation for measuring to 1mm accuracy. A good motivator was thought to be visual illusions to force accuracy in measurements.

Illusions: Cardboard pieces on which three lines had been pasted were shown to students. Students were asked which line was longer. On measuring the length of the lines, students found that they had been wrong at times. Thus the idea was introduced that often our senses deceive us and accurate measurement is important. The activity was repeated with the Muller-Lyer illusions.

Pictorial folders Folders on measurement prepared by HBCSE for non-formal education were used in class. The headmaster at one of the *Ashramshalas* asked to convert them into wall charts.

Students measured the length of the black board using their hand- span and compared it with scale measurement using a thread. Idea of least count was introduced.

Proportionality of units Students counted number of tiles along the wall on one side and compared them with scale measurement. They then repeated the measurements by counting steps needed to walk across, predicting the answer for various students. Proportionality of the various measurements was discussed. Since this idea presented some problems, simpler examples of proportionality were taken up. After this, the students (particularly the girls) quickly realised that this was a kind of division problem.

The proportionality aspect was continued with volume measurement, for example, if a glass can hold 3 small cups full water, while a pot gets full with 10 glasses, then how many cups full water would fill the pot?

Angles: Construction of various geometrical shapes (triangles, rectangles, squares) by drawing and by paper folding. Students could recognise shapes but not always name properties. The terms acute, obtuse and right angle were not known. Locating mid-points.

Area: Measurement of perimeters and areas of regular and irregular shapes using graph papers. Perimeters by walking around figures; constructing a 1cm grid pattern.

Tangrams: Students constructed "Tangram" pieces and made different figures.

Matchsticks and cycle tubes (Due to Shri. Arvind Gupta): Students were asked to make 2-d and 3-d shapes using these. Geometrical shapes were not common; rather students made different objects like glasses, bow and arrow, roof, hut, lamp, cradle, cap (quite intricate), butterfly, star, table and chair.

Volume: Students were given cylinders of different lengths and asked to identify which had more volume by filling them with sand of equal measure.

Time: A simple shadow clock was constructed in each school with a *bhala* (spear). Stop watch and sand clock were used with experiments on drainage of water. Another activity was, counting of pulse beat in one minute using stop watch and sand clock. Duration of a second and minute was not commonly known. Though students knew about 60 minutes to an hour, very few knew there were 60 seconds in one minute.

V. Practice in doing a variety of experiments

Muscular force: Three students held their arms raised and other three students tried to push them down. This was compared with the experience of holding up a number of books on an upraised arm.

Stretching rubber bands: The students stretched rubber bands with muscular force, then compared the stretching with weights attached to the bands.

Inclined plane: Demonstration of force needed to slide weights up or down an inclined plane.

Light and shadows: Shadows cast by various materials: transparent, translucent and opaque. Variation of size of shadow with various factors.

Transpiration: Four mango leaves were taken: one leaf was coated with vaseline on the front side, the second was coated on the back, the third on both side, the fourth kept as it was. Students noted the changes periodically.

Germination: Students were asked to sow seeds of peas, *chawli* and *jowar*, and note the changes daily. The same was later done in a sieve to see movement of roots.

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