Chapter 14
Developing Science Teachers' Representational Competence and Its Impact on Their Teaching

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Abstract This book has consisted of a series of chapters that describe and discuss the knowledge that has been accumulated regarding teachers' meta-representational competence (MRC) and the pedagogies within which it is displayed. Relatively little literature on this theme has so far been published. This book ha identified the gaps in knowledge that must be filled, for example: the nature of the curriculum through which MRC can be taught; how MRC enables a teacher to respond to students' difficulties in understanding and producing representations. In this, the last chapter, key themes in the use of representations in teaching and learning are revisited and integrated into a whole.

Keywords Meta-representational competence • Internal and external representations • Representational modes • Approaches to teachers' education for MRC • Science teachers

14.1 The Increasing Importance of Visualisation

These challenges are both important and pressing. Ever since explicit science education began, initially in Western Europe and perhaps in the sixteenth century, it has been dominated by words, both spoken by a teacher and written in a textbook, with some tactile learning taking place through practical work in laboratories and

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elsewhere. The inclusion of illustrations of all kinds – pictures, diagrams, graphs – in verbal presentations and textbooks has gradually expanded as printing has become cheaper, more versatile, and lately, much more colourful. However, it is the advent of the personal computer, with its ever-expanding memory capacity, that is having the greatest impact. There is now little restriction on the number and complexity of the visual representations that may be included in close proximity to words in written text or oral presentation. Educational systems, responding with their usual glacial slowness (Van den Akker 1998), are gradually including the use of computers, and, by implication, visual representations, in the teaching methods used in well-funded schools. The full impact of information technology on formal education has yet to be felt. However, on the positive side, the informal education of both school-age students and adults is already making extensive use of computers, and hence of visual representations, in the self-directed learning activities that are increasingly available.

14.2 Visualisation as Internal and External Representation

Given their importance in learning and teaching, we must clarify the meaning of the words 'representation' and 'visualisation'. Whilst the Concise Oxford Dictionary provides one definition for 'representation' i.e.

> 'A statement made to convey meaning' (Pearsall 1999) (p. 952)

this does not specify what a 'statement' is. Moreover, two distinct definitions are provided of 'to visualise' i.e.

> '1. Form a mental image of, to imagine. 2. Make visible to the eye' (Pearsall 1999) (p. 1301)

The first of these definitions refers to a visualisation as being a representation of an object in the brain, in either the presence or the absence of that object, and may also be called a 'mental image' or, more generally, an 'internal representation'. The second meaning refers to that that representation which is perceived by the eye, an 'external representation'. There is considerable evidence that understanding an 'external representation' and a corresponding 'internal representation' share the same mental processes. In what follows, we will use the word 'visualisation' to refer to either an 'external representation' or an 'internal representation', dependent on the context in which the word is used.

14.3 The Modes of External Representation

Although the physiological nature of internal representations is still the subject of inquiry and intense speculation by neuropsychologists, a rough taxonomy of external representations can be produced in terms of the media in which they are produced. The five generic modes, each of which has a distinct capability to produce an external representation (each having a distinct 'code of representation') are:

14.3.1 The Verbal Mode

The verbal mode plays a major role in all external representations in science, for two reasons. First, speech is the most widely used mode of representation for all human communication. As such, it usually accompanies the use of a representation in any one of the other modes. Mammino (this volume, Chap. 9) emphasises this vital synergy between language and other forms of representation. She points out that a lack of language mastery makes it difficult for students both to understand the textbooks with which they are provided and to express ideas in their own words. Second, a major component of the verbal mode is the use of analogy, this playing a major role in science and science education generally, and most importantly, when abstract ideas are being presented. However, if students are not familiar with the source from which the analogy is drawn, or if an inappropriate analogy is used by the textbook or teacher, then misunderstanding may result, indeed, misconceptions may be acquired. Liu, Won and Treagust (this volume, Chap. 5) provide examples of where these errors lead to confusion, rather than clarity, in students' understanding of diagrams in biology.

14.3.2 The Concrete/Material Mode

This mode is most commonly used to present a tactile, three dimensional representation of a physical structure, the emphasis being placed on its detail and three-dimensional nature e.g. a ball-and-stick representation of a crystal, a 'cut away' representation of the veins/arteries relationship in the blood circulation in body, a 'blown-up' representation of a micro-electronic circuit.

The universal availability of computers with large memory stores has enabled the development of software packages to be developed of virtual versions of concrete/material representations. The three-dimensional nature of the representations is indicated by the inclusion of visual clues (e.g. relative distance, shading) from which that nature can be inferred once the appropriate code of representation is known. These virtual representations can be inverted, rotated, and orchestrated into dynamic systems, to show spatial and temporal change. This is done, for example, in the 'slowmation' system produced by Loughran (this volume, Chap. 4). Such virtual representational systems are playing an ever-greater role in science education, although doubt must remain over whether the understanding that can be acquired from them is of the same quality as tactile learning.

14.3.3 The Visual Mode

The scope of the visual model includes a wide range of different forms, many of which are not readily distinguishable from each other. They are most commonly referred to collectively as 'diagrams'. The taxonomy of diagrams has been produced by (Hegarty and Carpenter et al. 1991), who divide visual representations into three broad classes based solely on their appearance: 'Iconic diagrams',

where

> 'the spatial relations of the referent object are isomorphic to the spatial relations in the graphic depiction'.

Examples are photographs and line drawings: the visual representation looks like that which is being represented i.e. the referent.

'Schematic diagrams',

which

> '… depict very abstract concepts and rely on conventions to indicate both the components and their organisation …'

Examples are Venn diagrams, flow charts, linguistic trees. The conventions of representation bear no physical resemblance to what they depict, such that they must be fully known if the system is to be used;

'Charts and graphs',

where

> '… the referent to be depicted is some set of isolated facts or records that are typically quantitative'.

Examples are line graphs, polar charts, pie graphs. Entities are presented abstractly, the emphasis being on their number rather than their nature.

This approach to classification has three drawbacks. First, it is only concerned with first-order distinctions between types of representation based on their ontological composition, whereas many diagrams are hybrids of two of them e.g. weather forecasts are often iconic diagrams that include schematic elements. Second, it is assumed that they will be interpreted in isolation, whereas, in common practice, the diagram and accompanying text or speech complement each, to some extent at least. Third, it also assumes that the entities depicted in diagrams will only be stationary, whereas many of them move in space or time. This scheme was proposed before the advent of personal computers made dynamic simulations of events commonplace.

14.3.4 The Gestural Mode

In the gestural mode, the body, or some part of it, is used, consciously or unconsciously, to depict some aspect of a representation. Although non-verbal communication is very important in the analysis of interpersonal relations, the gestural mode of representation is under- valued in education and hence is under-researched. This under-valuation probably arises from the fact that gestures are normally accompanied by speech and are perceived to be subordinate to that speech. Nevertheless, gestures do seem capable of reinforcing the meanings intended by speech. For the hard-of-hearing, gestures are invaluable. Whilst they can be made with any part of the body e.g. shrugging the shoulders, averting ones gaze, the variety of gestures most commonly used in science education are produced by the movement of hands and arms.

14.3.5 The Symbolic Mode

There are two specific 'symbolic modes': the mathematical and the chemical. The use of the mathematical mode of representation, most commonly referred to as the 'mathematical equation', is most highly prized in science and science education, for it can be used to:

- build succinct quantitative representations of a topic of interest in terms of the incidence of the variables that describe it's behaviour. For example, the Ideal Gas Equation ($PV = nRT$). Thus, a measure of pressure (P), when multiplied by a corresponding measure of volume (V) is the same as the corresponding measure of its temperature multiplied by a constant;
- provide a language with which to argue about the relationships between those variables. The equation provides a factual base against which the reasons for the relationships can be explored;
- undergo a process of manipulation, of development, so that it can be used to explore the possible behaviour of a phenomenon and hence to make predictions that are capable of being empirical tested. The equation can be rearranged so that the values of P, V, T, for a fixed amount of a gas can be anticipated and the deviance from ideal behaviour quantified.

The intellectual power of the mathematical mode is such that a person cannot become a highly productive scientist without having great skill in the use of its variants.

Chemical equations are the other form of symbolic representations. This indicates the quantitative relationship between the reactants and products of a chemical reaction that proceeds to completion. After several hundred years in which conventions for writing chemical equations have evolved, that representational convention adopted by the International Union of Pure and Applied Chemistry is now used in all formal communications about chemical reactions (IUPAC 2013).

14.4 The Notion of Meta-representational Capability

As internal and external representations play a major role in all teaching and learning, it is important that teachers and learners of science are competent in all the knowledge and skills that these phrases implies. When discussing what this competence entails (diSessa and Sherin 2000) say that:

> 'We add the prefix 'meta' to denote our more encompassing aims. We are interested in whatever students know *about* representation (*meta*- representation), whether or not it con-

> cerns instructed representations … The prefix meta may invoke a connection to meta-cognition. However, we do not intend our use of meta-representation to make this link. There may be meta-cognitive or reflective components of MRC, but … this is an empirical matter to be investigated, not an assumption' (p.386)

It is therefore necessary to define, by example, the scope of MRC.

A fully meta-representationally capable person should be able to:

- Demonstrate an understanding of the 'codes of representation' for the five major modes of representation. That is what kinds of entities may be depicted and how, what types of relationships (e.g. angle, distance, causality) between them can be shown, what types of relationship cannot be shown;
- Demonstrate a capacity to translate a given model between the five modes of representation in which it can be depicted. For example, to be able to relate a visual representation (a diagram) of the human torso to a concrete/material representation of it;
- Demonstrate the capacity to construct a representation within any of the five modes. For example, to produce a visual representation of the human torso from a concrete/material representation of it;
- Demonstrate the capacity to solve novel problems with the use of suitable representations. For example, to produce a full description of the layout and behaviour of the lungs and heart, making use of visual and concrete/material representations of it (Gilbert 2008)

Such a person could be said to have achieved full meta-representational competence. Having this degree of competence is one of the major indicators of expertise as a scientist. If we know how such competence is developed, then it will be possible to design a scheme of education to achieve it.

There are a number of individual, notionally separate, issues relevant to meta-representational competence that have still to be addressed, as have emerged in earlier chapters. These are the need to explore more fully:

- a broader range of the many issues that govern the nature and development of meta-representational competence;
- the value of individual representations in the understanding of the nature of and the relationship between the macro, sub-micro, and symbolic levels of representation;
- the determinants of the cultural acceptability of the various types, origins, and uses, of representations;
- the interdependence of the development of understanding and use of language and of representations.

It is only when these issues have been substantially addressed that it will be possible to produce a systematic overview of representational competence, as is discussed next.

14.5 Theoretical Underpinnings to the Development of Meta-representational Competence

The development of meta-representational competence is based on three distinct ideas.

14.5.1 The Manipulation of Signs

The idea is concerned with the nature of the entities that are manipulated in both external and internal representations to produce meaning. These are signs, the basic material of the science of semiotics, first defined by (Pierce 1931) and presented in this volume by Loughran in the following terms:

> 'meaning is made when a sign represents an object (such that): i) an object or referent is the concept or content being represented; ii) the sign that is created is called a representation; iii) the meaning generated from the sign is called an interpretant'

Each of the five modes of representation can be thought of as distinctive signs or as an assembly of such signs, for this language convention makes it possible to discuss how signs are associated with meaning. To be fully meta-representationally competent, an individual must know the relation between the objects represented (the referents), the representations produced, and the interpretants (the resulting meanings) for all the modes of representation.

14.5.2 The Acceptance That Understanding Results from the Response to Stimuli, Whether External or Internal

The overall sum of the stimuli that can be experienced by a person may be divided into two types: the verbal, words received either orally or in written form; the non-verbal received from gestures, images (of objects, diagrams, graphs etc), sounds, or by touch (Paivio 1986) has produced a model, Dual Coding Theory, for how these stimulate – or rather the signs that are generated from them – are processed by and stored by the brain. Within the verbal system, the meanings of words are stored separately but 'associative structures' can be formed amongst them, such that complex phenomena can be understood through the existence of such linkages. Within the non-verbal structure, visualizations etc are also stored separately, and associative structures can again be formed amongst them, again such that complex phenomena can be understood. Perhaps most importantly, referential links can be formed between the two systems, so that their different representational capabilities can be brought to bear on one phenomenon. The output of the two systems, whether verbal or non-verbal, is informed by the associated and/or referential structures that have been formed within and between them. The strength of the Paivio model is that it recognises the equal value for understanding resulting from the processing of signs generated in both the verbal and non-verbal systems.

14.5.3 The Exploration of the Pedagogic Implications of the Making Meaning from Signs

The third major underpinning for meta-visual capability concerns the mechanism by which meaning is made from signs and hence the pedagogic approaches that may be adopted to increase the precision, the accuracy, of that meaning. The general precepts of this mechanism are provided by constructivist psychology. The main 'school' of constructivism on which attention is currently focused assumes that people learn by active mental engagement, by relating new knowledge to what is already understood. This takes place in a social context. It places less importance on the significance of the individual in that process, as compared with that of the surrounding society. The all-important social dimension to learning is moved centre-stage in the 'social constructivist' approach of Vygotsky (1978, 1986). This sees learning as a process of social enculturation of a learner by interaction with an authority e.g. a teacher. Only that knowledge which lies within the 'zone of proximal development' of the learner, an unclear phrase that seems to mean 'the range of possible new knowledge that is sufficiently related to existing knowledge that it can be understood'.

In the social constructivist model, it is assumed that successful learning results from a high level of interaction between the teacher (or other social agency e.g. a book) and the taught, such that the mental activity of the later is prompted and shaped by the former, leading to the gradual build-up of knowledge through the use of signs, with verbal and visual input playing complementary roles. In this volume, Mammino provides extensive and detailed examples of how this process of interaction and knowledge development take place. In short, signs are acquired both verbally and non-verbally, being related to each other through the classroom activities that support the social construction of knowledge. That is, by the posing and answering of verbal questions, the construction of representations of all types, and by the discussion of the cognitive value of these products by students and the 'social agent' (the teacher).

14.6 The Significance of Personal Meta-representational Capability for Science Teachers

Given the central importance of visualisation in science education it is vital that science teachers are themselves fully meta-representationally capable. This would entail them being conversant with the operation and implications of the Peircean notion of signs, appreciating the complementary nature of the contributions to meaning made by both the visual and the non-visual modes of experience of stimuli, and by being able to deploy the principles of constructivism in their classrooms. There are three reasons why the acquisition of these capabilities is so important.

14.6.1 The Notion of 'Levels' of Representation

The first reason relates to the 'levels', the types, of representation that are used in science and hence in science education. In chemistry and chemical education, three levels of representation are used (Johnstone 1993). These are the:

- Macro level. This consists of samples of exemplar chemical phenomena (named pure elements, compounds, or mixtures), together with their empirical properties, for example, their mass, density, concentration, pH, temperature .
- Sub-micro level. The empirical properties of the macro level are explained at the sub-micro level by the use of models in which the arrangement of the entities of which they are thought to consist (e.g. atoms, ions, molecules, free radicals) are depicted as external representations. Models of the sub-micro level also include the distribution of bonding electrons resulting in the depiction of inter- or intra- entity shapes.
- Symbolic level. At the symbolic level, the explanatory models at the sub-micro level are simplified to the use of signs (e.g. Mg) to represent a particular atom species, the use of superfixes to indicate electrical charge (e.g. Cl^{-}), the use of subfix letters to indicate the physical state of entities (e.g. $Na_{(s)}$), and the inclusion of all these in chemical equations such that the law conservation of matter is obeyed. After (Gilbert and Treagust 2009) (p.4)

In view of the of the differences between biology and chemistry, (Treagust and Tsui 2013) produced a four-level model of representation for biology and biology education. They see the four levels to be:

> '(1). The macroscopic level at which biological structures are visible to the naked eye; (2) the cellular or sub-cellular (microscopic) level at which structures are only visible under a light microscope or electron microscope; (3) the molecular (sub-microscopic) level involving DNA, proteins, various biochemicals … (4) the symbolic level that provides explanatory mechanisms of phenomena represented by symbols, formulas, chemical equations, metabolic pathways, numerical calculations, genotypes … etc'(Treagust and Tsui 2013) (p. 8)

The levels used in physics and physics education will be discussed in the forthcoming volume in the 'Models and Modelling in Science Education' series: Treagust, D., Duit, R., Fischer, H. *Multiple Representations in Physics Education.*

There is little doubt that students are all-too-often unable to 'translate' between levels of representation and hence have not acquired meta-representational competence. Cheng and Gilbert (this volume, Chap. 6) outline sources of the particular problems that students have in chemical education. Namely:

- Teachers' use of simplified terms for the macro level e.g. the use of the word 'air' when the active agent in a reaction is 'oxygen';

- The assumption that individual sub-micro representational entities have the same properties as the corresponding macro level;
- The misrepresentation of sub-micro species e.g. the use of $Na^{+}Cl^{-}$, which implied the existence of specific ion pairs at the macro level;
- The failure to use standard terminology e.g. 'NaCl' (the empirical formula) rather than 'sodium chloride';
- Lack of exact knowledge of the complex conventions for the symbolic level as laid down by IUPAC.

It is therefore important that students are systematically introduced to the representational levels used in the sciences, thus acquiring a major manifestation of meta-representational competence. Cheng and Gilbert (this volume, Chap. 6) set out and illustrate a sequence of steps for this to be done i.e.

1. Practical introduction to the macro level;
2. Presentation of and experience with the conventions used in the sub-micro level;
3. Use of the conventions of the sub-micro level to explain properties of the macro level;
4. Presentation of and experience with the symbolic level;
5. Use of the conventions of the symbolic level to explain the sub-micro level;
6. Development of the capability to move between the macro, sub-micro, and symbolic levels, in any order, for a given chemical phenomenon.

14.6.2 Teachers' Use of Visualisations in Teaching

In their paper, Ainsworth and Newton (this volume, Chap. 2) note that relatively little research has been done into teachers' roles when they employ representations in their teaching. A recognition by the editors of this omission was one of the major drives behind the assembly and orchestration of the papers presented in this volume. Ainsworth and Newton (this volume, Chap. 2) provide an effective background to this endeavour by analysing the general significance of representations in science education as reflected in the focuses of the abstracts of research papers and through interviews with teachers. For both these groups, representations were found to be important, although there was a wide diversity in the terminology used for the many perceived types of them. Whilst graphs, diagrams, animations, and text were seen to be important, teachers evidently thought graphs to be less worthy of attention than did researchers. Both groups saw the educational effectiveness, the quality of the design, and the scope for choice, as themes of importance in the actual choice of representations for use in teaching. Echoing established views on the central importance of multiple representations in science and science education e.g. by (Lemke 2004), Ainsworth and Newton (this volume, Chap. 2) noted the value of multiple representations to both researchers and teachers.

This value arises because focus on diverse issues in the provision of effective teaching, for example, when what is wanted is an address to both the problems of understanding met by students and the diversity of their preferences for modes of representation. However, there are commonly severe limitations to the use of multiple, or even just different types of, representations, for a range of reasons.

In their chapter, Eilam, Poyas, Hashimshoni report a study in which they asked serving science teachers: to generate visual representations to be inserted into a diverse range of textual scenarios; to choose the most suitable representation (from a range provided) to accompany a particular piece of text; and finally, at interview, to discuss the reasoning behind their products and choices. There were three major outcomes. First, they found that the semantics of a piece of text resulted in the narrowing of the choice of representational type that teachers felt they could adopt. This narrowing was accentuated where the text was in one language, for example Hebrew, whilst the first language of a particular teacher was different, for example Arabic. These culturally-determined differences have serious implications for teacher education. Second, these issues of the nuances of language are reflected in teachers' ability to write effective captions for representations, thus limiting the educational use that students could make of them. Third, and perhaps most significantly, teachers tended to use a small, simple, and presumably familiar, range of representational types. Of these, the Table was a favoured form, probably because it is socially ubiquitous. However, teachers were often incapable of designing tables that enabled valuable ideas to be perceived. Again, there are implications for teacher education.

From an observation-based study of five biology teachers over a period of 7 months, Liu, Won, Treagust (this volume, Chap. 5) also showed that teachers tend to use forms of visualisation that are both intellectually relatively simple and with which they are evidently very familiar. They drew three general conclusions from their study. First, the teachers tended to mainly use visual representations of the iconic variety – those that were pictures or drawings of concrete objects (Hegarty and Carpenter et al. 1991) – and then largely during the introduction of topics to students, rather than during the subsequent elaboration of those topics, concentrating on the exposition of core concepts rather than on the formation of links between concepts. Second, they made changes between the types of visualisation they use, largely moving on from iconic representations to the corresponding schematic representations – those consisting of abstract imagery (Hegarty and Carpenter et al. 1991) – when providing explanations, but often without justifying that change of use. Third, such changes in type were rendered more complicated, and perhaps more confusing for the students by the extensive use of analogies, many of them created *in vivo* by the teacher. This despite evidence from earlier work that such an approach brings problems in its train, for these' created analogies' are often inappropriate or inaccurate (Treagust and Harrison et al. 1998). Again, it is only through extensive pre-service and in-service teacher education that these limitations to the use of visual representations will be overcome.

14.6.3 Prerequisites to Research-Based Science Teacher Education for Visual Literacy

Before suitable teacher education aimed at visual literacy can take place, additional research is needed. Ainsworth and Newton (this volume, Chap. 2) point to five major areas where more work is needed. First, we know far too little about how science teachers go about the process of deciding what visualisations to use and when to use them. Put another way, we must know more about teachers development and use of pedagogic content knowledge (Shulman 1987) about visualisation. Second, we know far too little about the individual differences of understanding between students in respect of the visualisations with which they are commonly presented. Pedagogic content knowledge can only be deployed if teachers are fully aware of the cognitive status of the students in regard to the content being discussed. Third, we must know more about the effects on students' engagement and motivation of teachers' use of visualisations. We would hope that students would reward a display of meta- representational capability on the part of their teachers by learning more effectively! Four, and looking at matters more broadly, there is a clear need for a meta-analysis of the whole field of research into representation in science education, so that the significance of what is already, known, what comes to be known, and what needs to be known can be properly evaluated. Fifth, and lastly, improvements in science teacher education in respect of representation only take place in teachers are willing to access research and to consider its implications for their practice. As has been shown over many years, getting this is take place is an enduring problem (Levin 2013).

However, all decisions are always taken without complete knowledge of all the factors in operation. So it is with science teacher education for meta-representational competence: we must make the best progress that we can with the knowledge that we have.

14.6.4 Approaches to Science Teacher Education for Meta-representational Competence

It is not appropriate to rehearse successful approaches to mainstream science teacher education, for these have been extensively explored elsewhere e.g. (Gilbert 2010). Sufficient to say that they should be expanded to include both the explicit treatment of visualisation in general (Eilam, Poyas and Hashimshoni) (this volume, Chap. 3) and the planning of suitable teaching activities in particular (Bamberger) (this volume, Chap. 13).

The essence of any such inclusions must be that the teachers have direct experience of the generation and use in teaching of representations produced both by themselves and by their students. This volume includes accounts of four such approaches. First, Parnafes and Trachtenberg-Maslaton (this volume, Chap. 12) report a study in which such in-service education was provided by a teacher requiring school pupils to develop, discuss, and evaluate their own representations, here in respect of the difficult topic of energy. The study concluded that the in-service education that resulted included a substantial shift in the teachers' epistemological beliefs. The second approach reported was based on the consideration by teachers of the educational value of the representations included in 'popular books about science' – those books that, whilst not textbooks, discuss the implications, applications, and technological consequences of science, and which usually include a large number of diverse types of representations (Gilbert and Afonso) (this volume, Chap. 14). The third approach involves expanding teachers' experience and use of interactive simulations -those computer-based representations into which students can enter variables and observe their effects, thus providing support for an inquiry-based approach to science education (Geelan and Fan) (this volume). The fourth approach involves introducing teachers to the creation and use of 'slowmations', 'flip books' of images which show how events in respect of a chosen phenomenon are slowed down such that their relationship to each other can be understood (Loughran) (this volume, Chap. 4).

However, there is one theme, so often overlooked in mainstream science teacher education: the cultural context in which science teaching takes place, that just cannot be ignored when the theme is 'representation'.

14.7 The Cultural Context of Science teachers' Use of Visualisations

Any enduring society develops distinctive ways in explaining the world-as-experienced in order to support the creation of an environment that sustains their way of life. From the fifteenth century and beyond, people in Europe and North America developed that way of explaining the world-as-experienced that came to be called 'science'. It depended on the acceptance of particular beliefs about what knowledge was and how it could be acquired, a distinctive epistemology. This epistemology evolved by assimilating and adapting elements in existing general cultures found there at that time. It was inevitable that such an epistemology formed the basis for the 'science education' that developed over the centuries, first in Europe/North America and more lately throughout the world.

Science education assumes that the students being taught are both familiar with and accept this epistemology. However, the growth of international travel and migration have lead to the circumstance that some, if not many, students is a given class, for example in any capital city, do not meet this criterion. The general cultures from which they come, that of their homes, have produced and continue to use – if only partially – epistemologies that are alternative to those of western science. They will range from simple superstitions e.g. that the position of planets governs patterns in human affairs, to the codified tenets of formal religions e.g. that the dictates of a deity directly governs the actions of everyday life. In general terms, the most clearly delineated forms of such epistemologies are based on: the reliance of non-mechanical entities as the basis for the explanation of phenomena and events; the use of methodologies of enquiry, those on which they depend, that are not available for critical review; the production of little first-hand concrete data, whilst much use being made of hearsay and historical precedent; an ethos of dogmatic assertion by those in valued social positions such that the acceptance of these epistemologies must be based solely on belief; a lack of experimentally verifiable predictions of future events.

Of course, few students in culturally mixed classes will have adopted the most extreme elements of such epistemologies. However, these epistemologies may be present to some degree: indeed, the science teacher may privately concur with some of their tenets. We do not wish to over-emphasise this point, merely to point out that science teaching cannot proceed effectively unless teachers are alert to the possible implications for a cultural non-compatibility between the science curriculum, the science teacher, and the students.

This is a complex issue and one of some delicacy, for an individual's epistemology is very much a part of his/her persona as is their membership of the group from which these ideas are drawn. As such, any tensions in respect of epistemology would be difficult to identify in any great detail.

However, their clearest manifestation is in the chapter by Waldrip, Satupo and Rodie (this volume, Chap. 8) who, in science classes in Melanesia and Indonesia, found the issue to come up in a variety of ways. To take two examples. First, whether a teacher was male or female had a major impact of the acceptance of ideas about visualisation that she/he put forward. The valuation of ideas independent of the identity of the proposer, a major tenet of orthodox nature of science, was not seen in this case. Second, the social status of individual students, as ascribed by their membership of a particular ethnic group, had a major impact on the nature of the consideration given to their ideas. Ideas produced by 'low status' students were derided or ignored. Indeed, major differences over epistemology can exist in countries with very different cultural backgrounds, as de Vries and Ashraf (this volume, Chap. 7) discuss in respect of the types of representations that are used in France and in Pakistan.

It is hoped that this volume will help focus attention on the importance of MRC in the learning of science and hence the pressing need for it to be given a higher saliency in science education at all levels. In particular, by having emphasised what is already known about MRC, researchers will be encouraged to fill the important gaps in existing knowledge and to introduce the theme into teacher education.

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